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# The Role of Extreme Weather Events, Mass Movements, and Land Use Changes in Increasing Natural Hazards

*A Report of the Preliminary Field Assessment and Workshop on Causes of the Recent Damage Incurred in South-Central Nepal (July 19-20, 1993)*

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# Foreword

The Steep Slopes, unstable geology, and the intense monsoons combine to make the Hindu Kush Himalayas one of the most hazard-prone areas in the world. As human activities rapidly expand across these mountains, these also become subject to the influence of hazards, often resulting in severe natural disasters. Such an event occurred in Nepal in the Southern parts of the Central Development Region during July 19 and 20, this year.

As an institution focussing on integrated mountain development, ICIMOD's concerns have been directed at identifying alternative methods of hazard mitigation and improving disaster preparedness. In such cases, prevention is always the preferred alternative. With the objective of better understanding the factors and processes involved, ICIMOD organised a discussion of the natural events, bringing together concerned professionals from the Planning Commission, government departments, and the University.

The meeting recommended an immediate reconnaissance study of the affected areas. ICIMOD fielded a reconnaissance study team, consisting of faculty members of Tribhuvan University, to study three of the worst-affected areas. This report contains the findings of the study team and the conclusions and recommendations arrived at from the study team's findings during a workshop held on November 23rd and 24th, 1993.

ICIMOD is grateful to Dr. Binayak Bhadra, Member of the National Planning Commission, for his full support and to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) for providing the funds for this study and the workshop; to Tribhuvan University for contributing the time of their dedicated professionals; to all the agencies involved from HMG/Nepal for their whole-hearted cooperation; and to the local residents in the areas visited who took the time, in the midst of such a terrible disaster, to provide us with information. To all of these, we owe our heartfelt appreciation.

E.F. Tacke
Director General

# Acknowledgements

This study was funded by the International Centre for Integrated Mountain Development (ICIMOD) and supported by the National Planning Commission of HMG/Nepal. We are grateful to all those involved. From ICIMOD, we would especially like to thank the Director General, Dr E.F. Tacke, the Director of Programmes, Dr. M. Banskota, and Professor S.R. Chalise for their support, guidance, and encouragement. Thanks are due to Greta Rana, Archana Singh Karki, and Udaya Tegi for their speedy work in preparing the document for publication at such short notice. Ram Maharjan was of assistance to us on tour. We were also greatly helped by students: Subas Sunuwar and Danda P. Adhikari from the Central Department of Geology; Binod Shakya and Pradeep Man Dangol from the Central Department of Meteorology; and Moti Ghimire and Buddhi Krishna Dulal from the Central Department of Geography. Their cooperation and help in the field, as well as in the office, are sincerely acknowledged. We are also thankful to the personnel of the Nepal Electricity Authority at Markhu, Kulekhani, and Dhorsing, the staff members of Daman Horticultural Farm, the Kulekhani Watershed Management, and the Bagmati Irrigation Project. The cooperation of the personnel from the district and Village Development Committee offices as well as the help of the local people in the area are also sincerely acknowledged.

Megh Raj Dhital
Narendra Khanal
Khadga B. Thapa

# Authors' Contributions to the Text

| | |
|---|---|
| Part One: | The Introduction and Description of Natural Events were written by **Narendra Khanal**, Lecturer, Geography Department, Tribhuvan University, and the Assessment of Climatic Events was prepared by **Khadga B. Thapa**, Reader, Central Department of Meteorology, Tribhuvan University. |
| Part Two: | Part II was the work of **Megh Raj Dhital**, Lecturer, Geology Department, Tribhuvan University. |
| Part Three: | The Assessment of Land Use Changes and Their Impact was prepared by **Narendra Khanal**. |
| Part Four: | The final overall assessment was based on contributions from all three authors and on the Workshop Discussions. |

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# The Preliminary Reconnaissance

## Introduction

Unprecedented floods and landslides were experienced in Eastern and Central Nepal during the third week of July 1993. As a result of the floods and landslides, heavy losses of infrastructure, lives, and property were reported. Several districts of the *terai* were inundated, and huge landslips occurred in Ramechhap and Panchthar Districts, destroying several villages. The Bagmati Barrage, the East-West Highway, the Prithvi Highway, and the Tribhuvan Highway also suffered considerable damage.

These types of natural calamity are not uncommon in Nepal. In 1978, a huge flood on the Tinau River destroyed a newly-built bridge at Butwal. Another catastrophic flood was experienced on the same river in 1981. Several landslide damming occurrences can be seen between Kerabari and Dumre along the Tinau River. A debris torrent originating from the outburst of the Dig Cho glacier lake washed away the Namche small hydroelectricity project and a village in 1985. In the same year, the landslide dam on the Trishuli River caused severe damage to the hydroelectricity project and a settlement downstream. The bridge over the Malekhu River was also washed away in the same year, and it was destroyed again during the recent flood. The bridge over the Kankai River was damaged by floods in 1986. In 1987, a large segment of the Kodari Highway was washed away by a flood along the Sunkoshi. The same year, floods on the Charnawati caused severe damage to the Lamosangu-Jiri Road. The 1988 earthquake was another natural disaster that resulted in severe damage to infrastructure and property. In the same year, the flooding of the Sharda River destroyed a considerable area of cultivated land in Salyan District.

Preliminary estimates of recent flood and landslide damages (July 1993) are shown in Table 1.1 and Map 1.1. The scale and diversity of the damage are overwhelming, indicating the destructive power behind some of these processes. While it may be psychologically appeasing to consider these as rare events, with an occurrence probability of once in every 50 or 100 years, the frequency of these events is not only increasing, but their cumulative impact appears to be worsening also. Events that had relatively little impact earlier are taking a heavier toll today because floodplains and marginal lands are cultivated, steep hill slopes become denuded, quarrying is unmanaged, settlements grow haphazardly in disaster-prone areas, and enforcement of a sound land use policy is lacking.

In spite of the fact that such disasters are occurring from time to time in the fragile and young Himalayan region, hardly any studies have been carried out, by institutions or individuals, focussing on the extent, type, and causes of such disasters. Neither are any attempts made to mitigate the hazards and prepare maps depicting the hazard and/or risk associated with these events.

## Table 1.1: Flood Relief Operation 2050

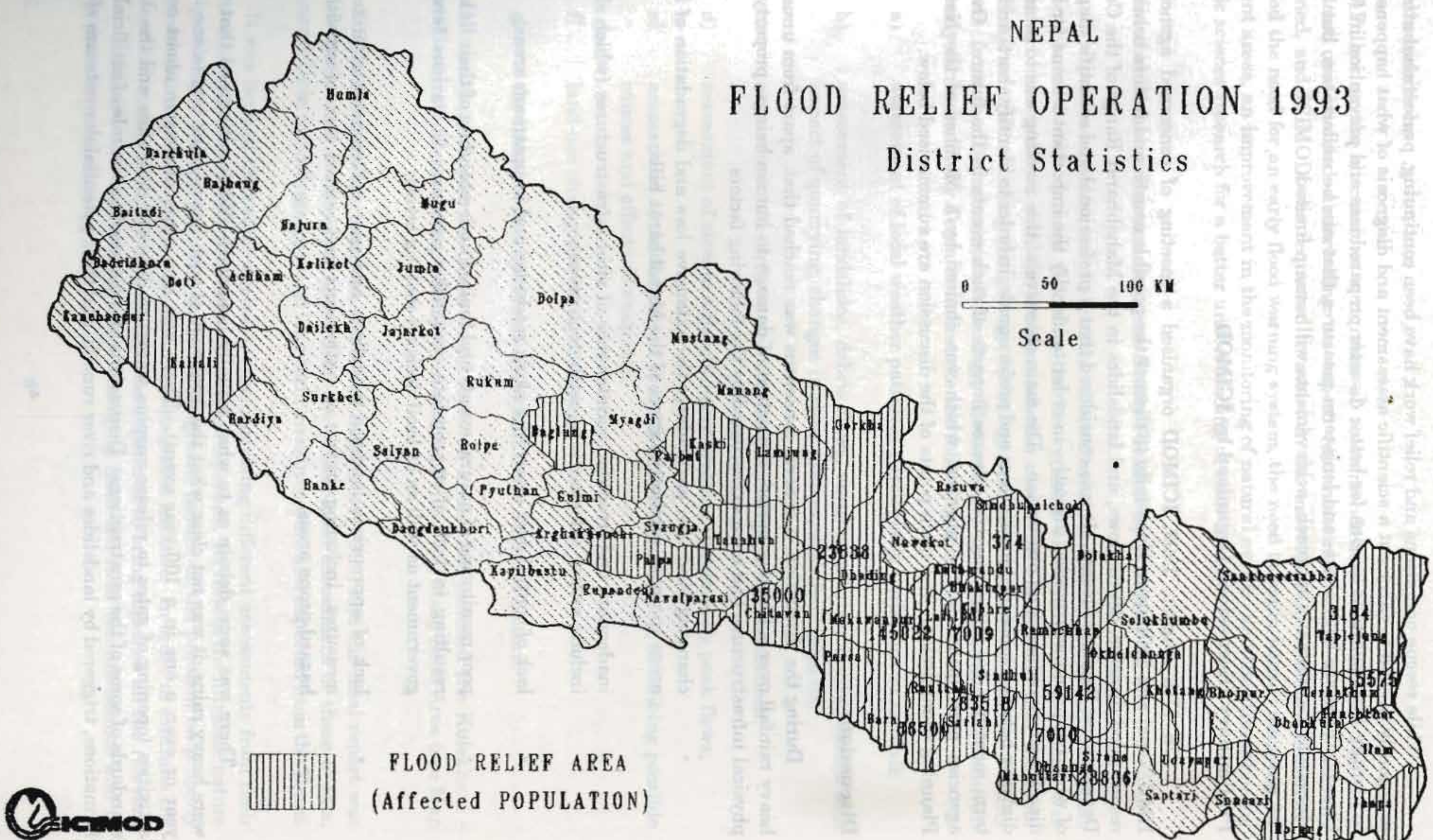
Date : 08/21/93

## District Statistics on Loss of Lives and Property (Preliminary Report)

Time : 04:40:43

| S.No | District | Affected HH | Affected Pop | Deaths | Destroyed Houses Complete | Destroyed Houses Partly | Land loss Area | Land loss Unit HA | Crop Loss Area | Crop Loss Unit | Food Grain Loss Qty | Food Grain Loss Unit | Livestock Loss | Roads | Bridges | Dams | Kuld | Publ. Bldg. | Total Worth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BAGLUNG | 12 | 0 | 1 | 13 | 2 | 11 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 10 | 0 | 0.00 |
| 2 | BARA | 41 | 0 | 2 | 63 | 41 | 34 | | 549.000 | BIGHA | 0.000 | | 0 | 6.00 | 0 | 0 | 0 | 0 | 0.00 |
| 3 | CHITWAN | 2489 | 35000 | 22 | 68 | 613 | 1522 | | 0.000 | | 0.000 | | 1012 | 0.60 | 2 | 2 | 0 | 0 | 0.00 |
| 4 | DHADING | 317 | 23828 | 23 | 141 | 0 | 997 | | 0.000 | | 2856.480 | TON | 211 | 1.29 | 16 | 0 | 1 | 3 | 0.00 |
| 5 | DHANUSHA | 1045 | 7000 | 0 | 49 | 250 | 34 | | 9391.000 | HA | 100.000 | TON | 17 | 10.00 | 5 | 9 | 74 | 5 | 159615100.00 |
| 6 | DOLAKHA | 0 | 0 | 0 | 0 | 30 | 1 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 7 | GORAKHA | 28 | 0 | 0 | 21 | 0 | 12 | | 38.000 | ROPANI | 0.000 | | 0 | 0.00 | 9 | 0 | 0 | 1 | 2394000.00 |
| 8 | JHAPA | 0 | 0 | 0 | 18 | 11 | 1 | | 2.600 | BIGHA | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 9 | KAILALI | 0 | 0 | 2 | 0 | 0 | 0 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 10 | KASKI | 0 | 0 | 1 | 0 | 0 | 0 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 11 | KATHMANDU | 0 | 0 | 2 | 8 | 0 | 3 | | 0.000 | | 0.000 | | 0 | 0.00 | 1 | 0 | 0 | 0 | 0.00 |
| 12 | KAVRE | 1638 | 7009 | 20 | 892 | 0 | 583 | | 0.000 | | 0.000 | | 58 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 13 | KHOTANG | 0 | 0 | 1 | 30 | 0 | 0 | | 0.000 | | 0.000 | | 100 | 0.00 | 0 | 0 | 4 | 14 | 13932086.00 |
| 14 | LALITPUR | 0 | 0 | 6 | 57 | 51 | 135 | | 0.000 | | 0.000 | | 0 | 0.00 | 2 | 0 | 0 | 0 | 0.00 |
| 15 | LAMJUNG | 0 | 0 | 0 | 1 | 5 | 0 | | 512.000 | MURI | 0.000 | | 0 | 0.00 | 1 | 0 | 1 | 0 | 0.00 |
| 16 | MAHOTTARI | 13 | 0 | 8 | 0 | 0 | 0 | | 0.000 | | 0.000 | | 0 | 0.00 | 12 | 0 | 0 | 0 | 0.00 |
| 17 | MAKWANPUR | 1500 | 145022 | 241 | 1047 | 510 | 2042 | | 85460.000 | MURI | 0.000 | | 665 | 7.92 | 16 | 1 | 251 | 118 | 772015911.00 |
| 18 | MORANG | 0 | 0 | 0 | 0 | 0 | 5 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 19 | OKHALDHUNGA | 76 | 0 | 0 | 63 | 13 | 5 | | 0.000 | | 0.000 | | 35 | 0.00 | 1 | 0 | 0 | 0 | 0.00 |
| 20 | PALPA | 0 | 0 | 1 | 0 | 0 | 0 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 1 | 0 | 0.00 |
| 21 | PANCHTHAR | 1115 | 5575 | 22 | 13 | 164 | 152 | | 4585974.000 | RS | 0.000 | | 23 | 0.00 | 0 | 0 | 0 | 0 | 18717191.00 |
| 22 | PARSA | 0 | 0 | 2 | 28 | 107 | 5 | | 1300.000 | BIGHA | 36.000 | TON | 104 | 4.88 | 5 | 0 | 1 | 5 | 155916000.00 |
| 23 | RAMECHHAP | 0 | 0 | 3 | 166 | 218 | 191 | | 0.000 | | 4.000 | TON | 8 | 0.00 | 0 | 0 | 16 | 21 | 0.00 |
| 24 | RAUTAHAT | 8876 | 66500 | 111 | 1934 | 0 | 982 | | 5601.000 | HA | 3579.600 | TON | 3135 | 40.00 | 13 | 0 | 1 | 22 | 899680261.00 |
| 25 | SARLAHI | 34020 | 163518 | 601 | 6152 | 12196 | 25966 | | 25966.000 | HA | 0.000 | | 17736 | 266.00 | 81 | 4 | 117 | 184 | 1118918500.00 |
| 26 | SINDHULI | 10996 | 59142 | 48 | 1080 | 1336 | 10210 | | 8145.000 | BIGHA | 1186.000 | TON | 1800 | 26.00 | 41 | 5 | 6 | 24 | 776811500.00 |
| 27 | SINDHUPALCHOK | 59 | 374 | 0 | 3 | 13 | 12 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| 28 | SIRAHA | 1145 | 28806 | 0 | 64 | 440 | 26 | | 1418.000 | BIGHA | 0.000 | | 7 | 0.00 | 0 | 2 | 0 | 2 | 43500000.00 |
| 29 | TANAHU | 0 | 0 | 2 | 3 | 0 | 5 | | 0.000 | | 0.000 | | 0 | 0.20 | 1 | 11 | 0 | 0 | 0.00 |
| 30 | TAPLEJUNG | 811 | 3184 | 28 | 93 | 1 | 166 | | 0.000 | | 0.000 | | 3 | 0.00 | 0 | 0 | 46 | 0 | 17756395.00 |
| 31 | TEHRTHUM | 0 | 0 | 0 | 45 | 0 | 0 | | 2238960.000 | RS | 5.670 | TON | 54 | 0.00 | 1 | 0 | 0 | 0 | 0.00 |
| 32 | UDAYPUR | 0 | 0 | 1 | 0 | 0 | 0 | | 0.000 | | 0.000 | | 0 | 0.00 | 0 | 0 | 0 | 0 | 0.00 |
| | GRAND TOTAL | 64181 | 544958 | 1148 | 12052 | 16001 | 43100 | HECTARE | | | 7767.750 | TON | 24968 | 362.59 | 207 | 34 | 529 | 399 | 3979256944.00 |

Map 1.1


NEPAL
FLOOD RELIEF OPERATION 1993
District Statistics
0 50 100 KM
Scale
FLOOD RELIEF AREA
(Affected POPULATION)
ICIMOD
MENRIS '93
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Kanchanpur
Kailali
Dailekh
Jajarkot
Dolpa
Mustang
Surkhet
Rukum
Bardiya
Manang
Myagdi
Baglung
Salyan
Rolpa
Kaski
Parbat
Lamjung
Gorkha
Banke
Pyuthan
Gulmi
Rasuwa
Dang Deukhuri
Syangja
Tanahun
Sindhupalchok
Arghakhanchi
23838
Nuwakot
374
Dolakha
Palpa
Kapilbastu
Dhading
Kathmandu
Bhaktapur
Rupandehi
Nawalparasi
35000
Kabhre
Sankhuwasabha
Chitawan
Makawanpur
Lalitpur
145022
7009
Ramechhap
Solukhumbu
3184
Taplejung
Okhaldhunga
Parsa
Sindhuli
Rautahat
83518
59142
Khotang
Bhojpur
Terhathum
5575
Dhankuta
Panchthar
Bara
36500
Sarlahi
7000
Ilam
Siraha
Udayapur
Dhanusa
Mahottari
23806
Saptari
Sunsari
Morang
Jhapa

While rescue operations and relief work have been continuing, professional attention is urgently needed to carry out a scientific assessment and diagnosis of what happened and to identify the important lessons for better disaster preparedness and prevention in future. Clearly, there are both short- and long-term measures that can be undertaken, but in the absence of a systematic approach, achievements will remain limited.

## Preliminary Discussions Organised by ICIMOD

On 17th August, 1993, ICIMOD organised a meeting of concerned agencies of HMG/Nepal and Tribhuvan University to discuss the possible causes and factors behind the recent flood disaster, debris flows, and landslides in the Mahabharat Range of the Central Development Region of Nepal. It was considered that a professional and scientific diagnosis of what happened was needed urgently, in order to identify the important lessons for better disaster preparedness and prevention. The main objective of this meeting was to promote a dialogue between concerned institutions and professionals, in order to identify short- and long-term measures for mitigating the adverse impacts of such events in the future. Over 20 agencies participated in the meeting, which was chaired by a Member of the National Planning Commission. The main points of the discussion are summarised below.

## Discussions

During the discussion, a general consensus was reached that, apart from unusually heavy rainfall over a two-day period, the extent of damage to human beings, property, and physical infrastructure had been exacerbated by the following factors:

- changing land use, particularly the extensive loss and degradation of forest areas in upper catchment areas of the Mahabharat hills;
- inadequate and irregular maintenance of vital infrastructures (which should include proper safeguards in catchment areas);
- lack of control over quarrying along roadsides and in upstream areas;
- poor monitoring of natural events and limited understanding of their linkages, resulting in lack of appropriate preventive measures at various levels of government as well as at local decision-making levels;
- lack of appropriate land-use guidelines and poor enforcement of protection measures, including growth of settlements and related human activities in hazard-prone areas.

There was some debate as to what actually happened. While all agreed that there were heavy rains, it was not clear what the frequency of such heavy rains was (a one in 10-year or even a one in a 100-year event). There was also some discussion about control activities (opening of gates to release surplus water) at different dam sites and the design standards of some of the constructions. Discussions also focussed on the role of artificial lake formations, triggered by landslides and river runoffs, and their potential downstream effects.

**Recommendations**

Following the discussions a number of recommendations were made. The most important one involved undertaking an expert reconnaissance study of what actually happened, and ICIMOD was requested to assist in the exercise. Other recommendations included the need for an early flood warning system, the need to begin hazard mapping for different areas, an improvement in the monitoring of natural events, and the strengthening of basic science research for a better understanding of such events.

**The Natural Disaster Reconnaissance Study Fielded by ICIMOD**

An expert reconnaissance study of the affected areas, to identify the main factors that had contributed to the damage following the heavy rains of July 19 and 20, 1993, was undertaken in accordance with the recommendation made. It was decided that the team would focus on understanding the geology, hydrology, and land-use related factors. Faculty members from the Departments of Geology, Meteorology, and Geography of Tribhuvan University formed a Study Team to undertake the following activities:

a) assessment of local weather patterns, particularly variations in rainfall;

b) assessment of landslides, debris flows, scouring of river banks, extent and impact of quarrying, changes in river courses, and their impacts;

c) assessment of overflows and low flow discharge in the watersheds;

d) assessment of stream adjacent, mass wasting triggered by peak flows;

e) assessment of the formation of artificial lake phenomena, describing possible causes and effects downstream;

f) land-use changes in watersheds; and

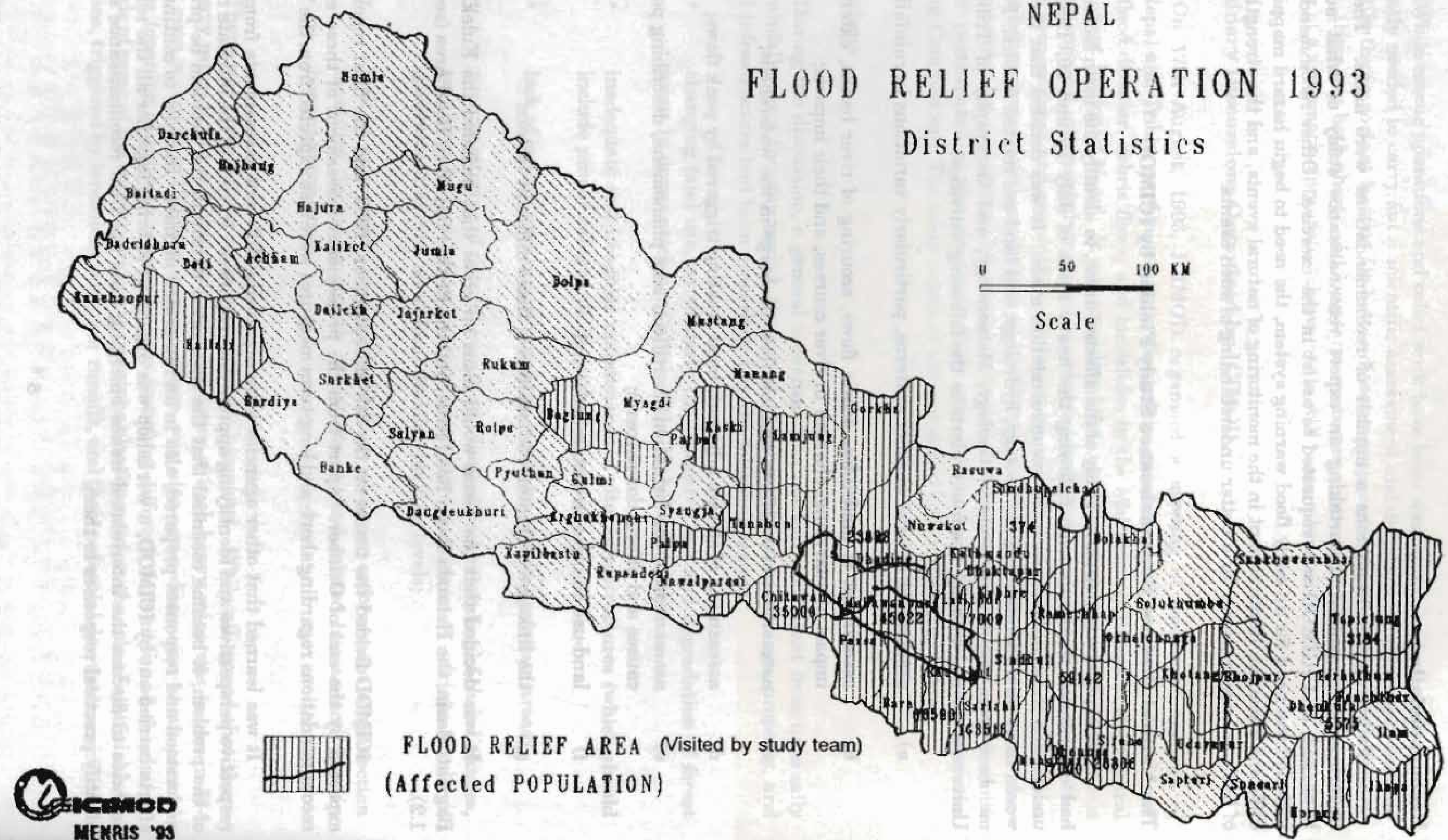
g) the linkages and interrelationships of these different factors.

It was decided that the Team would focus on areas that included the Kulekhani - Bagmati Basin, the Hetauda Rapti Road Area, and the Prithvi Raj Marg Road Area (see Map 1.2).

ICIMOD fielded the teams on the 8th of September, 1993, and the final report was expected by the end of October. Apart from the professional assessment of these events, recommendations regarding short- and long-term measures were also expected from the Team.

It was learned that other agencies were organising different assessments from their respective perspectives and identifying appropriate responses. In view of the intricate nature of the problem, it became essential that the integrated nature of the problem be properly understood and responses prepared, also in an integrated manner. In order to continue the efforts carried out by ICIMOD, a workshop was organised to bring together all the relevant agencies to discuss the interrelated issues emerging from the field reconnaissance and to identify practical responses to them.

Map 1.2


NEPAL
FLOOD RELIEF OPERATION 1993
District Statistics
0 50 100 KM
Scale
FLOOD RELIEF AREA (Visited by study team)
(Affected POPULATION)
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Kalikot
Jumla
Dadeldhura
Doti
Achham
Kanchanpur
Kailali
Dailekh
Jajarkot
Dolpa
Mustang
Surkhet
Rukum
Bardiya
Salyan
Rolpa
Banke
Pyuthan
Gulmi
Baglung
Myagdi
Manang
Kaski
Lamjung
Gorkha
Syangja
Tanahun
Rasuwa
Nuwakot
Dhading
Sindhupalchok
Kapilbastu
Rupandehi
Nawalparasi
Palpa
Chitawan
35000
Makwanpur
45022
Lalitpur
Kathmandu
Bhaktapur
Kabhre
7000
Ramechhap
Dolakha
Solukhumbu
Okhaldhunga
Sankhuwasabha
Taplejung
3154
Sindhuli
Parsa
Bara
Sarlahi
50142
Khotang
Bhojpur
Terhathum
Dhankuta
Panchthar
Udayapur
Ilam
Siraha
Saptari
Sunsari
Morang
Jhapa
MENRIS '93

## General Description of the Natural Events (July 19 and 20, 1993)

This part is based upon the field visits made to the Palung-Tistung area, the Kulekhani watershed, the Bagmati basin up to the barrage, Chitwan, and the Prithvi Raj Marg. The team did not visit Sarlahi District where the downstream flood events were most severe. It did not visit the Sindhuli and Kabhre districts which also contributed to the floods downstream.

Unprecedented high intensity precipitation occurred in the upper part of the Mahabharat Range of Makawanpur and Dhading districts, covering three major watersheds-Bagmati in the east, Trishuli in the north, and Rapti in the south - on July 19, 1993. The volume of precipitation within 24 hours, recorded within the area, ranged from 362mm at Nibuwatar in the southern part of the Mahabharat Range to 320mm at the Kulekhani dam site, 337mm at Markhu (1530m), 373mm at Daman (2,364m), and a maximum of 539.5mm at Tistung (1,940m). Such high intensity rainfall occurred over about 530 sq.km. with a maximum east-west length of 40km and maximum north-south width of 20km (Map 1.2). The area of high intensity rainfall was determined based upon discussions with different projects and local people, and upon the extent of landslides and debris flow activities observed during field visits. Almost all the VDCs located in the Mahabharat Range and its adjoining areas of Makawanpur and Dhading districts were affected by mass movement activities triggered by this torrential rain. Nearly 8,000 families of 17 VDCs, namely, Tistung, Bajrabarahi, Palung, Daman, Agra, Gogane, Namtar, Raksirang, Khairang, Kankad, Bharta, Surikhet, Kalikatar, Bhimphedi, Markhu, and Chitlang in Makawanpur district, and 3,000 families from Naubise, Thakre, Tasarpu, Pida, Baireni, and Gajuri VDCs in Dhading district, were affected by mass movement activities caused by the rainfall. Nearly 160 persons from these areas died. VDCs located far down in the Rapti Valley were also affected by the flood generated by the rain. Nearly 5,000 families in seven VDCs, namely, Bhandara, Piple, Kathar, Kumroj, Bachhauli, Padampur, and Khaireni of Chitwan district (about 40-60km downstream from the area of high intensity rain) were also affected, and 22 persons were swept away. Similarly, 1,600 families from five VDCs, namely, Manohara, Handikhola, Basamadi, Bhaise, and Nibuwatar in Makawanpur district, were affected, and 33 persons were swept away by the floods on the Rapti River. Almost all the bridges located over the rivers originating from the Mahabharat Range (area of high intensity rainfall) were swept away by the floods.

Another very high intensity precipitation event occurred in the Siwalik area and in the lower part of the Mahabharat Range on July 20, 1993, one day after the heavy precipitation in the Daman-Palung area (Map 1.2). This area of high precipitation fell in the eastern part of Makawanpur District (Phaperbari-Raigaun), in the southern part of Kavre district (Milche-Saldhara), and in the western part of Sindhuli district (Hariharpur-Marin *Khola*). The total volume of precipitation recorded in the Hariharpur area within 24 hours was more than 500mm. High intensity precipitation was concentrated in about 500-800 sq.km. with a maximum east-west length of 60km and a north south width of 25 km. Nearly 1,600 families in Kavre District, 11,000 families in Sindhuli District, and 4,000 families in Makawanpur District were affected by this rain. Similarly, about 35,000 families in Rautahat and Sarlahi districts in the downstream areas (20-60km) were affected and a total of 760 persons were swept away by the floods. Bagmati barrage, located about 20km downstream from the area of high intensity precipitation, was also badly damaged.

**Time-Sequence of Events**

In the Daman area (Mahabharat Range), light rain started in the morning at about 11 a.m. on July 18, 1993. High intensity rain, accompanied by a thunderstorm, started at about two in the afternoon on July 19 and continued until seven in the evening. Many small landslides occurred during the period. Unprecedented high intensity rainfall with thunderstorms and lightning occurred once again in the night at about 10 p.m., causing big landslides and debris flows. The rain continued throughout the night. (The times of occurrence of major mass movements associated with landslides, debris flows, and peak floods reported from different places and areas affected are presented in Maps 1.3 and 1.4.) It was reported that destructive floods hit Bhimphedi and the Mandu *Khola* area at about 9.40 p.m. High intensity rainfall with many landslide activities occurred from about 10-11 pm in the Daman area, whereas similar events occurred at midnight in the Phedigaun, Tistung, and Agra areas. It took about one hour to reach peak flood, and this was accompanied by huge volumes of debris from Chisapani (Agra) to Mahadevbesi (about 20 km downstream from Chisapani). Similarly, flooding started at about 9.40 p.m. from the upper watershed of the Rapti River (near Bhimphedi and the Gogane area) and reached the confluence of Manohari *Khola* with the Rapti River at about 11.30 p.m., Bhandara at midnight, and Padampur at about two in the morning. The flood took two to four hours to reach the areas further south in the Rapti valley where many lives and properties were lost. A checkdam on the Rapti River was destroyed by this flood and many villages in Chitwan district were inundated. This dam, which had been destroyed by a flood in 1990, had been reconstructed only recently. It was also reported that there was no heavy precipitation in lowland areas before and during the flood. Many people reported that the water level of the Rapti River on August 10, 1993, was as high as on July 19, 1993. On July 19, a huge amount of bed load was brought from the Mahabharat Range and deposited on the river bed, causing the water level to overflow its banks and flood large areas.

Almost all the bed load and logs brought from the high precipitation area in the upper catchment (Daman-Palung) of the Kulekhani River were stored in the *Indrasarobar* (Kulekhani lake). It has been estimated that the life of the dam has been reduced by 10 years due to the large amount of sediment deposits resulting from this event. A large volume of water was also stored in this lake. The water level in the dam on July 19 at nine a.m. was 1,498.63m, and it rose to 1499.33m at four p.m. The water level on July 20 at seven a.m. was 1,524.62m, rising to 1,525.05m at nine a.m. During this brief period, 26.42m of additional water was stored in the lake with a surface area of 2.2 sq.km. As the share of water from the Kulekhani was not so large ($27m^3/s$), it could not have accounted for any of the main damage occurring along the river course. Many people from the downstream areas of the Kulekhani dam site point out that the floods occurring on August 10, 1993, were more destructive than the floods on July 19. It was also reported that the river bed in the downstream reaches of the dam site rose by between four to five metres due to the deposition of bed load brought by the flood on July 19. The source areas for this large volume of sediment, deposited on the river bed along the Kulekhani *Khola*, were the landslides originating in the catchment areas below the dam site as well as the materials deposited at the time of dam construction (personal communication). Continuous rain on August 9 and 10 reinitiated a huge landslide in Chuakilekh which had first occurred 12 years previously.

Flooding on July 19 and 20 on the Bagmati River was not as extensive as on August 9 and 10, according to the villagers in Piutar, Asrang, and Gimdi VDCs of Lalitpur District. It was also reported from these areas that the volume of bed load and trees carried by the

Bagmati River was much greater during the flood of 1981 (September 30) when very high intensity rainfall occurred in the Lele-Bhardeo area of Lalitpur District. Only a limited number of landslides and debris flows was observed in these areas.

Another high intensity precipitation pocket with intense landslide activities was observed from the Durlung *Khola* to the Raigaun area in the Bagmati watershed (Map 1.1). Light precipitation started on July 17 and very high intensity rain with thunderstorms occurred at midnight on July 20, one day after the heavy precipitation in the Daman-Palung area, causing many landslides and debris flows. Peak flooding occurred on the same night from about two to three a.m. in the Raigaun area. The water level rose by 20m compared to the normal flow, inundating a large area near Raigaun where three rivers, namely, the Chiruwa, Marin *Khola*, and the Bagmati River met close to a very sharp bend (almost $90^0$) in the river course caused by the Sindhure *danda*. One person, 190 animals, and 27 houses from Purba *tole* and Murkush *tole* were swept away at about three a.m. These were new settlements built after 1959, and most of the inhabitants had migrated from the middle hills. It should be noted that the older settlements belonging to the Rai community, located at upper elevations (about 10-20m higher than the water level of the present peak flood), were not affected. Two settlements with 79 houses were destroyed by debris flow at Karauje of Raigaun VDC. Both these settlements were new and developed by people who had migrated from the middle hills and who had no experiences of the past geohydrological processes in the weak and unconsolidated Churia hills and floodplains of the inner *terai* (Doon valley). Damage to newer settlements and schools (located at lower elevations) and to the floodplains also occurred in Palung, Tistung, and downstream from the Kulekhani.

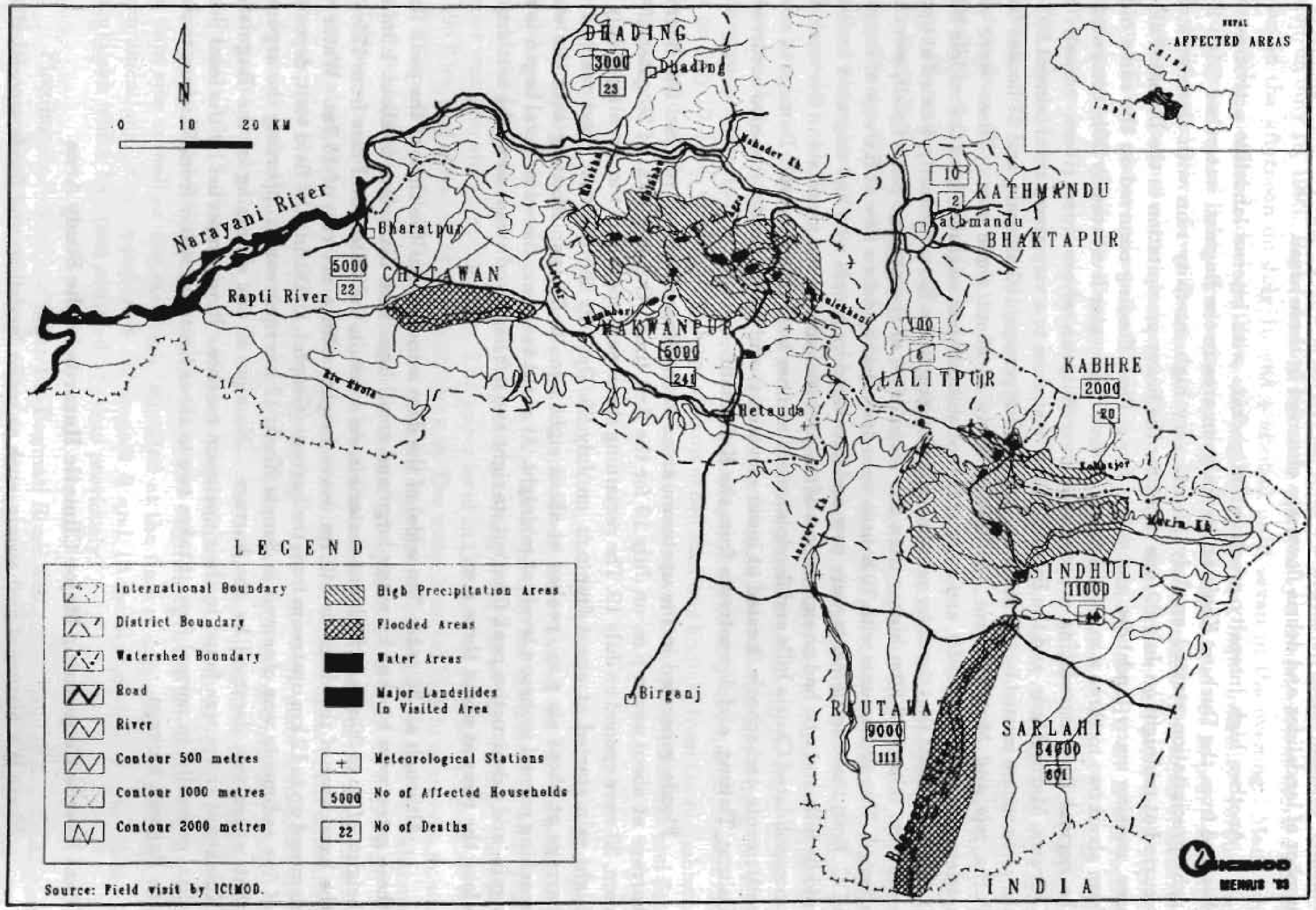
Floods generated in the upstream areas of the Bagmati River reached the Bagmati barrage at about seven p.m. on July 19 for the first time. Out of a total of 36 gates of the dam, 33 were opened on July 19. The remaining three were opened on the morning of July 20. Light rain started at about four p.m. on July 20. On July 20, the first flood reached the barrage at about six p.m., peaked at about eight p.m., and began receding with the water reaching normal monsoon levels at midnight. At about two a.m., the water level began to rise again, and a destructive peak flood cut its right and left bank and swept away the settlements along the river at about three a.m.

Although all 36 gates (9m wide) of the dam were open at the time of the peak flood, these gates were blocked by many large and small logs (with diameters of about 1.9m and heights of up to 30m) and bed load materials. As a result, the water level rose from 125m (at the base level of the dam) to 140.7m (wave height) with a net rise of 15.7m. Water was dammed up to 12 km upstream from the barrage (Graph 1.1). During the field visit, deposition of fine sediments was observed in Sangle *Khola* 12 km upstream, supporting the argument that water was dammed by the barrage. No sign of any damming of the Bagmati or Kulekhani rivers was found in their upstream reaches. It was reported by the local people that generally, in normal flow, it takes two to three hours for water from Raigaun to reach the Bagmati barrage.

### Past Events Concerning Major Climatic Hazards in the Study Area

There is a history of past events, such as major landslides and floods associated with incessant rain, reported by local people from different areas. It is useful to examine these also.

**Map 1.3: Areas Affected by Very High Intensity Rainfall on July 19 & 20, 1993**




Source: Field visit by ICIMOD.

**Map 1.4: Timing of Major Mass Movements and Flooding Activities Associated with the High Intensity Rainfall on July 19 & 20, 1993**

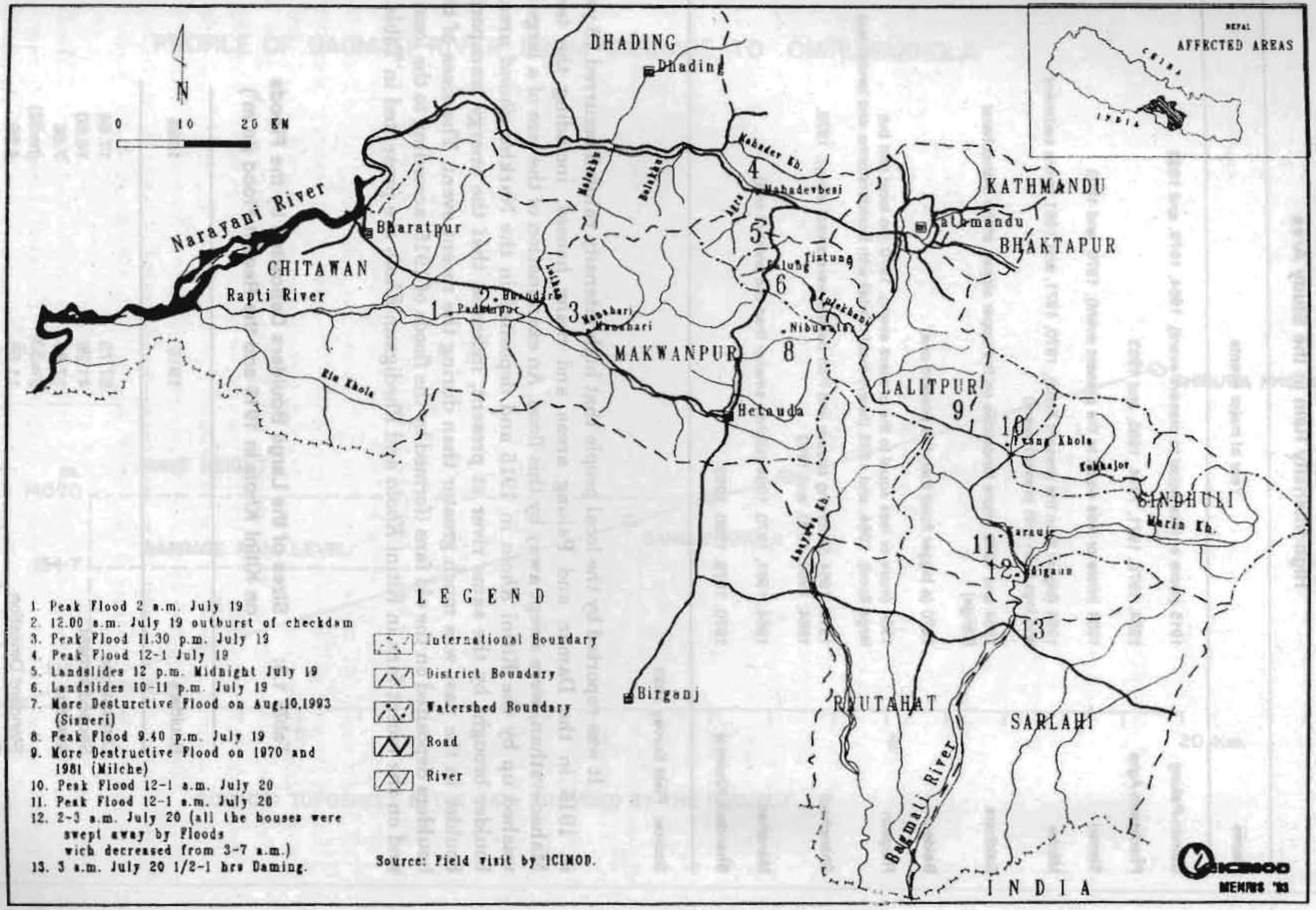


**Table 1.2: Major Landslides and Floods Associated with High Intensity Rain in the Study Area**

| Places | Year of major events |
|---|---|
| Daman-Palung | 1915 (more or less equal to present event), 1954, 1979, and 1993 |
| Phedigaun-Agra | 1954, 1970, 1971, 1974, 1985, and 1993 |
| Sisneri | 1954 (more or less equal to the present event), 1970, and 1993 |
| Milche | 1954 (bigger than the present flood), 1970, 1971, and 1981 (more sediment and logs than with present event) |
| Saldhara | 1954 and 1970 (more landslides on the upper slopes of the Mahabharat Range) |
| Baldeu | 1970 (a bigger flood than the present one) |
| Raigaun | 1954 (more or less equal to the present event), 1970 (no local rain but large flood), 1984, and 1993 (heavy local rainfall with thunderstorms and landslides) |
| Bhimphedi | 1915, 1954 (Ghorsing *bazaar* and Pati *bazaar* were swept away), 1973, 1984, 1986, 1990, and 1993 |
| Manahari | 1954, 1961, 1970, 1984 (slightly smaller than the present one) |
| Bhandara-Khumroj | 1970, 1979, 1990, 1993 |

Source: Field Survey 1993

It was reported by the local people that high intensity rainfall occurred 78 years ago in 1915 in the Daman and Palung areas and many houses, including the temple of Mahadevsthan, were swept away by this flood. An examination of the size of a large boulder washed up by the Kitini *Khola* in 1915 and deposited in the Narkhu *dhand* area, and a boulder brought by the same river at present, indicates that the energy transporting the boulder in the past was much greater than during the recent event. The sizes of the large boulders deposited on the old fans (formed by the floods of 1915, according to the local people) and on the recent fans in Kitini *Khola* and Phedigaun *Khola* are presented in Table 1.3.

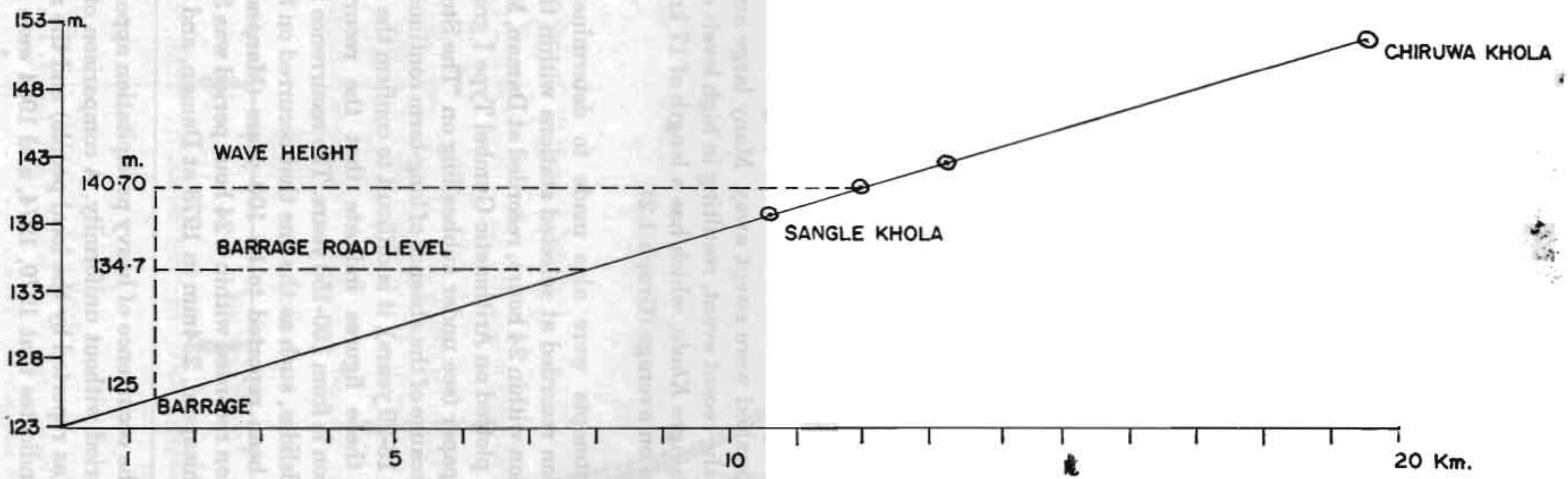
**Table 1.3: Sizes of the Large Boulders Deposited by the Floods on Kitini *Khola* in 1915 and the Recent Flood (in $m^3$)**

| Boulders | 1915 | 1993 |
|---|---|---|
| Largest one | 57.75 | 17.64 |
| Second largest | 41.26 | 16.60 |
| Average | 17.86 (n=33) | 7.56 (n=32) |
| Standard Deviation | 11.58 | 4.59 |
| T value | 4.69 | |

Source: Field Survey 1993

Graph 1·1

PROFILE OF BAGMATI RIVER FROM BARRAGE TO CHIRUWAKHOLA




SOURCE: TOPOSHEET & THE DATA PROVIDED BY THE PROJECT.

Table 1.4: **Size of the Big Boulders Deposited by the Flood on Phedigaun *Khola* in 1915 and the Recent One (in $m^3$)**

| Boulders | 1915 | 1993 |
|---|---|---|
| Largest one | 109.8 | 52.5 |
| Second largest | 57.98 | 20.4 |
| Third largest | 46.62 | 11.9 |
| Fourth largest | 5.07 | 11.8 |

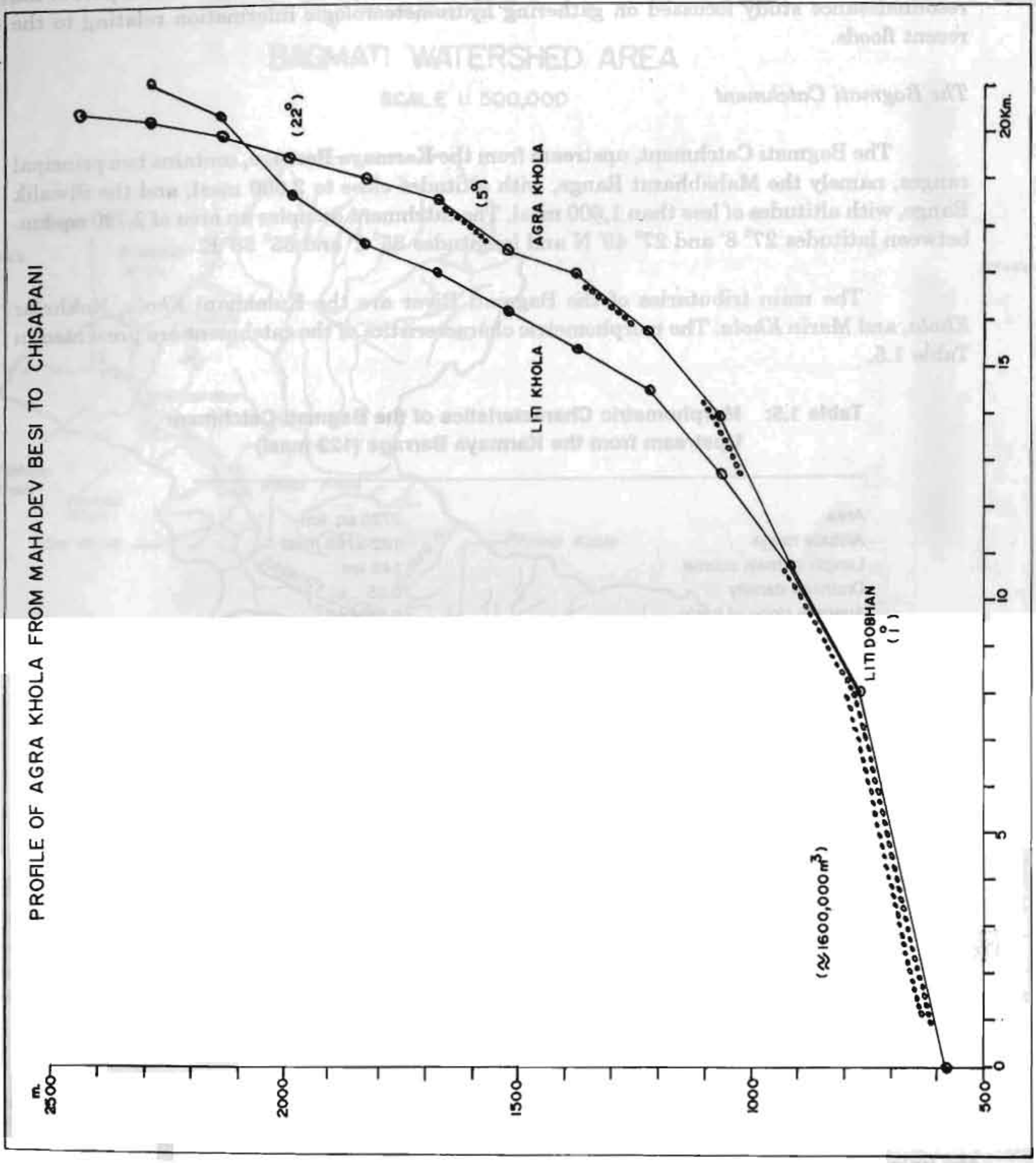
Source: Field Survey 1993

The ages of the large *simal* trees (*Bombax malabaricum*) deposited at the Bagmati barrage, as seen from their rings, were found to be from 53-65 years. *Simal* mostly grows on old fans and river courses, and it was the principal species deposited at the dam site. This could also suggest (based upon the age of these trees carried downstream by the floodwaters) that floods of similar magnitude have a recurrence interval of from 80-100 years.

Heavy precipitation in 1954 caused many landslides in the Agra *Khola* watershed. A hillslope near Deurali was cracked by rainfall in 1970. The incessant rain of 1974 again triggered large landslides, and the villages of Mahadevkharka and Unichaur in the Agra *Khola* watershed were swept away. Many large and deep landslides and debris flows were caused by the recent event, resulting in high levels of debris deposition downstream. The bed level of the Agra *Khola*, which has a length of 17 km with an average width of 40 m, rose by five metres on average (Graph 1.2).

Attempts were also made to determine the recurrence interval of 24 hours' precipitation recorded at selected stations within the study area. The maximum volumes of precipitation within 24 hours, recorded at Daman, Markhugaun, Chisapani, and Hariharpur, have been plotted on Arithmetic Gumbel Type I graph paper and Logarithmic Gumbel Type III graph paper (see under subheading on "The Storms from July 19th to 21st, 1993, p. 24, Part I). Because of the absence of long-term continuous data from these stations (past records cover only 18-29 years), it is difficult to confirm the recurrence interval of such precipitation. However, these figures indicate that the recurrence interval of such high intensity precipitation is from 100-150 years. The recurrence interval of high intensity rainfall causing many landslides, such as the one that occurred on September 30, 1981, in the Lele-Bhardeo area, has been reported to be 100 years (Manandhar and Khanal 1988). The maximum precipitation recorded within a 24 hour period was 388mm in 1979 at Hariharpur, 300mm in 1965 at Chisapani, 234mm in 1978 at Daman, and only 190mm at Markhugaun.

The occurrence of heavy precipitation appears uneven and highly localised within a specific period without uniformity. A comparison of the dates of major landslides and flood activities (as reported by the local people) and the maximum volume of precipitation within 24 hours indicates that 1970, 1974, and 1984 were periods of landslides and flood hazards.




Graph 1:2

PROFILE OF AGRA KHOLA FROM MAHADEV BESI TO CHISAPANI

**An Assessment of Climatic Events Occurring during July 19th - 20th, 1993**

As discussed in the previous pages, this reconnaissance study commissioned by ICIMOD mainly concentrated on the Bagmati Catchment. The field study, carried out from September 1st to 22nd, covered a distance of over 120 kilometres (Figure 1.1). This part of the reconnaissance study focussed on gathering hydrometeorologic information relating to the recent floods.

*The Bagmati Catchment*

The Bagmati Catchment, upstream from the Karmaya Barrage, contains two principal ranges, namely the Mahabharat Range, with altitudes close to 2,600 masl, and the Siwalik Range, with altitudes of less than 1,600 masl. The catchment occupies an area of 2,720 sq. km. between latitudes $27^0$ 8' and $27^0$ 49' N and longitudes $85^0$ 2' and $85^0$ 58' E.

The main tributaries of the Bagmati River are the Kulekhani *Khola*, Kokhajor *Khola*, and Marin *Khola*. The morphometric characteristics of the catchment are presented in Table 1.5.

**Table 1.5: Morphometric Characteristics of the Bagmati Catchment Upstream from the Karmaya Barrage (122 masl)**

| | |
|---|---|
| Area | 2720 sq. km |
| Altitude range | 122-2765 masl |
| Length of main course | 149 km |
| Drainage density | 0.25 |
| Average slope of basin | $9.08 \times 10^{-3}$ |
| Compactness coefficient | 1.73 |

Source: Topographic Maps 1:50,000, 1:500,000

The Bagmati River has the following general characteristics:

- the upper reaches are very steep (Figures 1.2 and 1.3),
- the lower reaches became braided near the Siwalik and the *terai* regions,
- the monsoon floods and sediment concentration are high, and
- the dry season flow is relatively low, as there is no snowmelt contribution (Figure 1.4).

Thus water resources' projects in this area depend solely on the monsoon.

*Vegetation and Settlement*

Population pressure has forced the frontiers of grazing, logging, and land clearing to the uplands as well as into the floodplains. With the exception of a few pockets, most of the forested areas have been destroyed, and this is contributing to slides along unstable slopes, rapid rainfall - runoff erosion, deterioration in water quality, and sedimentation of reservoirs and river beds; and all of which have led to a variety of undesirable socioeconomic and environmental consequences.

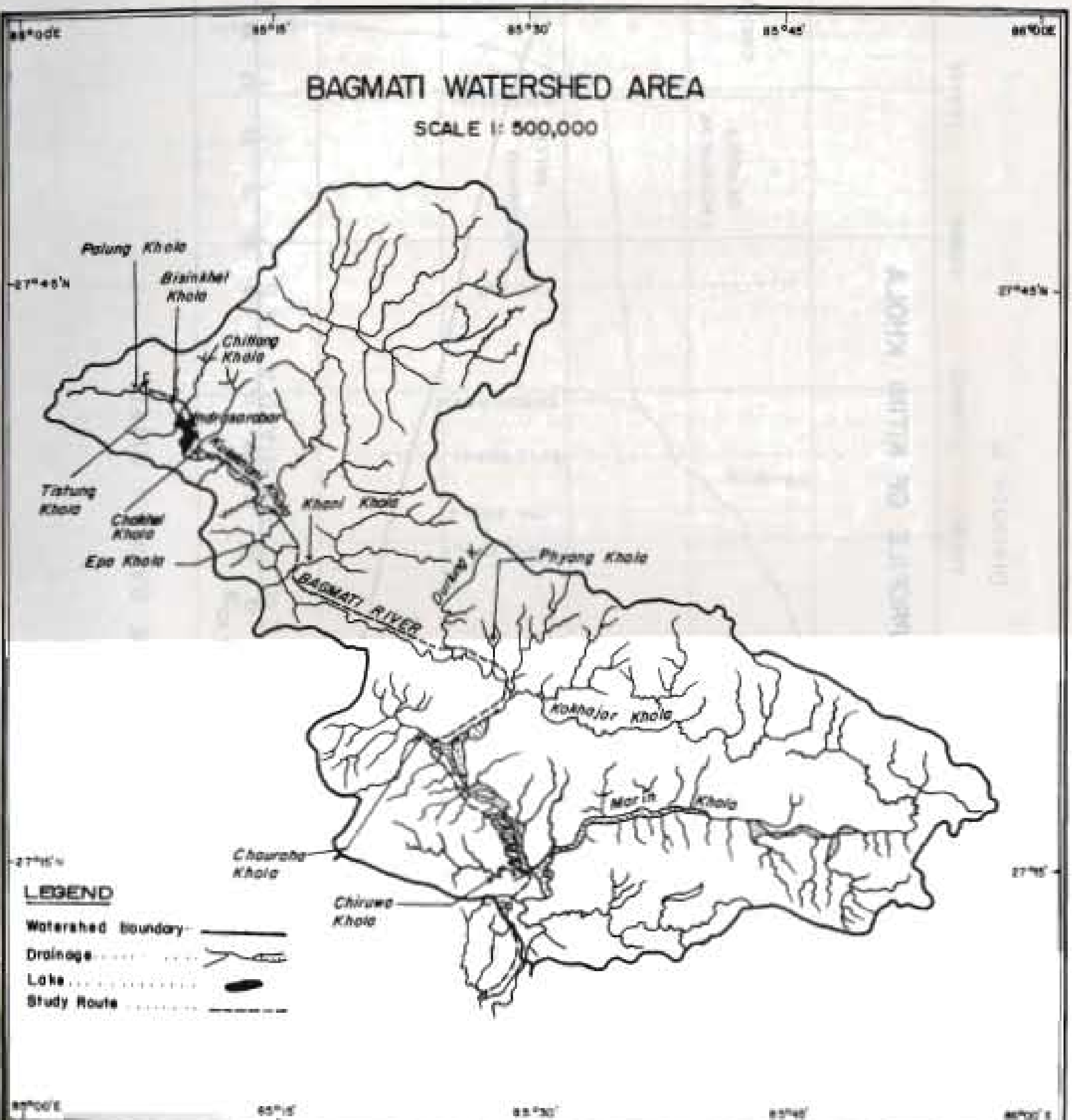



FIG.1.1: THE BAGMATI WATERSHED

FIG.1.2: LONGITUDINAL PROFILE OF KITINI KHOLA

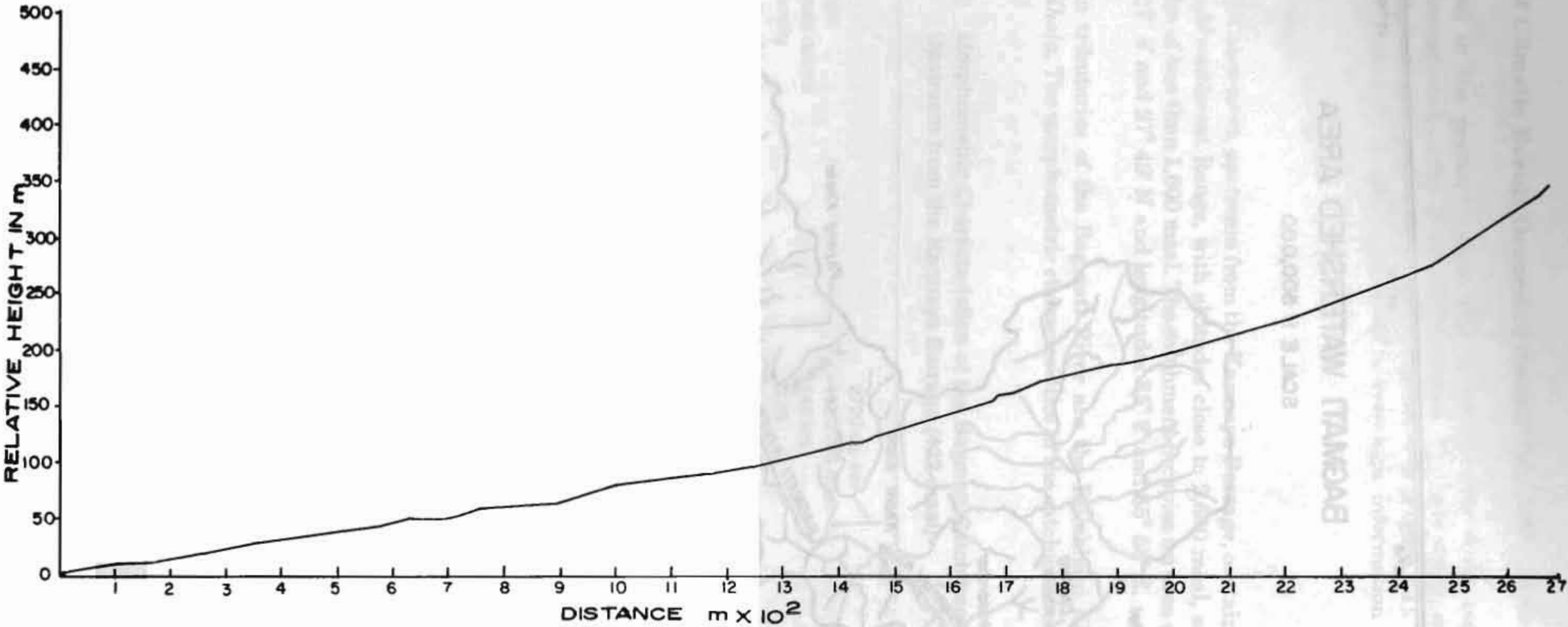


FIG-1.3: LONGITUDINAL PROFILE OF THE BAGMATI RIVER

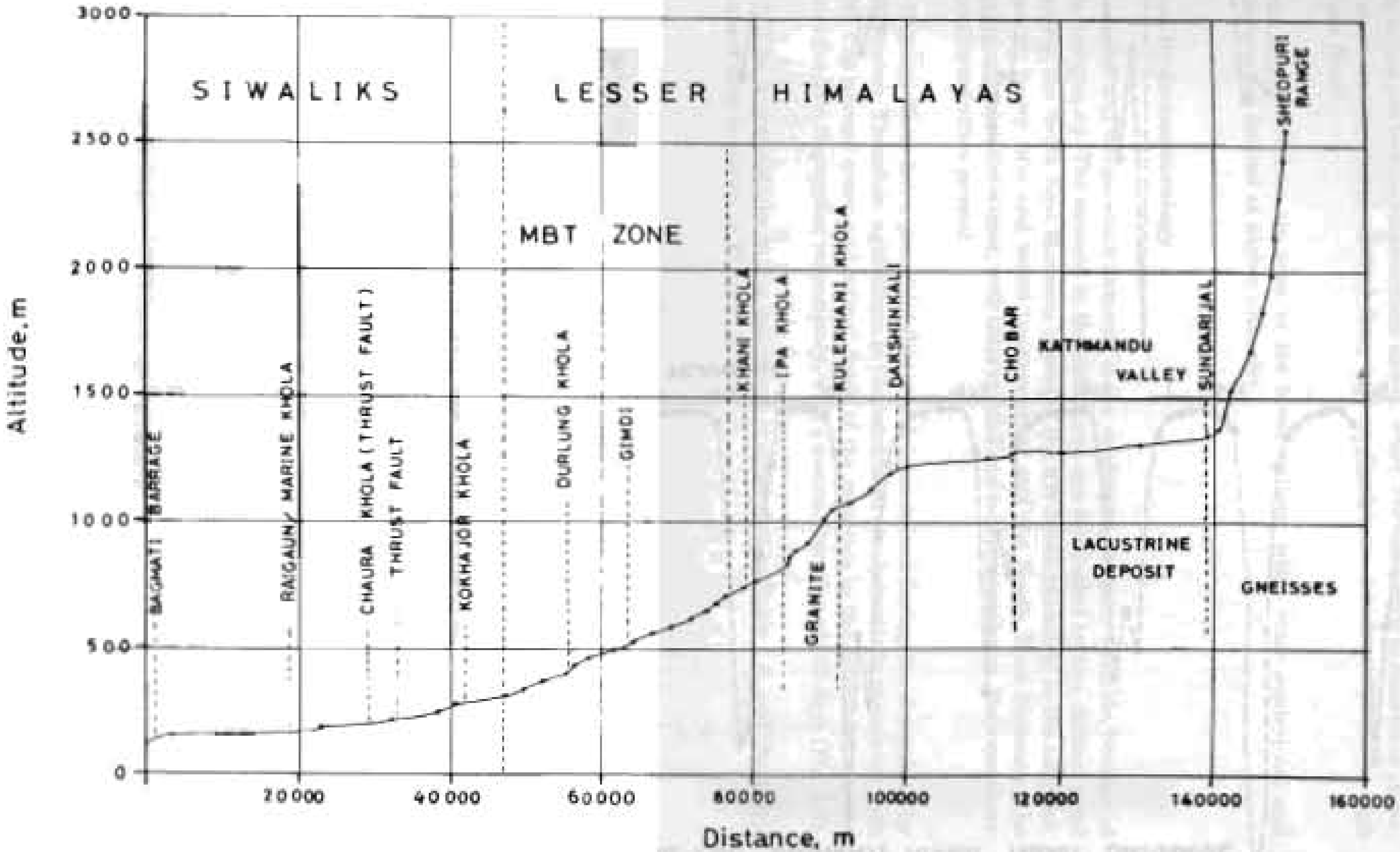
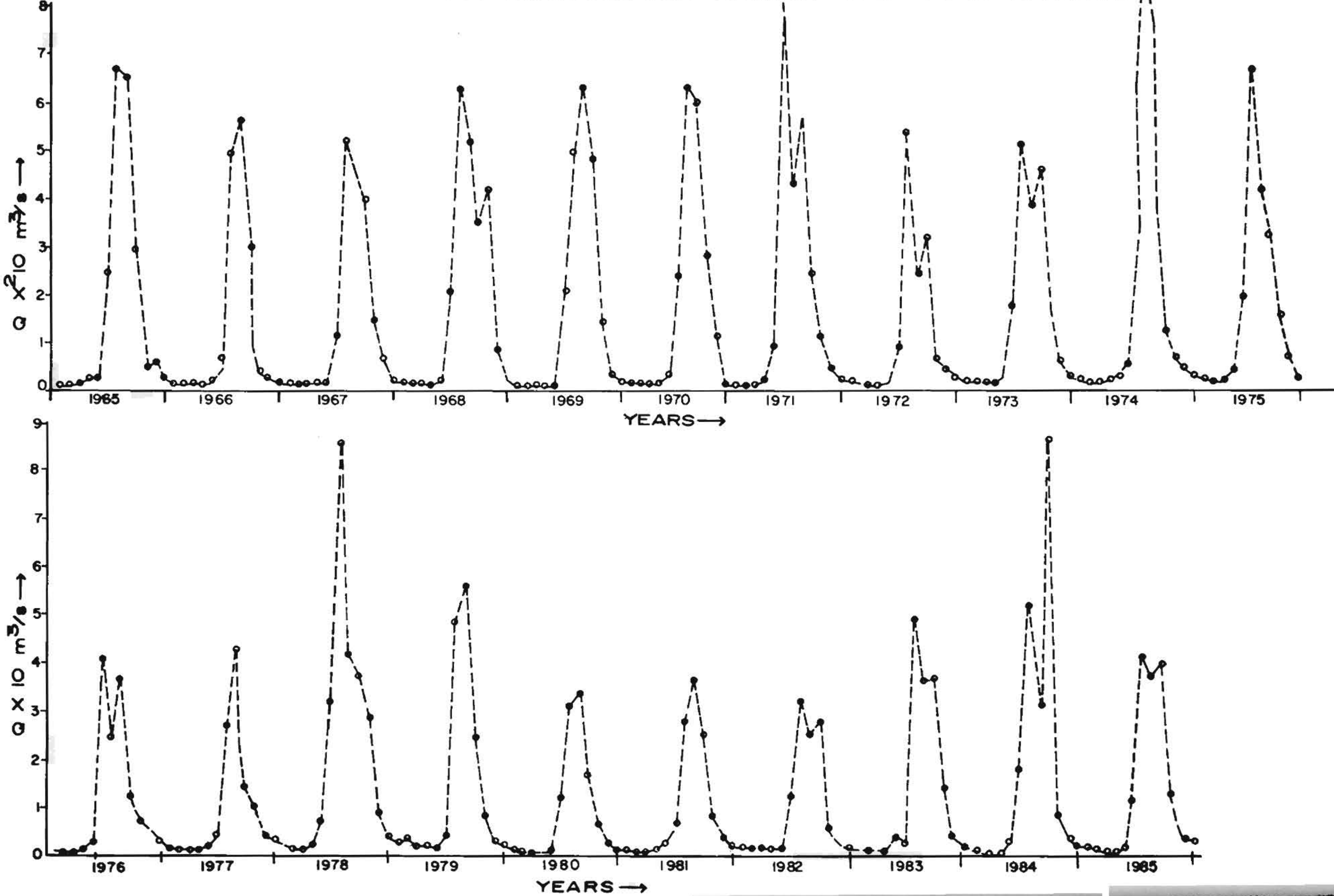


FIG.1.4: AVERAGE MONTHLY DISCHARGE FOR BAGMATI RIVER NEAR BARRAGE



Settlements are located on precarious slopes, which are vulnerable to disastrous slides, and along river banks, on old alluvial fans, and on floodplains which are prone to high intensity flash floods.

Sparse tropical forests are seen in the lower valleys, while some subtropical and temperate forests are located at higher altitudes.

## Climate and Hydrometeorology

The rainfall and temperature patterns in the catchment are quite variable, because of the intricate topography. The seasons in the catchment are dominated by two distinct wind systems; namely, the South East Monsoon (a part of the SW Asian Monsoon) in the summer, characterised by heavy rain and warm temperatures, and the North West Monsoon (the Western Disturbances) in the winter, with little rainfall and cold temperatures. Between these seasons, thunder activities prevail.

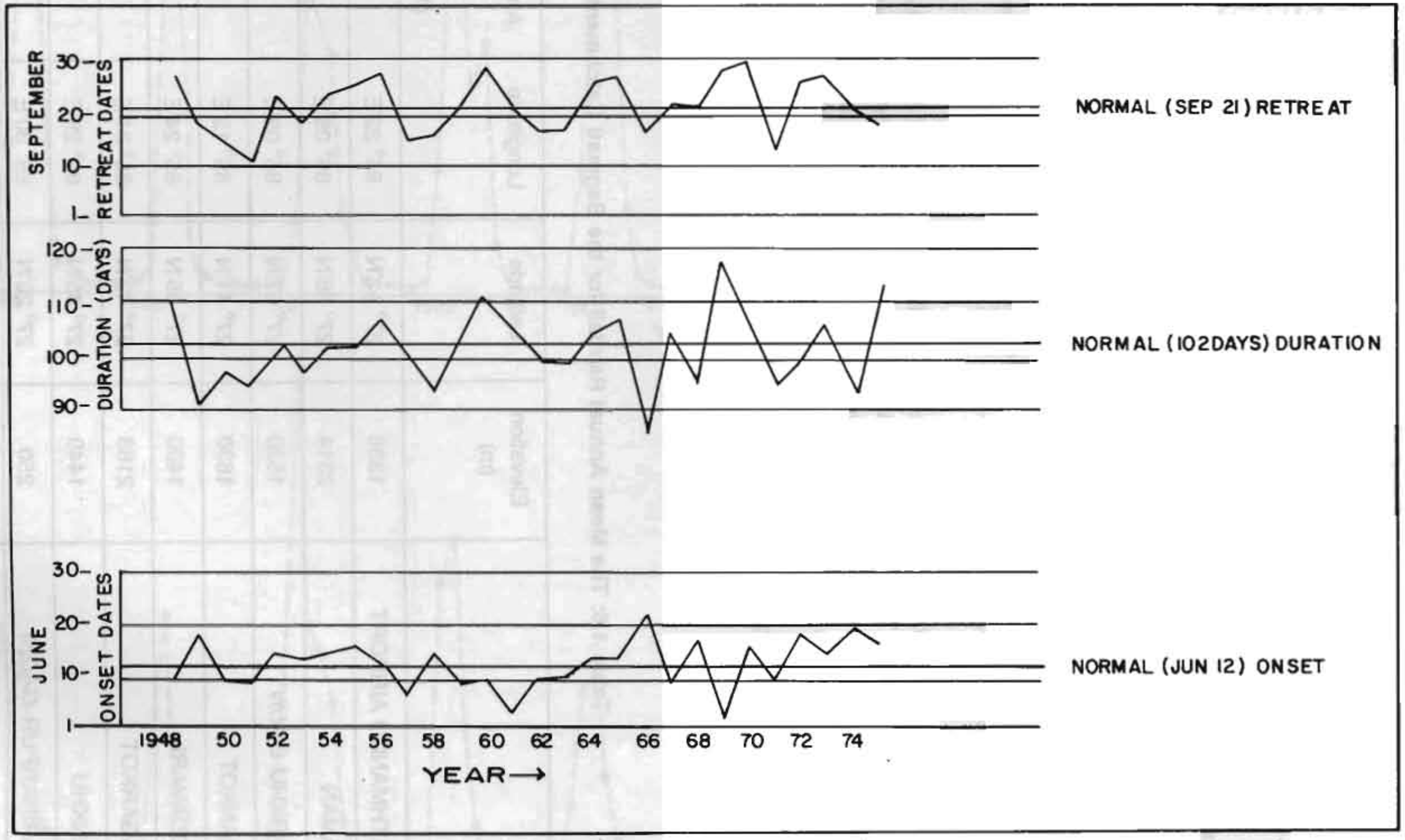
The Bagmati River has a perennial flow which is sustained during the dry season by groundwater sources. Therefore, agriculture in the catchment is substantially associated with the monsoon. The normal onset and retreat dates of the monsoon in the catchment are the 12th June and the 21st September respectively, with a normal duration of 102 days (Fig. 1.5).

Rainfall for a few stations in the catchment is presented in Table 1.6, and the mean annual isohyetal map is shown in Figure 1.6.

**Table 1.6: The Mean Annual Rainfall for the Bagmati Catchment**

| | Elevation (m) | Latitude | Longitude | Annual average Rainfall (mm) (1987 - 1990) |
|---|---|---|---|---|
| KATHMANDU AIRPORT | 1336 | 27° 42'N | 85° 22'E | 1376 |
| DAMAN | 2314 | 27° 36'N | 85° 05'E | 1748.25 |
| MARKHU *GAUN* | 1530 | 27° 37'N | 85° 09'E | 1362 |
| THANKOT | 1630 | 27° 41'N | 85° 12'E | 2100 |
| GODAVARI | 1400 | 27° 35'N | 85° 24'E | 1941.75 |
| NAGARKOT | 2163 | 27° 42'N | 85° 31'E | 1786 |
| SANKHU | 1449 | 27° 45'N | 85° 29'E | 2030 |
| HARIHARPUR *GADHI* | 250 | 27° 20'N | 85° 30'E | 2491.75 |
| SINDHULI *GADHI* | 1463 | 27° 11'N | 85° 58'E | 2630.33 |
| KARMAYA | 131 | 27° 07'N | 85° 28'E | 1717.66 |

## FIG.1.5: MONSOON IN KATHMANDU /NEPAL (1984-1975)




SOURCE: HMG. Dept. of Hydrology and Meteorology (Records from 1984-1985)

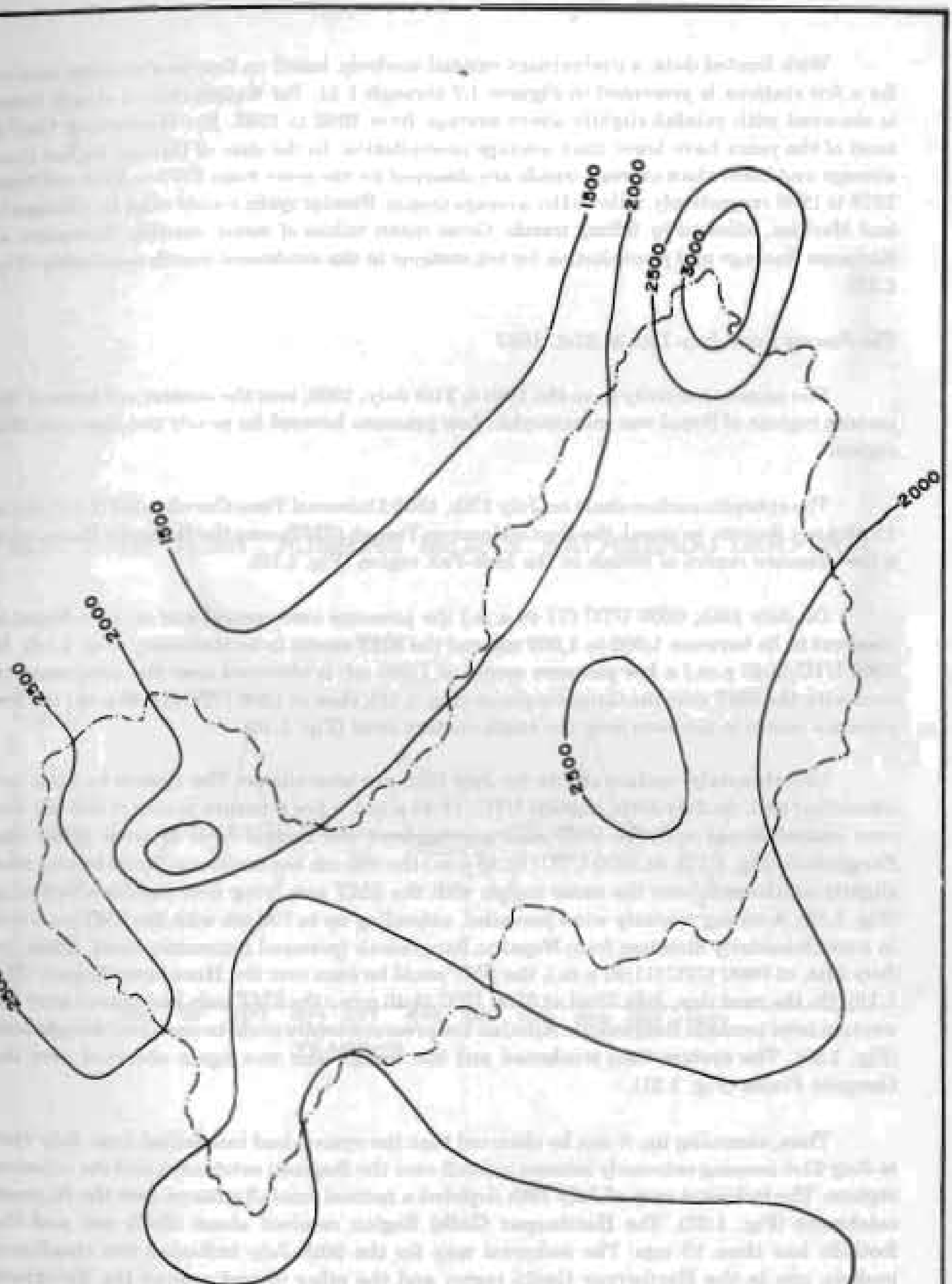



FIG.1.6: MEAN ANNUAL RAINFALL OF BAGMATI CATCHMENT (1982-1990)

With limited data, a preliminary rainfall analysis, based on five-year running means, for a few stations is presented in Figures 1.7 through 1.11. For Kathmandu, a steady trend is observed with rainfall slightly above average from 1982 to 1985. For Hariharpur *Gadhi*, most of the years have lower than average precipitation. In the case of Daman, higher than average and lower than average trends are observed for the years from 1973 to 1978 and from 1978 to 1985 respectively, followed by average trends. Similar cyclic trends exist for Chisapani and Markhu, followed by falling trends. Gross mean values of mean monthly discharges at Karmaya Barrage and precipitation for ten stations in the catchment match reasonably (Fig. 1.12).

*The Storms from July 19th to 21st, 1993*

The monsoon activity from the 19th to 21st July, 1993, over the central and some of the eastern regions of Nepal was catastrophic. Low pressure hovered for nearly two days over this region.

The synoptic surface chart on July 17th, 1800 Universal Time Coordinated (UTC) (local 11:40 p.m.) depicts, as usual, the South Monsoon Trough (SMT) over the Gangetic Plains with a low pressure centre of 996mb in the Indo-Pak region (Fig. 1.13).

On July 18th, 0600 UTC (11:40 a.m.) the pressure over central and eastern Nepal is observed to lie between 1,000 to 1,002 mb and the SMT seems to be stationary (Fig. 1.14). At 0900 UTC (2:40 p.m.) a low pressure centre of 1,000 mb is observed near the south-eastern *terai* with the SMT over the Gangetic plains (Fig. 1.15), then at 1800 UTC (11:40 p.m.) the low pressure centre is not seen over the south-eastern *terai* (Fig. 1.16).

Unfortunately, surface charts for July 19th are unavailable. The system by then had intensified and, on July 20th, at 0600 UTC (11:40 a.m.), a low pressure centre of 996 mb was over central Nepal with the SMT axis passing over the central *terai* towards Bihar and Bangladesh (Fig. 1.17). At 1800 UTC (11:40 p.m.) the 996 mb low centre could still be observed slightly southwards over the same region with the SMT axis lying over the Siwalik Range (Fig. 1.18). A strong westerly wind prevailed, extending up to 700 mb with the SMT observed in a south-easterly direction from Nepal to Bangladesh (personal communication). Then, on July 21st, at 0600 UTC (11:40 a.m.), the SMT could be seen over the Himalayan Region (Fig. 1.19). On the next day, July 22nd at 0300 UTC (8:40 p.m.) the SMT axis just passed over the western *terai* towards Bangladesh. Another low pressure centre could be seen over Bangladesh (Fig. 1.20). The system then weakened and the trough axis was again observed over the Gangetic Plains (Fig. 1.21).

Thus, summing up, it can be observed that the system had intensified from July 18th to July 21st causing extremely intense rainfall over the Bagmati catchment and the adjacent regions. The isohyetal map of July 19th depicted a normal rainfall pattern over the Bagmati catchment (Fig. 1.22). The Hariharpur Gadhi Region received about 60-80 mm and the foothills less than 10 mm. The isohyetal map for the 20th July indicated two cloudburst pockets, one in the Hariharpur Gadhi region and the other in and around the Kulekhani watershed with values ranging from 300 to 500 mm (Fig. 1.23). In contrast, not much rain was observed over the Kathmandu Valley and its adjoining catchments. This particular storm caused damage to the penstock in Jurikhet and disastrous landslides and floods in the Bagmati Catchment. This isohyetal map also hints at the possibility of an intense low pressure system over the catchment.

# FIG.1.7: FIVE-YEAR RUNNING MEANS KATHMANDU (AIRPORT)

FIG.1.8: FIVE-YEAR RUNNING MEANS (HARIHARPUR GADHI)

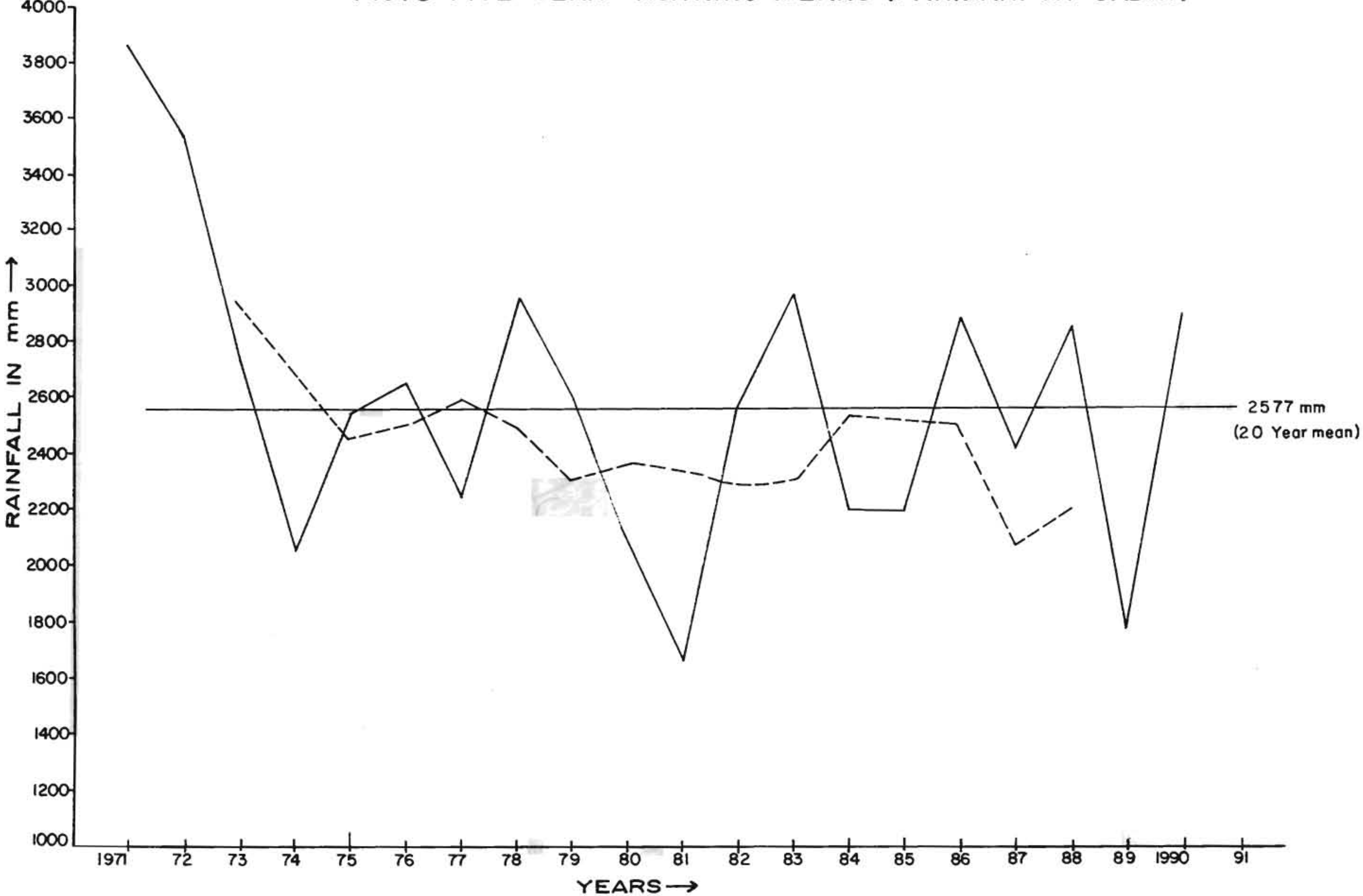


FIG.1.9: FIVE-YEAR RUNNING MEANS (MARKHU)

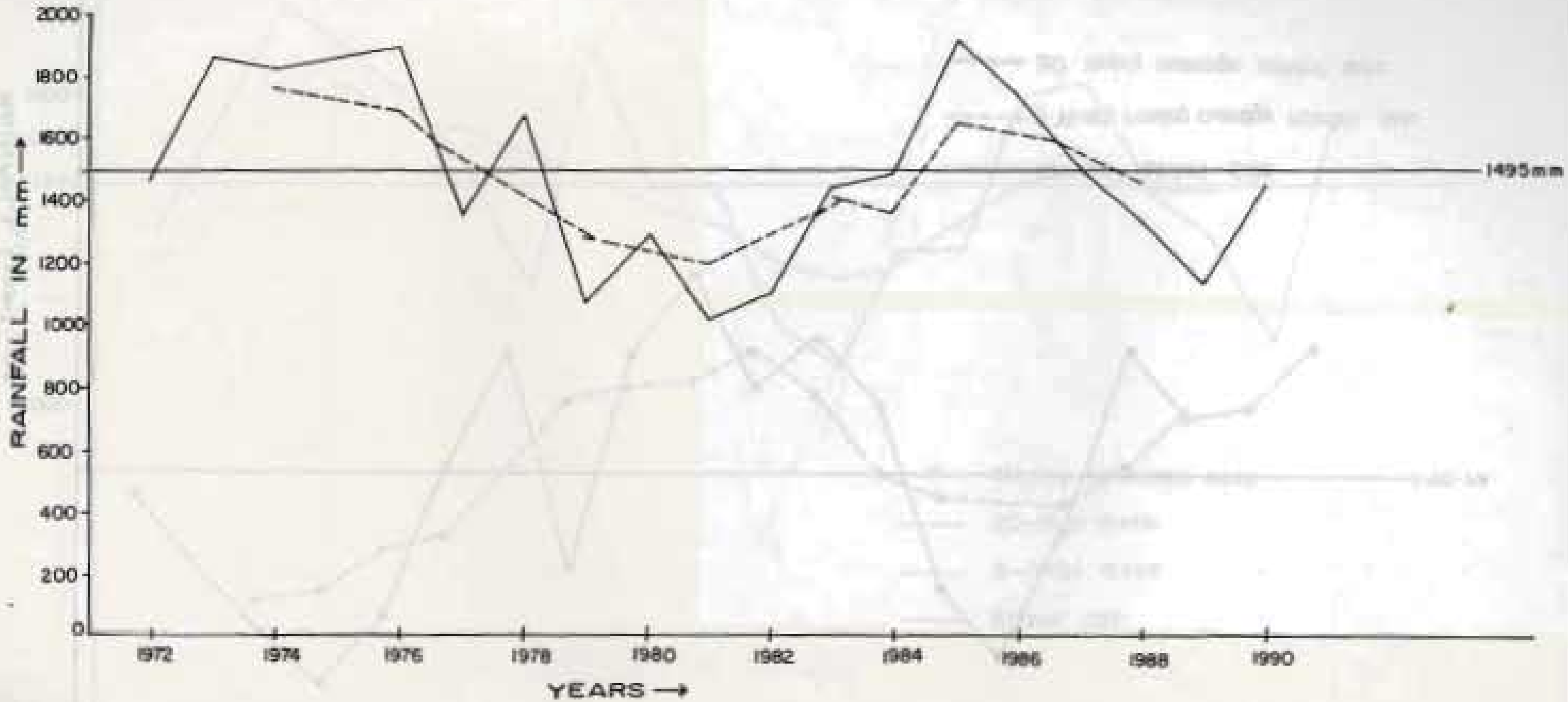


FIG.1.10: FIVE-YEAR RUNNING MEANS (CHISAPANI GADHI)

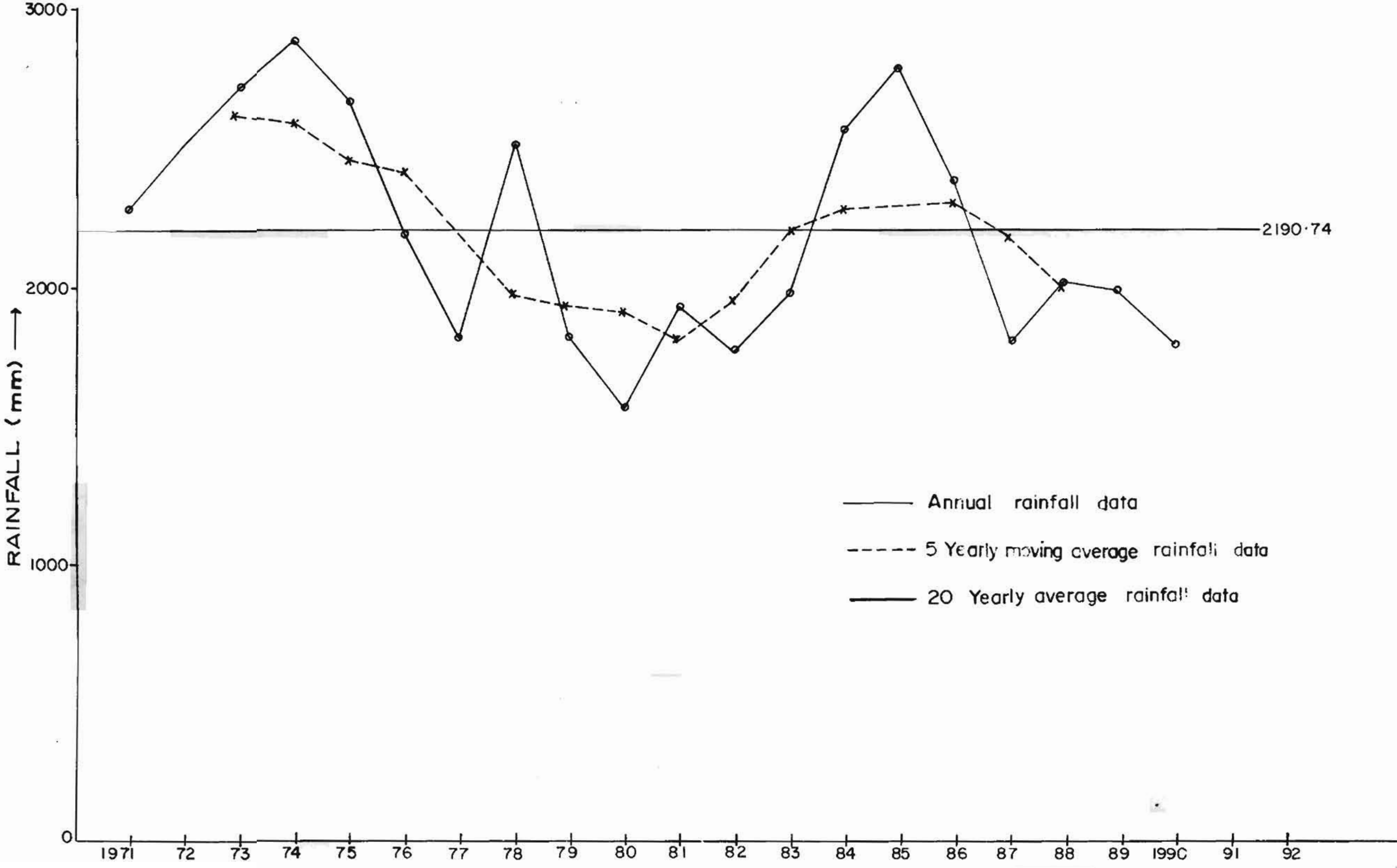


FIG.1.11: FIVE-YEAR RUNNING MEANS (DAMAN)

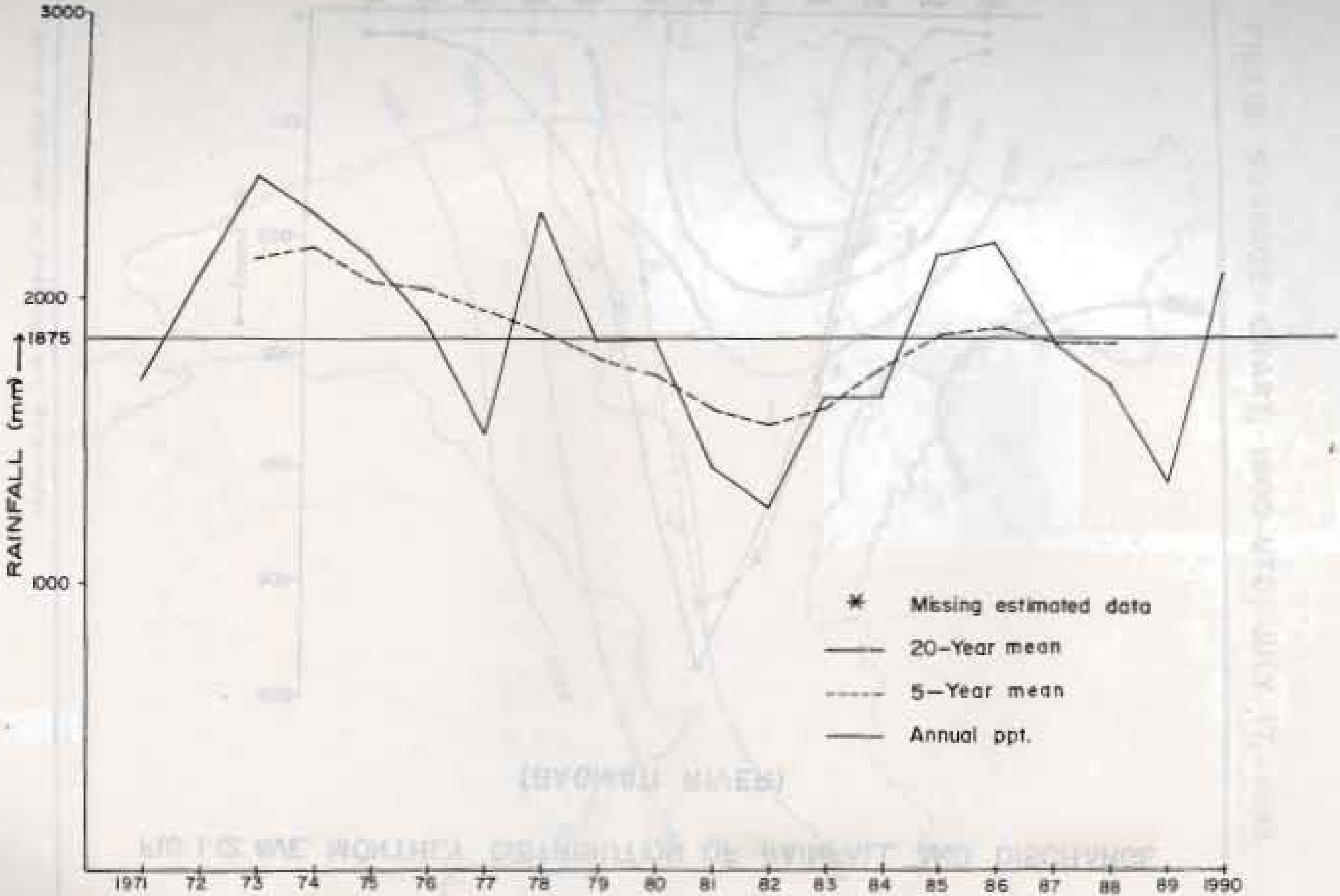


FIG.1.12: AVE. MONTHLY DISTRIBUTION OF RAINFALL AND DISCHARGE

(BAGMATI RIVER)

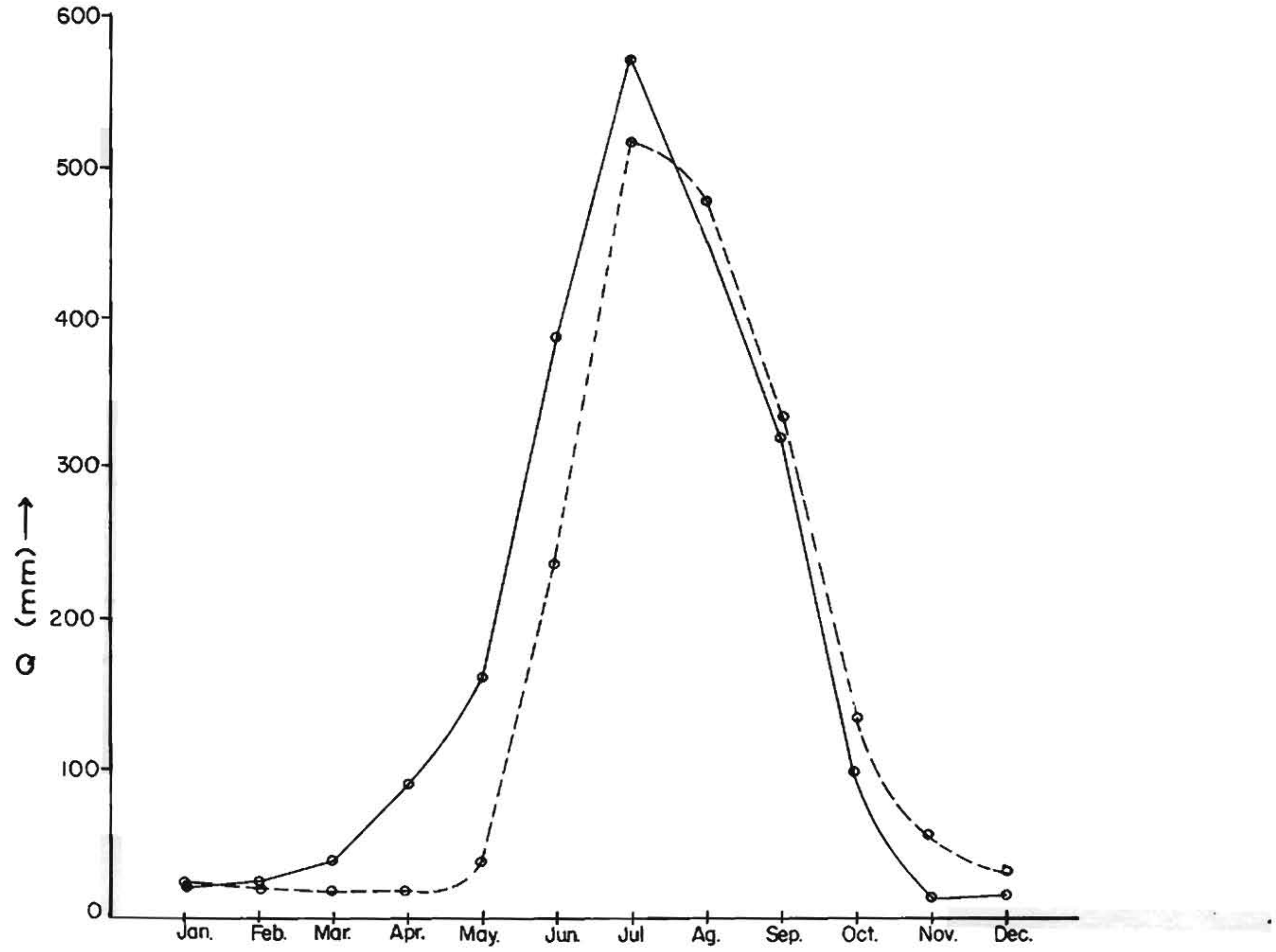
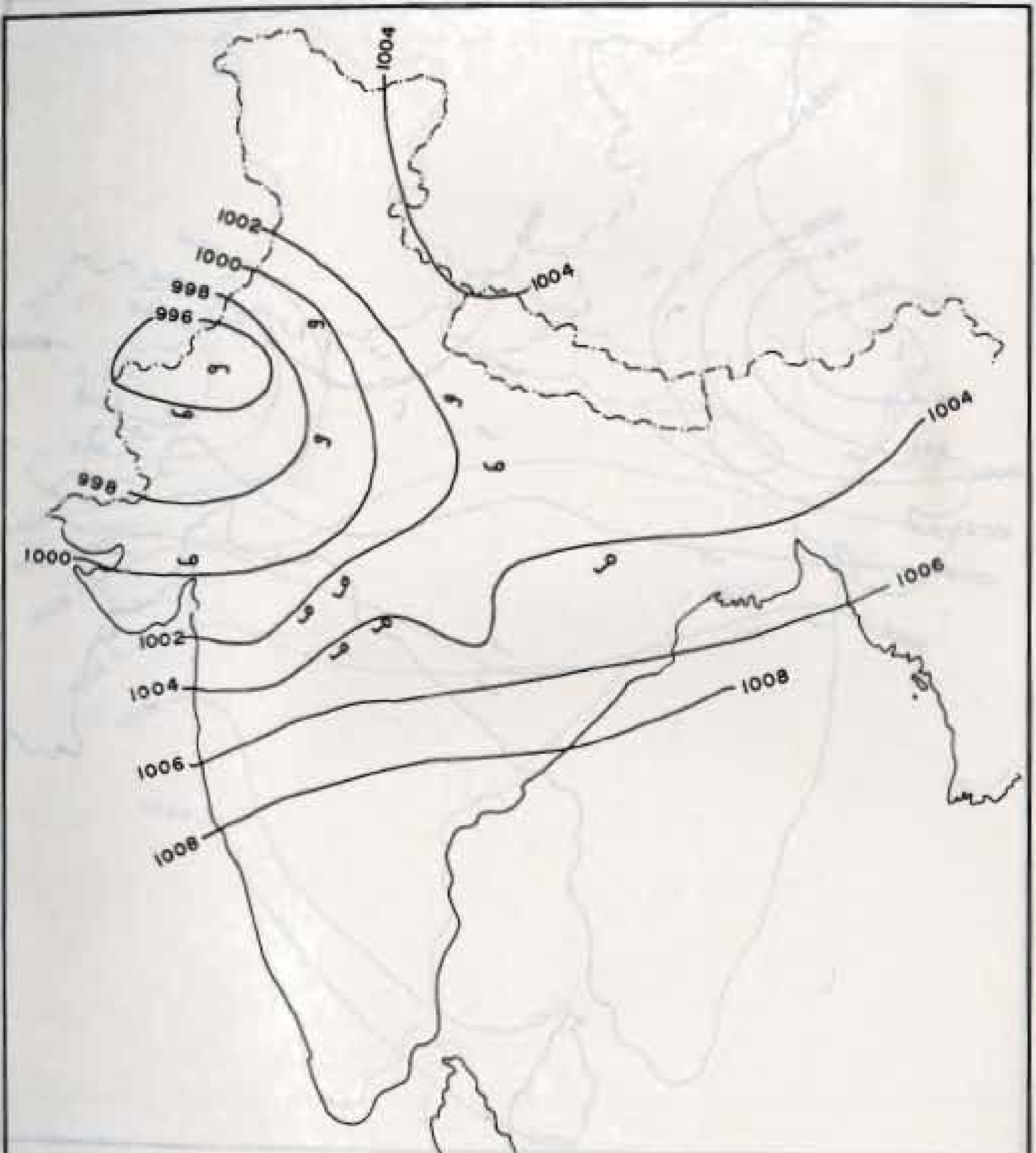


FIG.I.13: SURFACE CHART, 1800 UTC, JULY 17, 1993




Source: HMG/Dept of Hydrology and Meteorology

FIG.1.14: SURFACE CHART, 0600 UTC, JULY 18, 1993

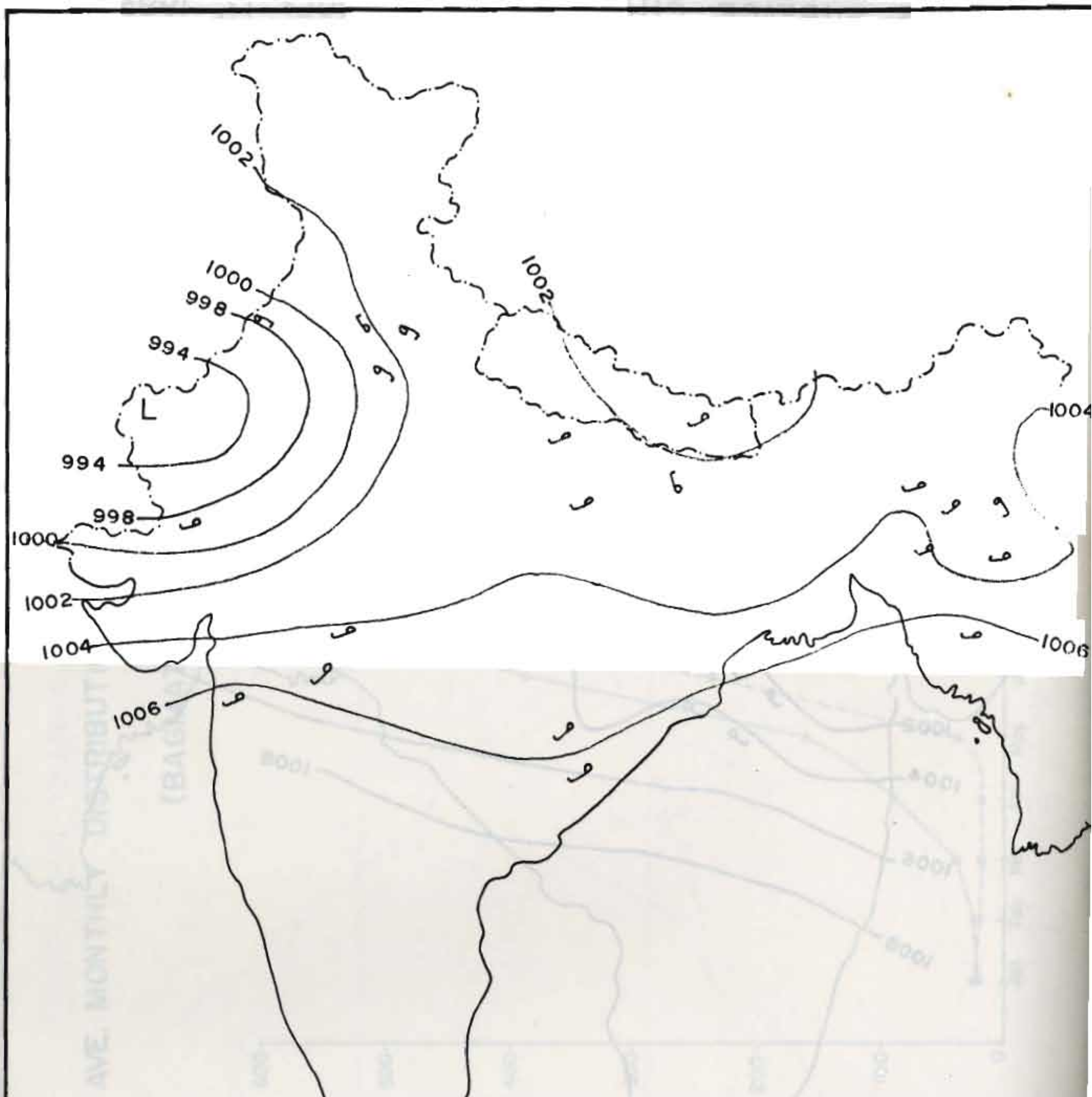


FIG.1.15: SURFACE CHART, 0900 UTC, JULY 18, 1993

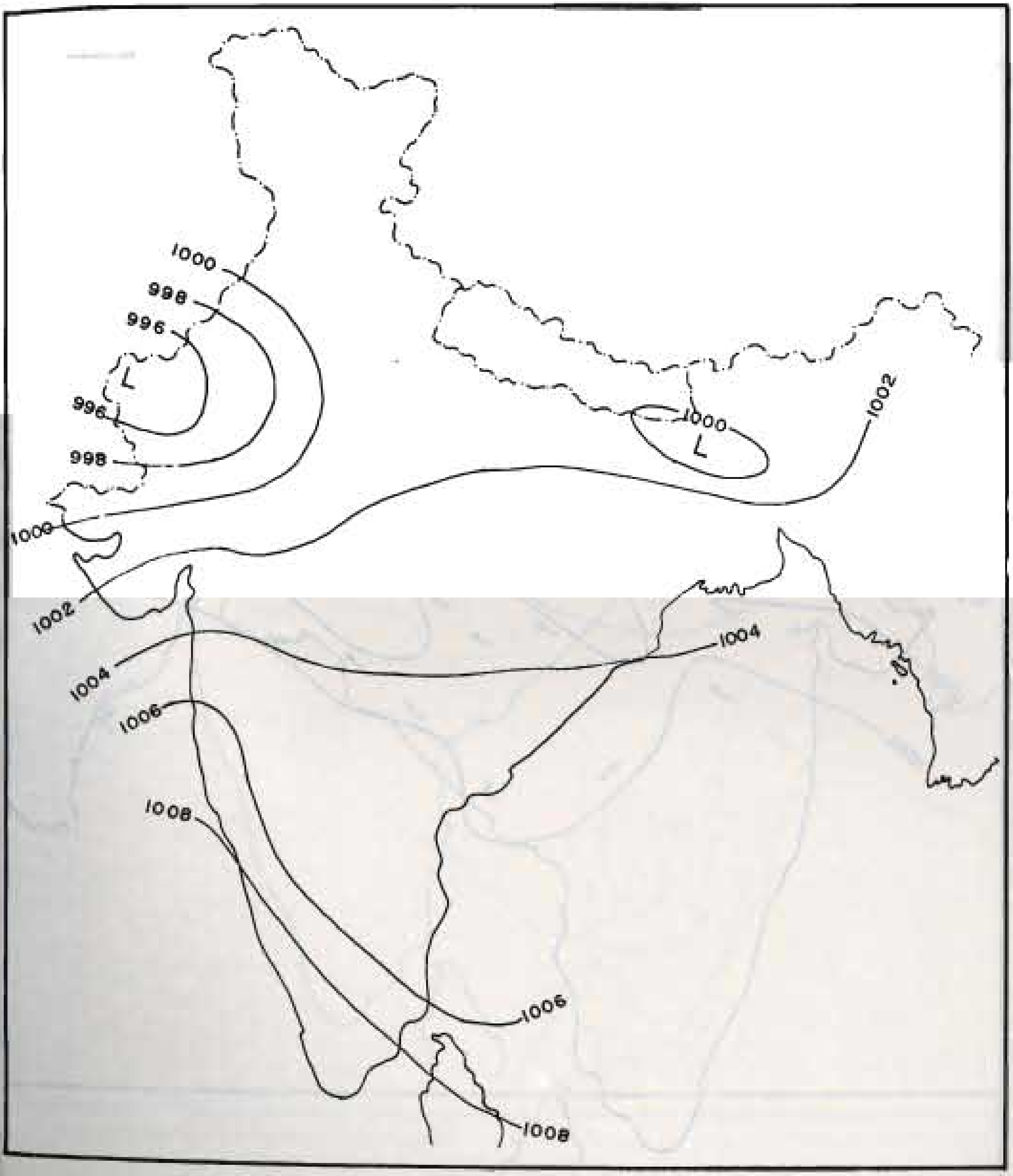


FIG.I.16: SURFACE CHART, 1800 UTC, JULY 18, 1993

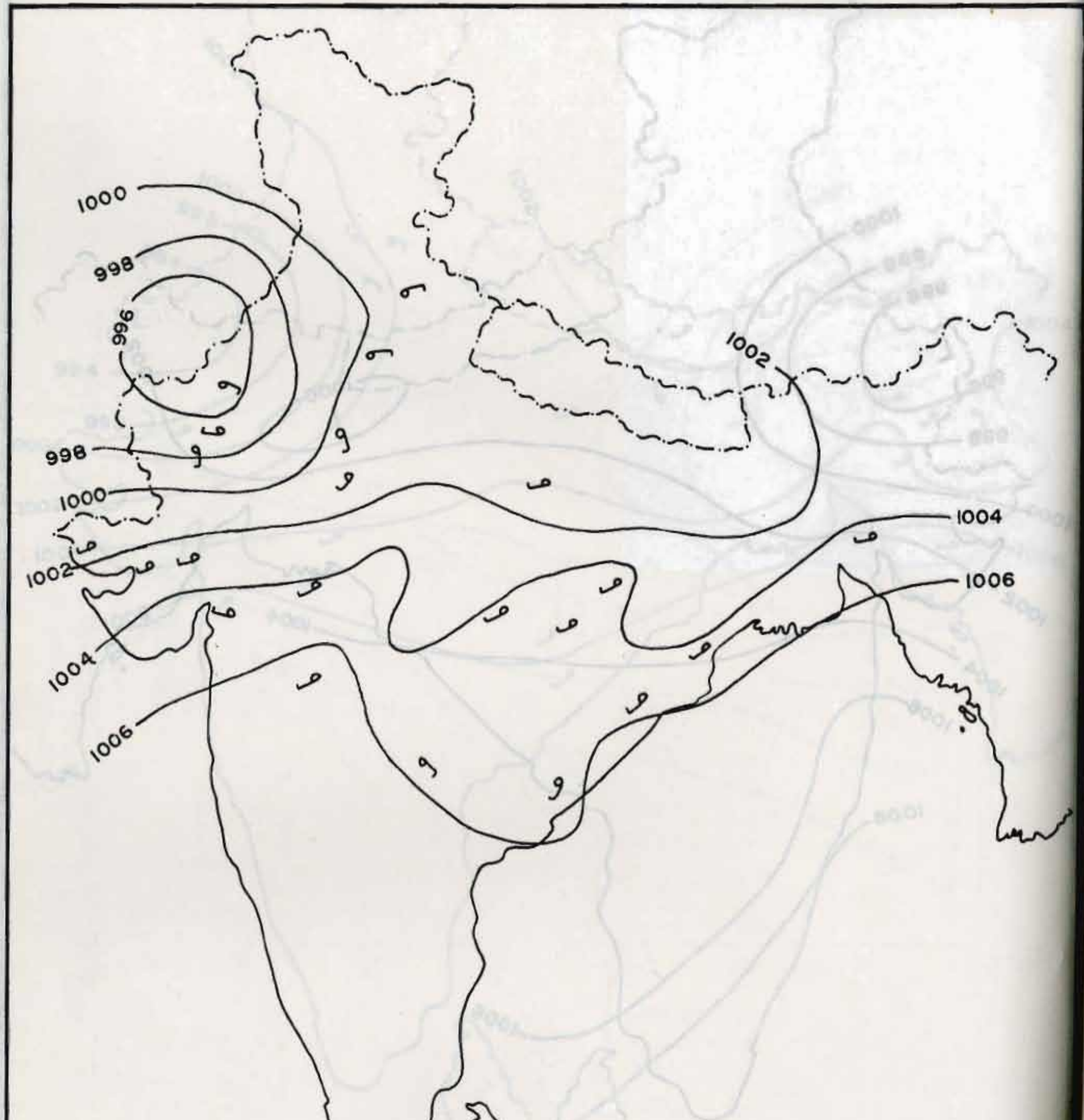


FIG.I. 17: SURFACE CHART, 0600 UTC, JULY 20, 1993

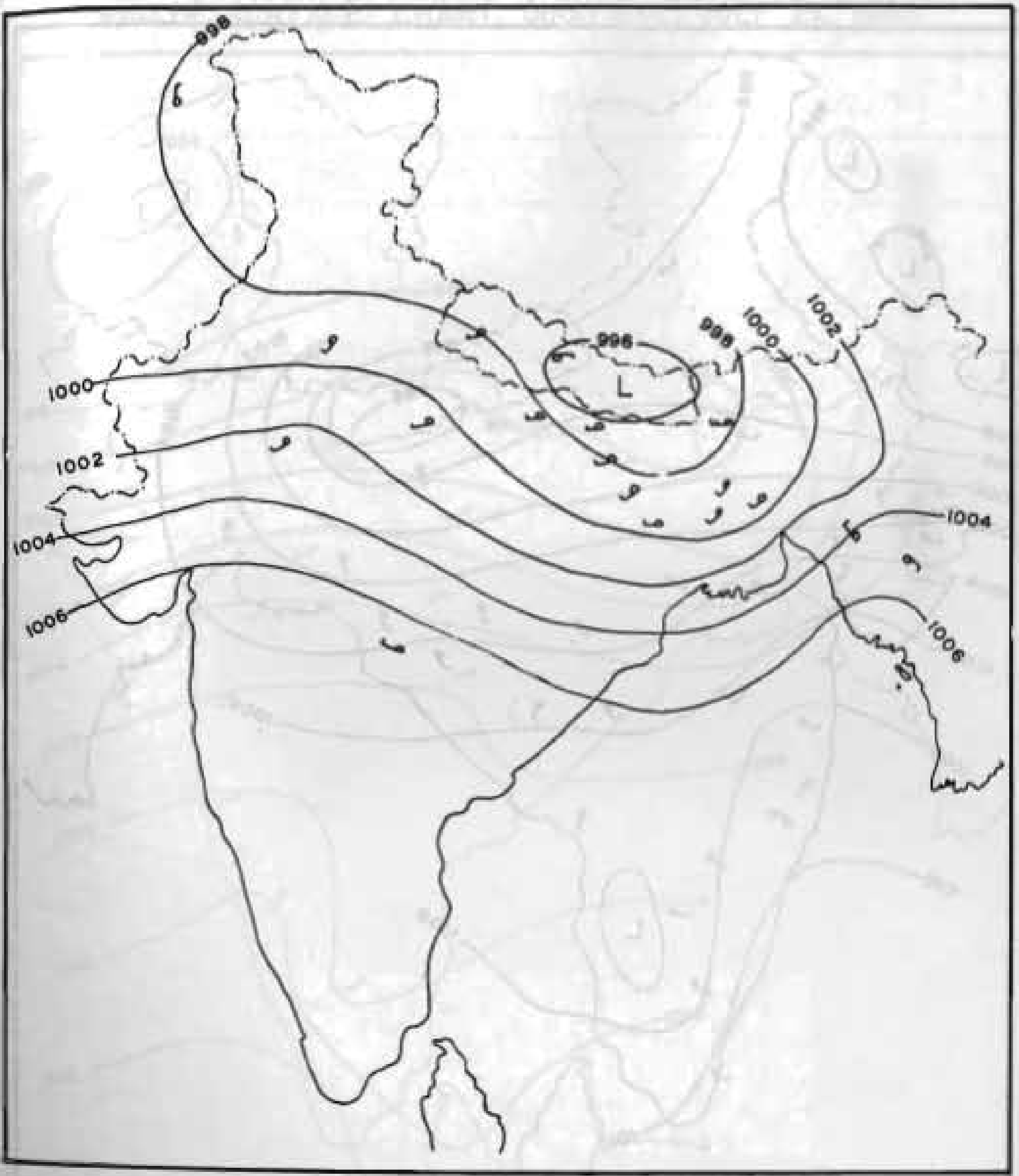


FIG.1.18: SURFACE CHART, 1800 UTC, JULY 20, 1993

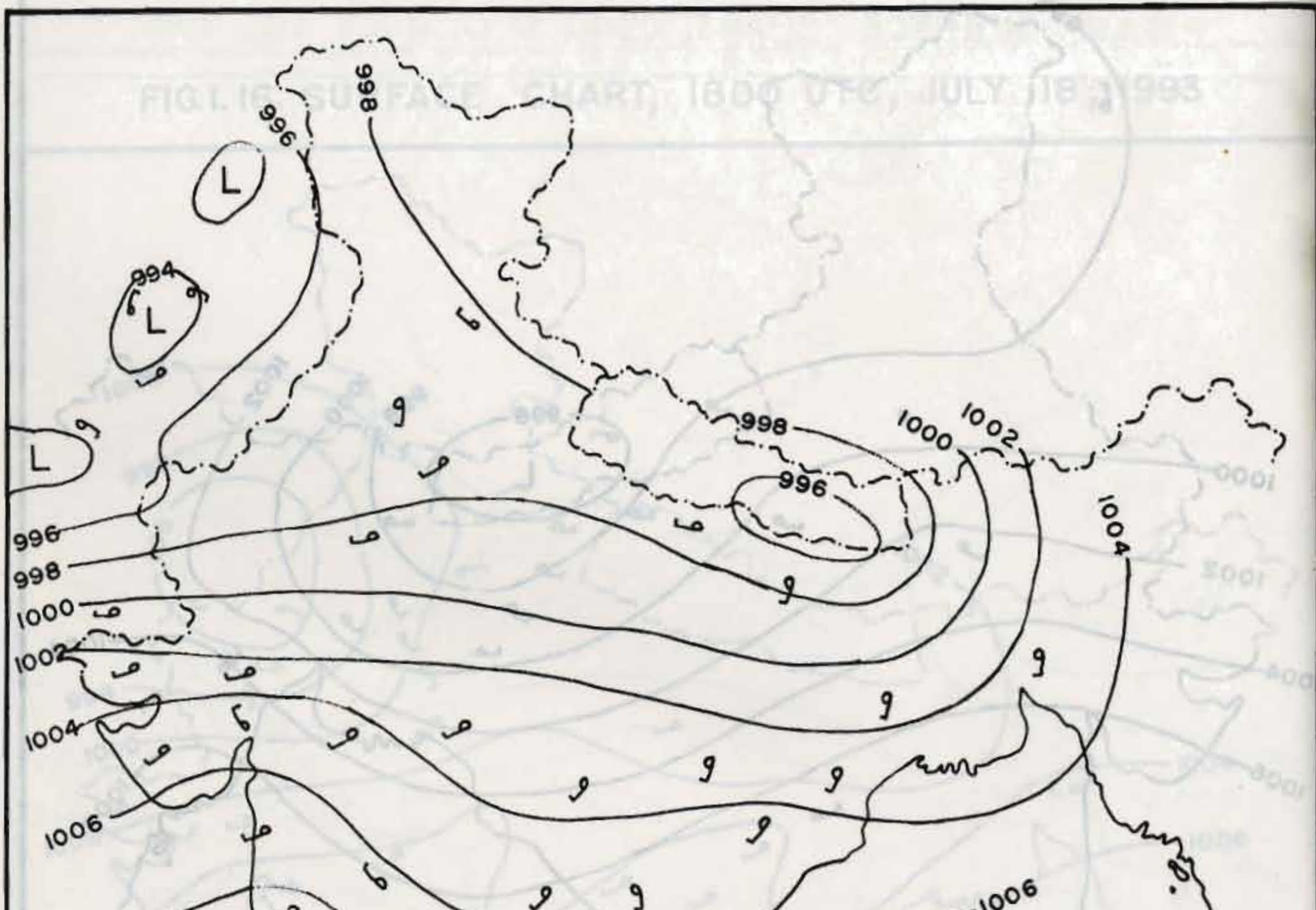


FIG.1.19: SURFACE CHART, 0600 UTC, JULY 21, 1993

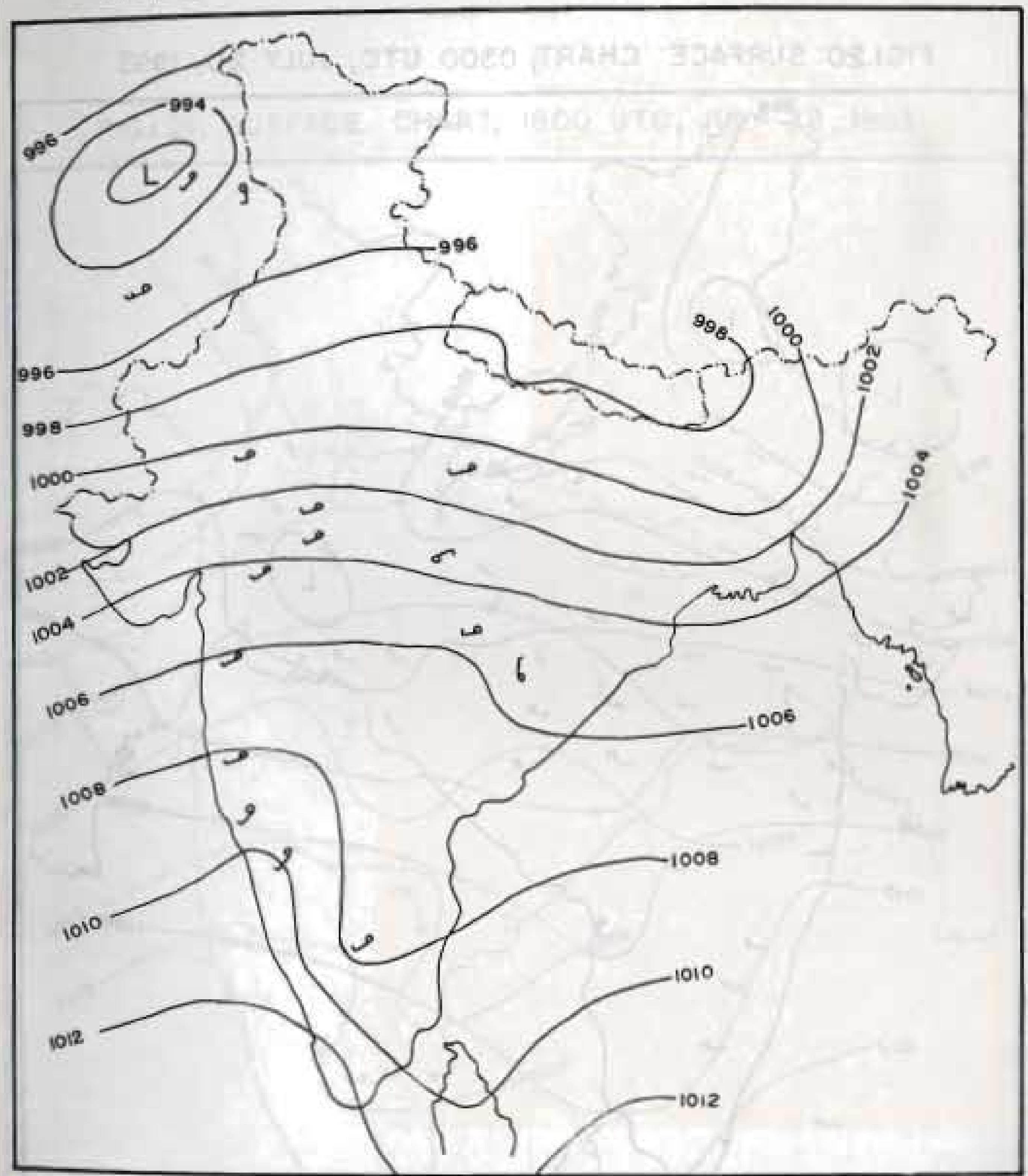


FIG.I.20: SURFACE CHART, 0300 UTC, JULY 20, 1993

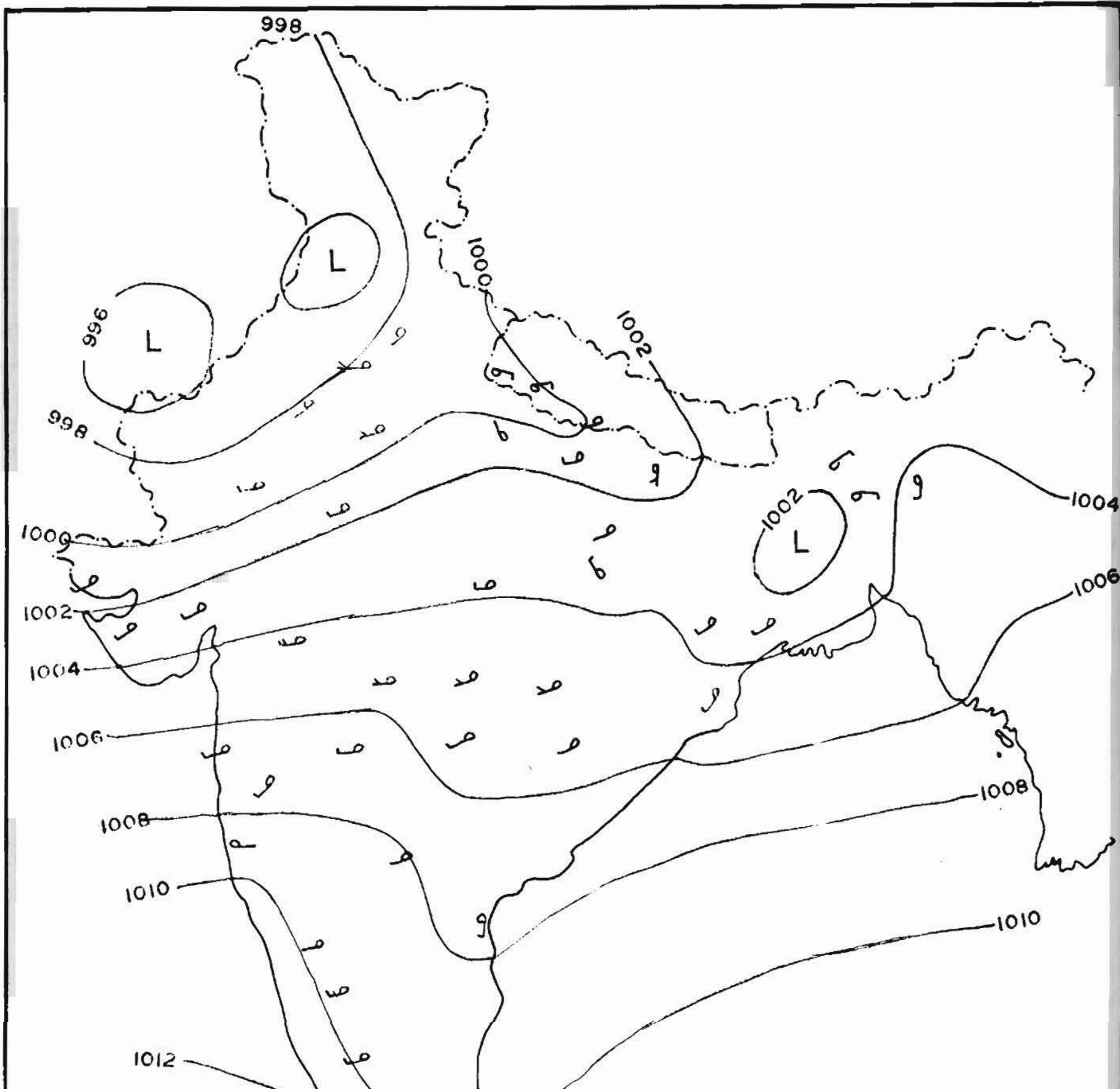


FIG.I.21: SURFACE CHART, 1800 UTC, JULY 22, 1993

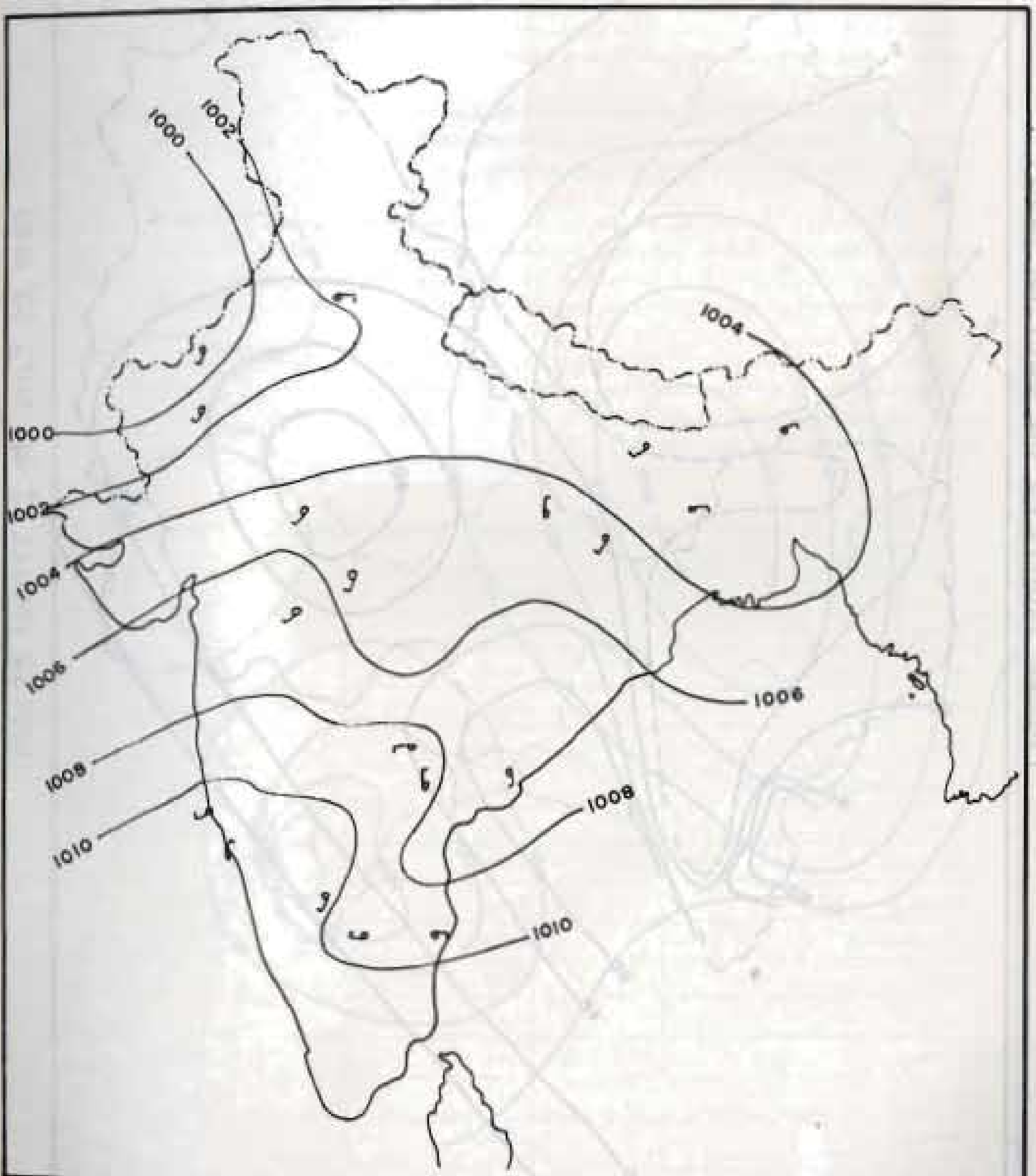


FIG.I.22: ISOHYETS ON JULY 19, 1993

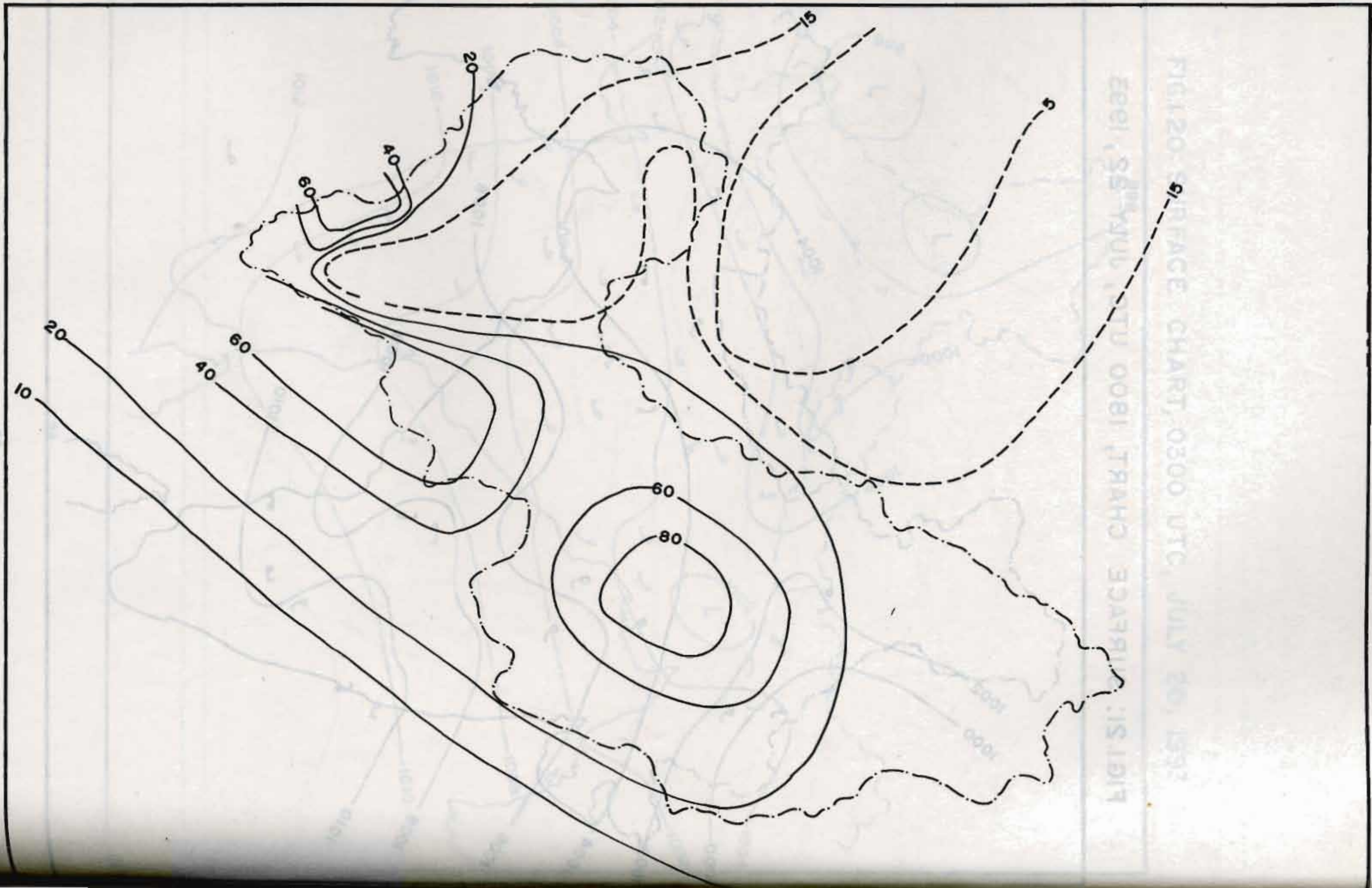
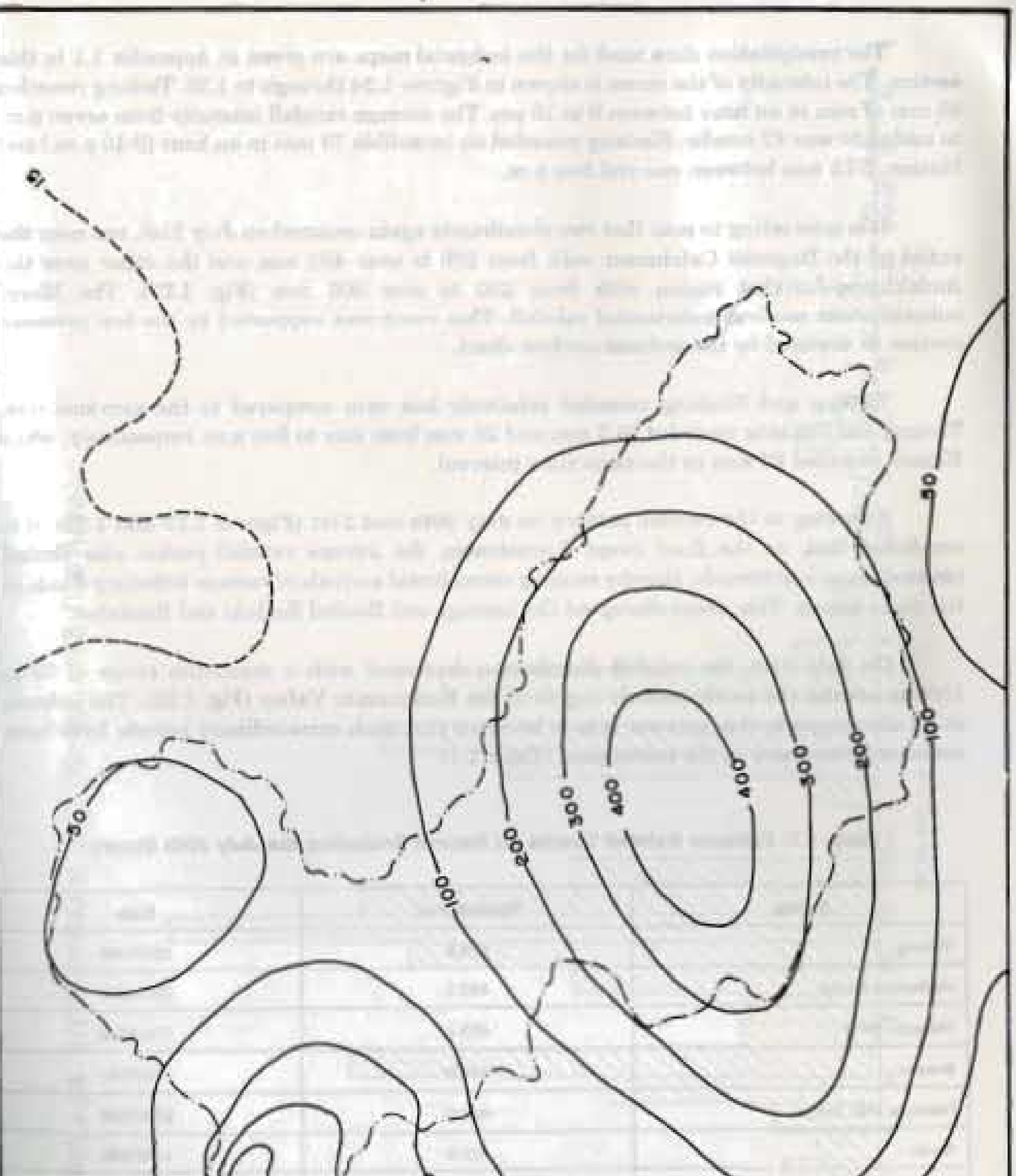


FIG.I.23: ISOHYETS ON JULY 20, 1993



The precipitation data used for the isohyetal maps are given in Appendix 1.1 to this section. The intensity of the storm is shown in Figures 1.24 through to 1.26. Tistung recorded 65 mm of rain in an hour between 9 to 10 pm. The average rainfall intensity from seven p.m. to midnight was 42 mm/hr. Simlang recorded an incredible 73 mm in an hour (9-10 p.m.) and Hazam, 57.3 mm between one and two p.m.

It is interesting to note that two cloudbursts again occurred on July 21st, one near the outlet of the Bagmati Catchment with from 200 to over 400 mm and the other near the Amlekhganj-Jurikhet region with from 200 to over 300 mm (Fig. 1.27). The Marin subcatchment received substantial rainfall. This event was supported by the low pressure system as depicted by the isobasic surface chart.

Tistung and Simlang recorded relatively less rain compared to the previous day. Tistung and Simlang recorded 45.5 mm and 28 mm from four to five a.m. respectively, while Hazam recorded 62 mm in the same time interval.

Referring to the rainfall pattern on July 20th and 21st (Figures 1.23 and 1.27), it is concluded that, as the flood swept downstream, the intense rainfall pocket also shifted (downstream) southwards, thereby causing coincidental arrivals of various tributary floods to the main course. This event disrupted the barrage and flooded Sarlahi and Rautahat.

On July 21st, the rainfall distribution decreased with a maximum range of 50 to 100mm around the south-easterly region of the Kathmandu Valley (Fig. 1.28). The isobaric chart also supports this pattern. It is to be noted that such extraordinary records have been measured elsewhere in the recent past (Table 1.7).

**Table 1.7: Extreme Rainfall Events on Record (Including the July 20th Storm)**

| Station | Rainfall (mm) | Data |
|---|---|---|
| Tistung | 539.5 | 20/7/1993 |
| Hariharpur Gadhi | 482.5 | 20/7/1993 |
| Hetauda (NFI) | 453.2 | 27/8/1990 |
| Baluwa | 446.0 | 29/9/1981 |
| Hetauda (IND Dist) | 438.0 | 27/9/1990 |
| Kanki | 437.0 | 16/9/1984 |
| Patharkot | 437.0 | 21/7/1993 |
| Bajura | 431.0 | 12/9/1980 |
| Mane *Bhanjyang* | 420.0 | 30/9/1981 |
| Tribani | 403.0 | 17/9/1984 |
| Semari | 401.0 | 13/9/1982 |
| Amlekhganj | 399.0 | 21/7/1993 |
| Markhu | 385.0 | 20/7/1993 |
| Daman | 375.0 | 20/7/1993 |

FIG.1.24: HYETOGRAPH JULY (19-20) 1993 (TISTUNG)

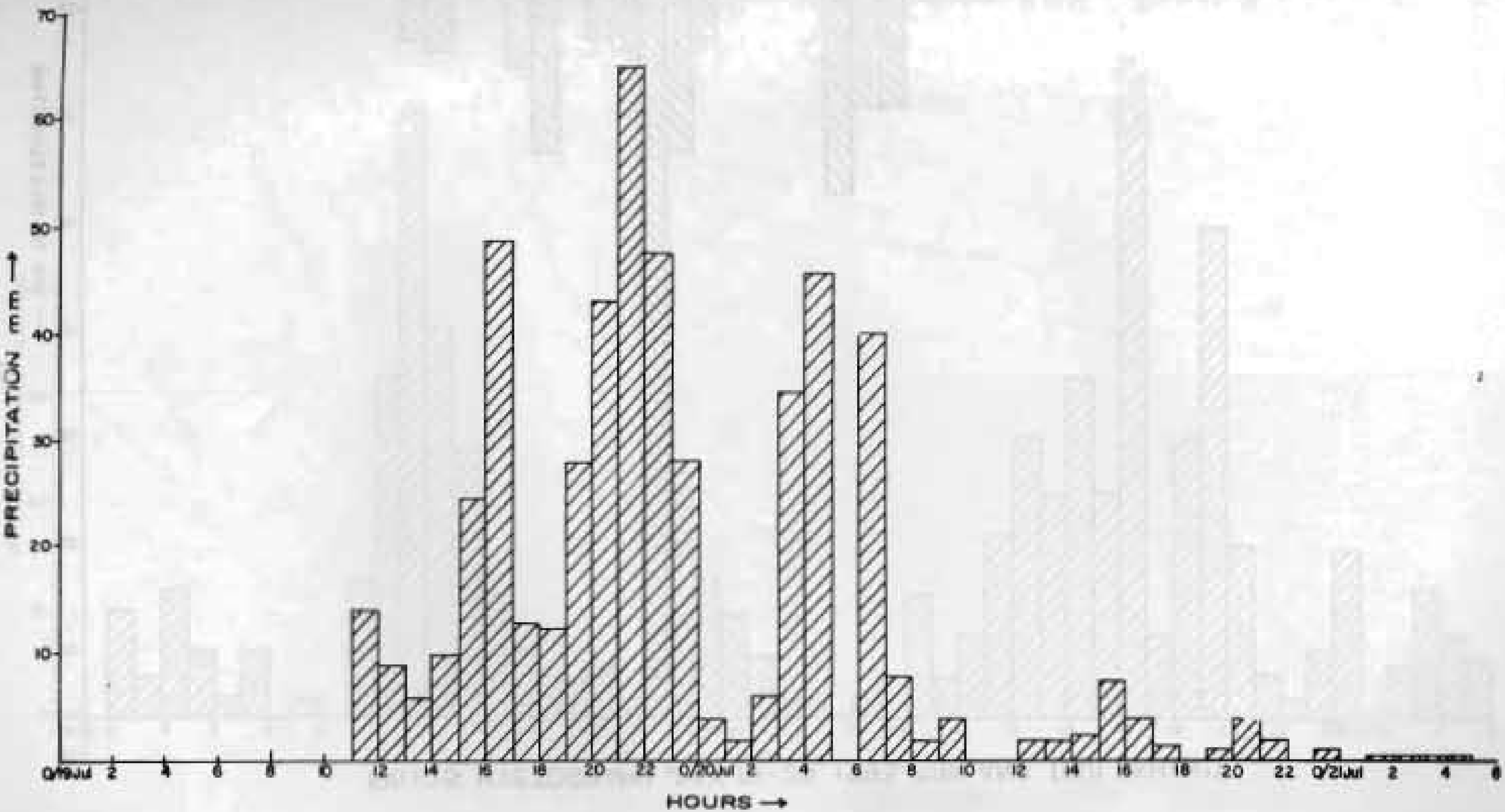


FIG.1·25: HYETOGRAPH JULY 19–20, 1993, SIMLANG (KULEKHANI)

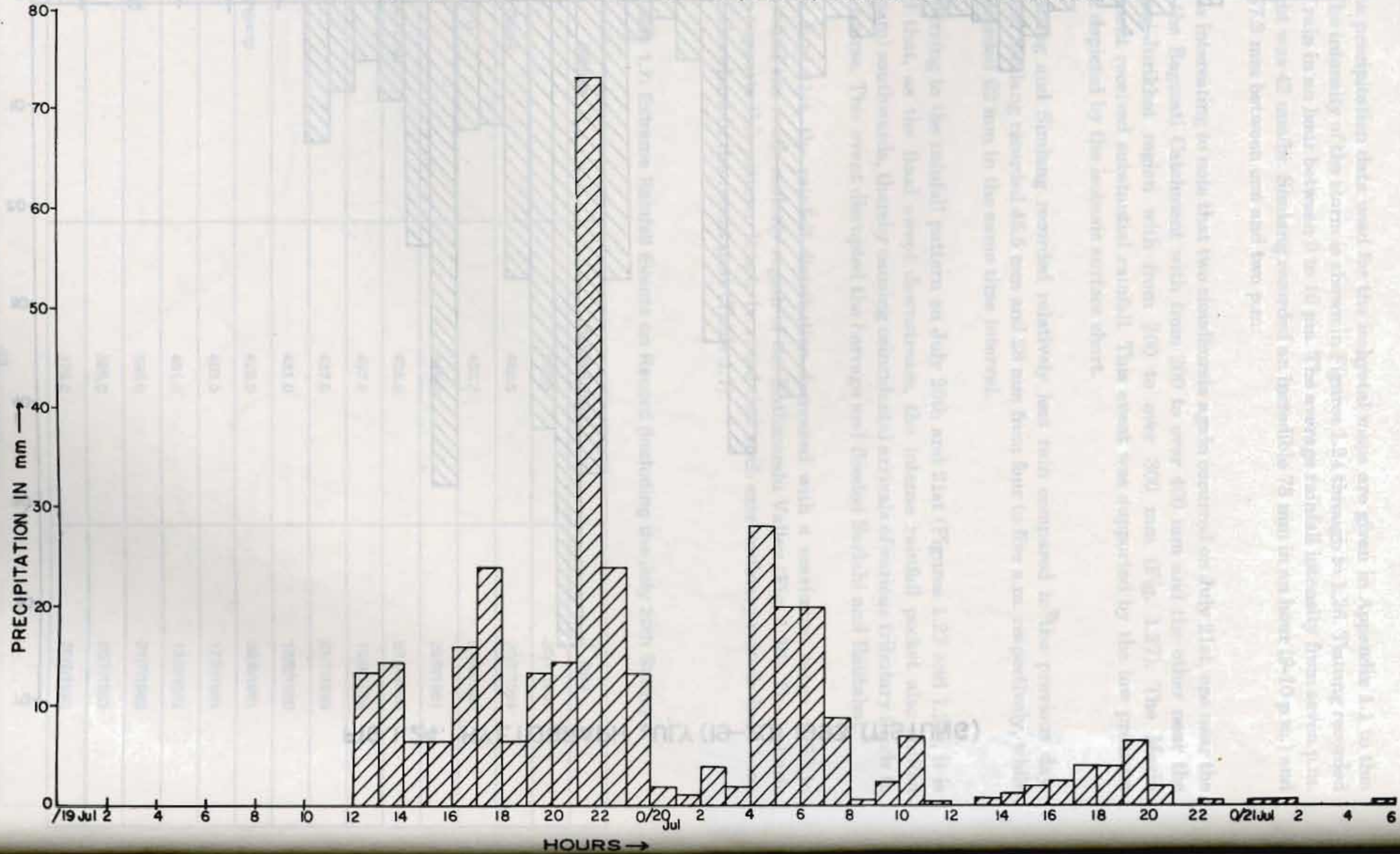


FIG.1.26 HYETOGRAPH, 19-21 JULY 1993, HAZAM

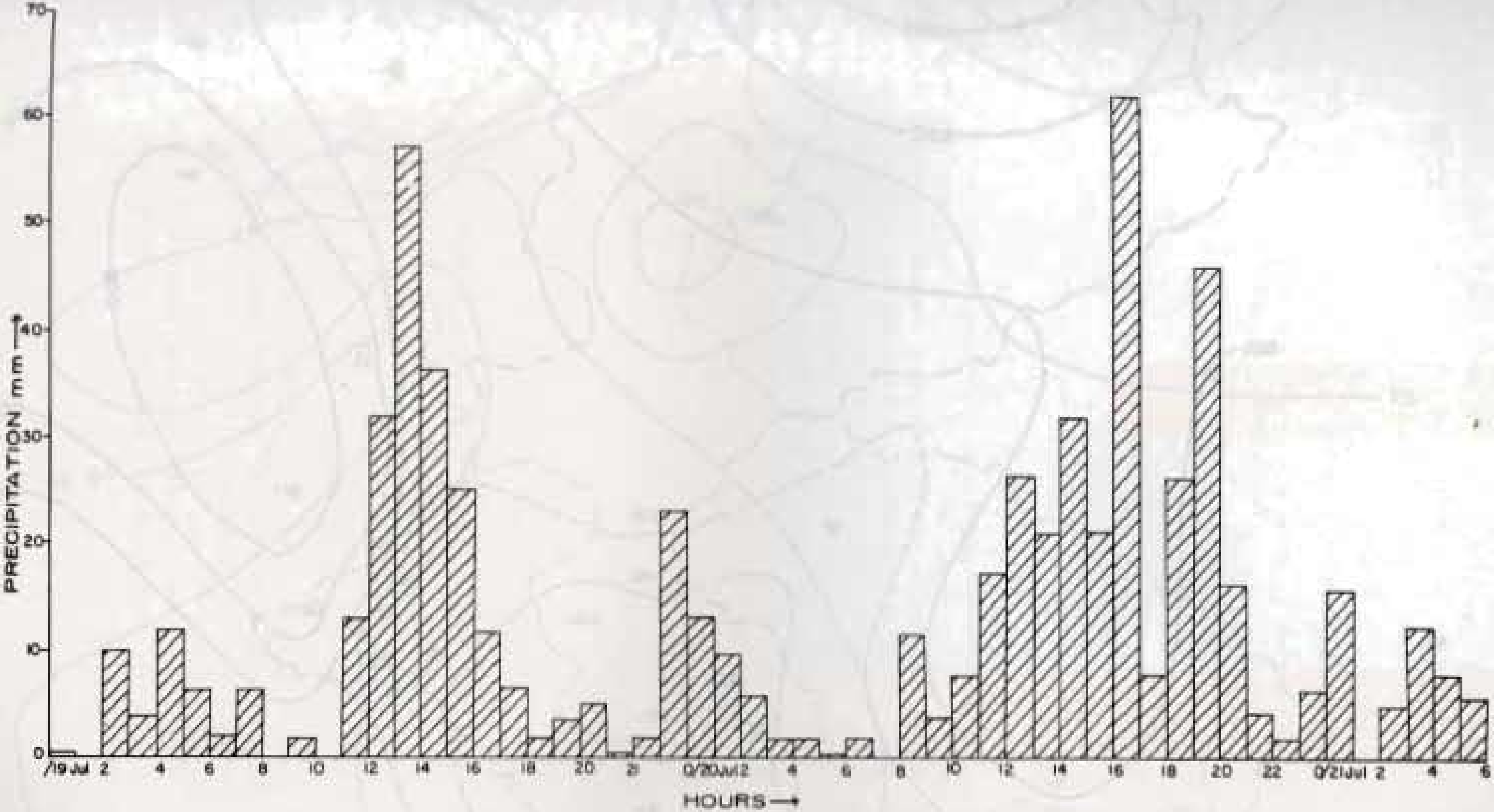


FIG.I.27: ISOHYETS ON JULY 21, 1993

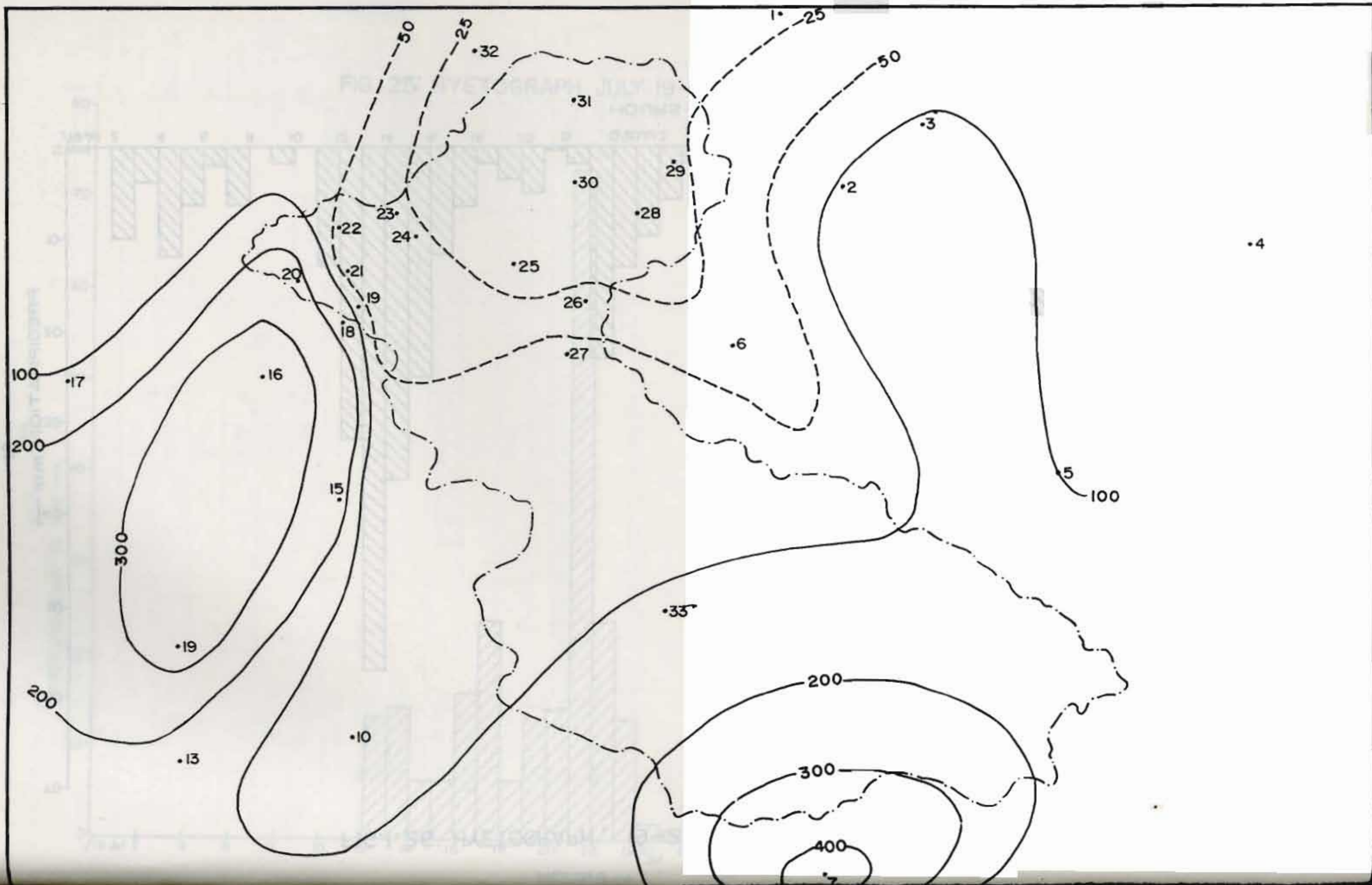
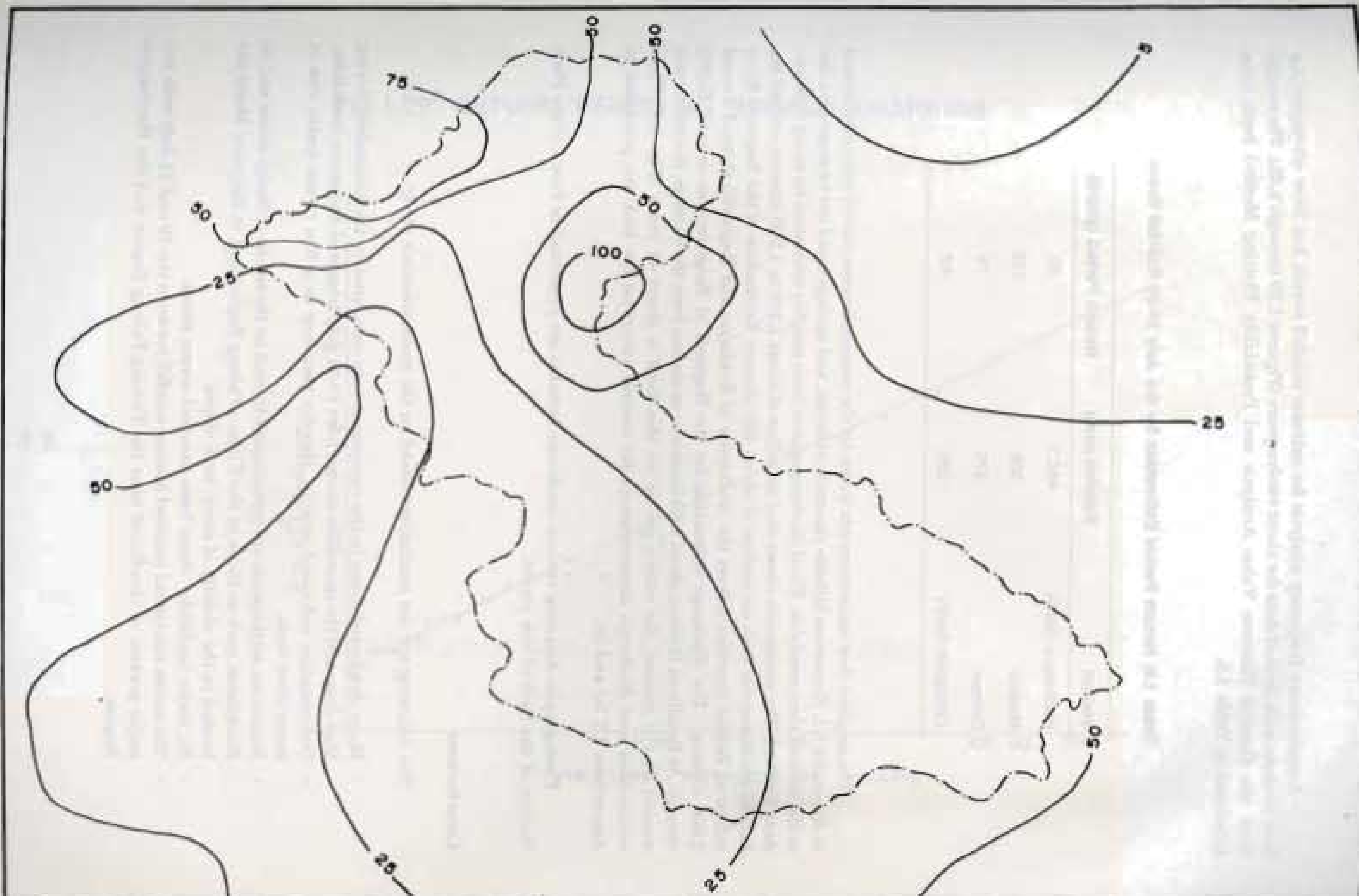


FIG.1.28: ISOHYETS ON JULY 22, 1993



A preliminary frequency analysis for extreme rainfall events has been attempted for four stations with limited data for about twelve years (Figures 1.29 through 1.32). The results from the Gumbel Extreme Value Analysis and Probability Plotting Method have been tabulated in Table 1.8.

**Table 1.8: Return Period Estimation for the July 19-20 Rainfall Event**

| Station | Rainfall (mm) | Return Period (years) |
|---|---|---|
| Hariharpur Gadhi | 482.5 | 52 |
| Markhu | 385 | 132 |
| Daman | 375 | 78 |
| Chisapani Gadhi | 295 | 52 |

The original flow measurements taken by the reconnaissance survey are summarised in Appendix 1.1. Numerous hillside channels, streams, and springs could not be measured due to the limited time available. Flood discharges have been roughly estimated by using a Slope - Area Method. The estimation shows that an inflow of about 1,100 to 1,200 cumecs entered the Kulekhani Reservoir with an outflow of about 420 cumecs. Estimation of the Bagmati River inflow at Baldev (upstream from the confluence of Kokhajor and Bagmati) showed around 2,600 cumecs. The discharge estimation for the Bagmati at Raigaun was around 10,062 cumecs. At Pandhera Dobhan about 1.8 kilometres upstream from the barrage, the inflow was around 11,116 cumecs, the return period for this flood is about 42 years (Fig. 1.3). Flood estimations and discharge measurements for various rivers on the trek are presented in Appendices 1.2 (a) and (b).

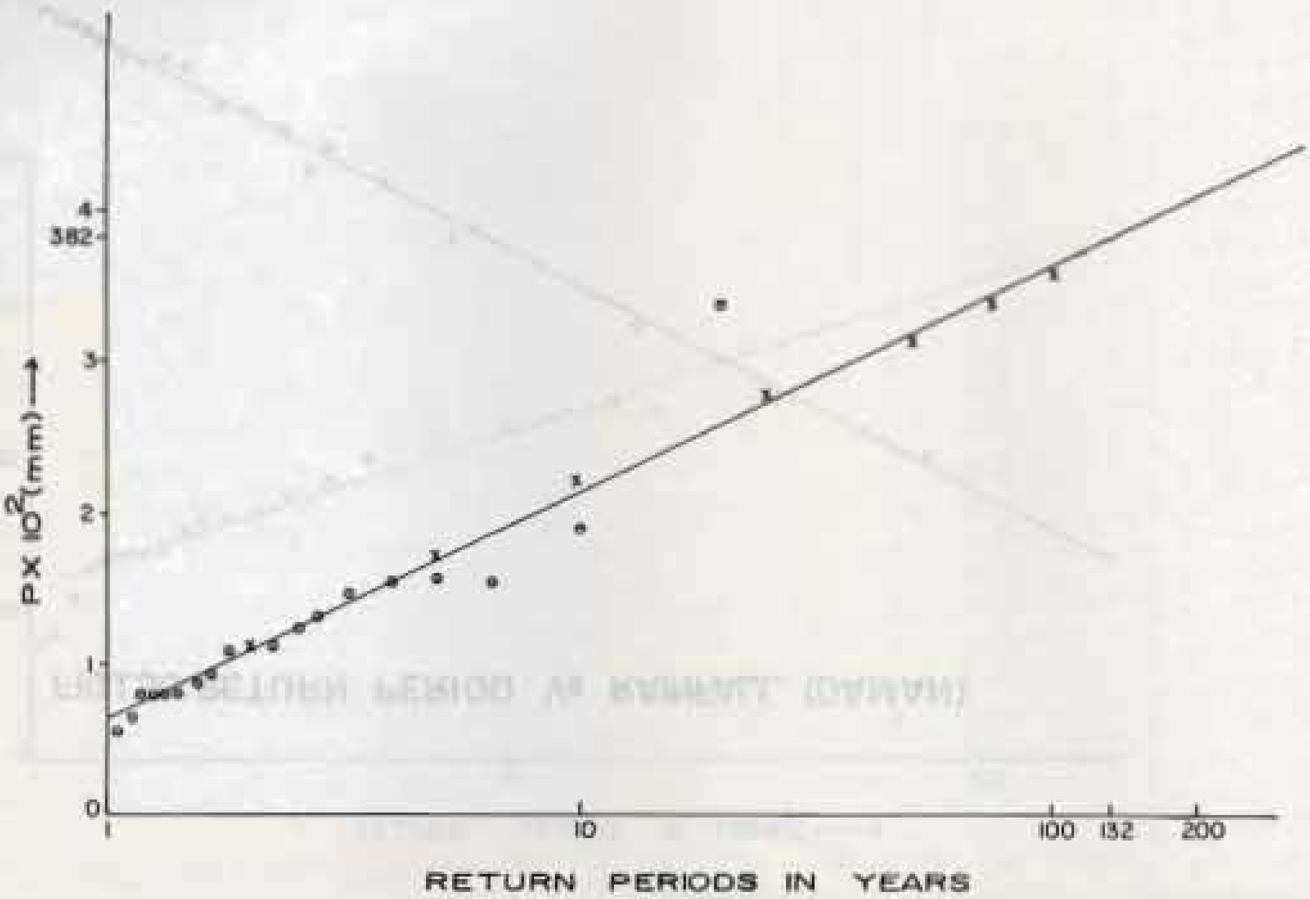
Photographs depicting various landscape features are presented in Part I of the Plate Section at the back of this report.

## Conclusions

The following are the conclusions based on the reconnaissance study.

- Many deforested areas in the catchment were saturated by the antecedent during May-June and the incredible storms from 19-21 July triggered disastrous landslides.
- Deforestation enhanced erosion, thereby resulting in a five to ten metre rise in many river beds.
- Numerous settlements are precariously located on the banks of flashy rivers and on floodplains such as those in the Kitim - Palung Region and in Raigaun. Many are located in the vicinity of steep, bare slopes.
- No major landslide - dams have occurred across rivers.
- The entire catchment received intense rainfall between the 19 and 21 July with two major pockets of cloudburst near the Tistung-Palung Region and the Hariharpur Region.

FIG.I.29: RETURN PERIOD Vs RAINFALL (MARKHU)



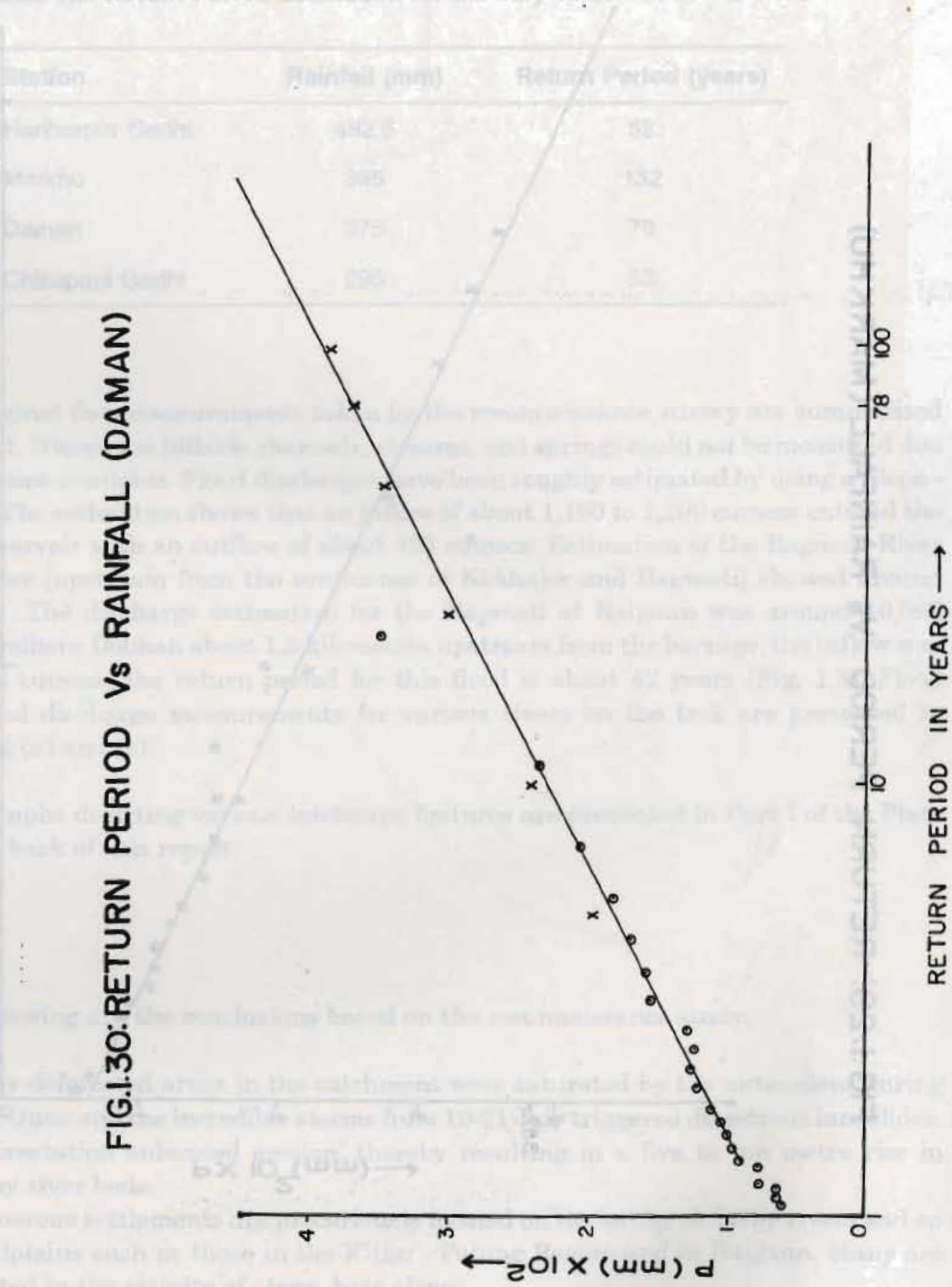


FIG.I.30: RETURN PERIOD Vs RAINFALL (DAMAN)
P (mm) X 10²
4
3
2
1
0
RETURN PERIOD IN YEARS
10
78
100

FIG.1.31: RETURN PERIOD Vs RAINFALL (CHISAPANI GADHI)

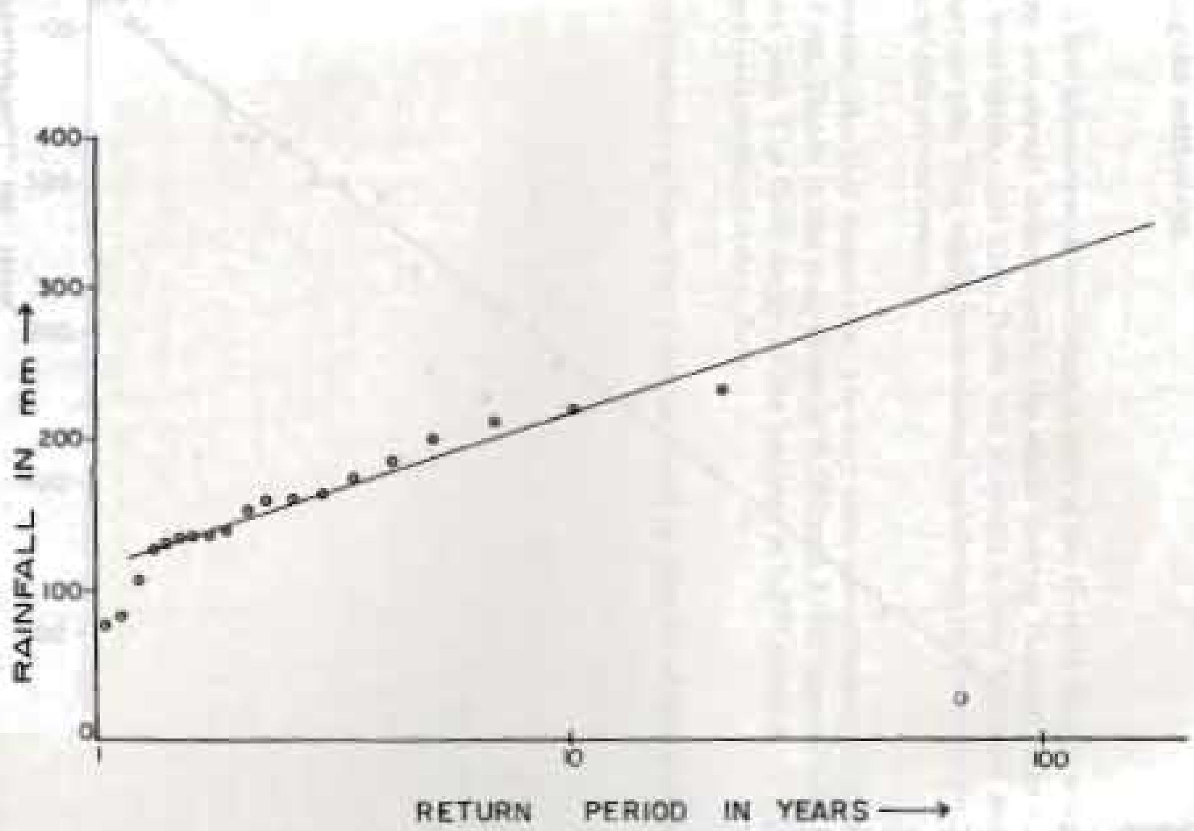
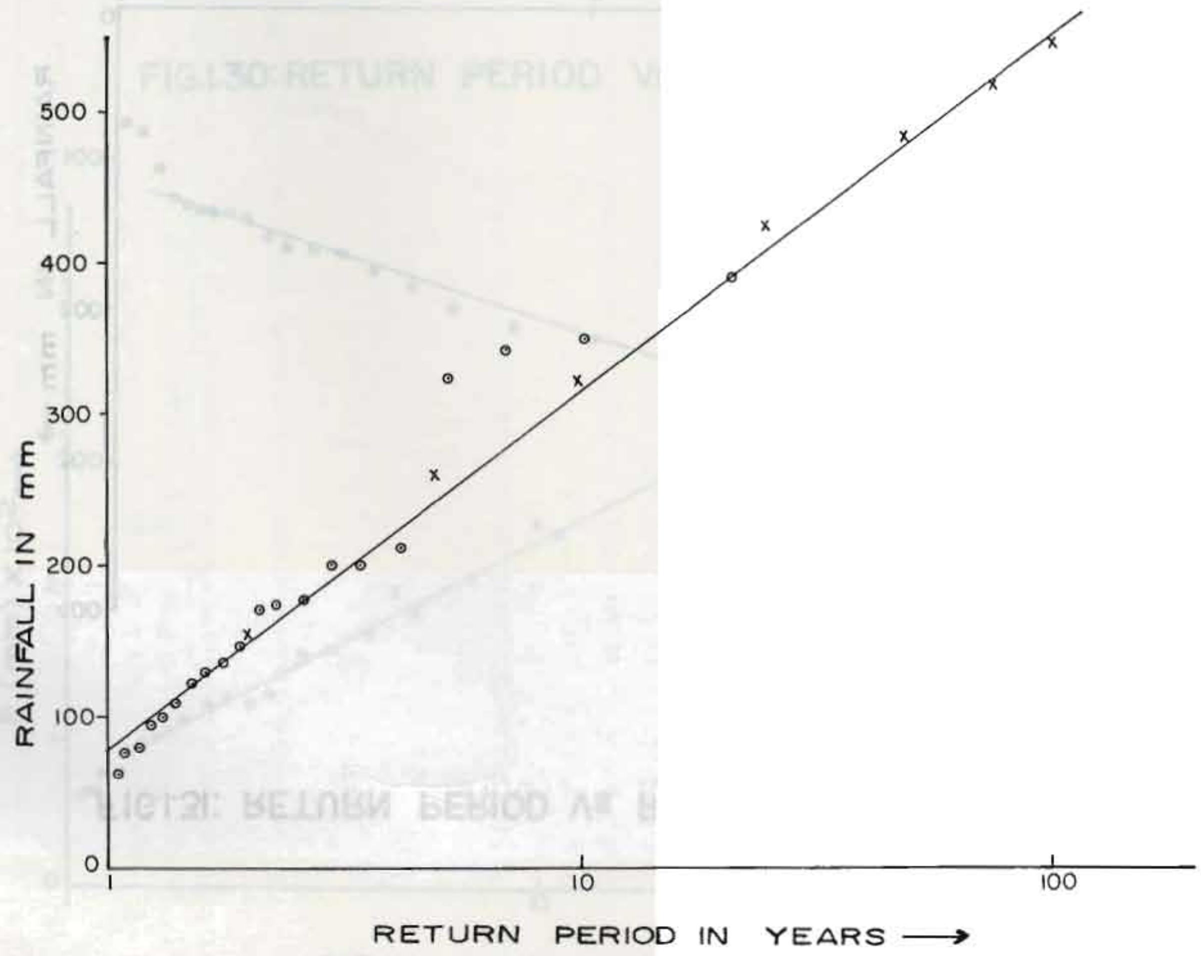


FIG.1.32: RETURN PERIOD Vs RAINFALL (HARIHARPUR GADHI)



- The rainfall distribution pattern caused more or less coincidental arrivals of various tributary floods to the main course.
- The Kulekhani Reservoir absorbed the incoming floods and contributed to desynchronisation of its modified outflow downstream.
- Watershed management has to be improved in the catchment. Unfortunately, this event has reduced the Kulekhani Reservoir's life by between six to ten years.
- The narrow gate clearances obstructed many uprooted trees, causing heavy sedimentation. The bed level then rose with the flood, surging over the gates, and causing havoc to the structure and floodplains.
- Raigaun was severely hit, as it is near the confluence of the Chiruwa, Marin, and Bagmati; Marin *Khola* was devasted by the deluge of the Bagmati westwards, flooding Raignun settlement.

Furthermore, a few kilometres downstream, a part of the Siwalik Range with an east-west orientation forms an abrupt obstruction to the south flowing Bagmati. The river then takes a sharp turn westwards, and then flows out through a long tortuous gorge-route southwards to the Barrage site. This might have caused inundation in the surrounding areas as well as in the floodplains downstream.

- Extreme events, like this recent one, are very rare, nevertheless preparedness is very important. Floods in the magnitude of 8,650 and 9,000 cumecs have occurred in the recent past. The flood design of the barrage is 8,000 cumecs.
- Most of the rivers suffered debris flow.

The recommendations emanating from Part I can be found in Part IV of this document.

## Appendix 1.1

## Rainfall Data for the Bagmati Catchment and Its Adjoining Catchments

| Situation No. | Station | Precipitation recorded at 9AM, 19th July (m) | Precipitation recorded at 9AM, 20th July (mm) | Precipitation recorded at 9AM, 21st July (mm) | Precipitation Recorded at 9AM, 22nd July (mm) |
|---|---|---|---|---|---|
| 1. | DUVACHAUR | 34 | 15 | 12 | 3 |
| 2. | MANDAN | 4.3 | 10.5 | 175.8 | 20 |
| 3. | CHAUTARA | 1.6 | 15 | 168 | 2.2 |
| 4. | CHARIKOT | 36 | 25 | 40 | 18 |
| 5. | NEPALTHOK | 10.2 | 76.2 | 100 | 44.3 |
| 6. | KHOPASI | 0.3 | 81.8 | 31.1 | 40.1 |
| 7. | PATHARKOT | 11 | 38 | 437 | 42 |
| 8. | TULSHI | 12.3 | 46.4 | 66.3 | 68.4 |
| 9. | RAMOLI BARYA | - | - | 129.9 | 14.7 |
| 10. | NEELGUDH | 3.4 | 187.6 | 42.5 | 10.2 |
| 11. | KALAIYA | - | - | 102.7 | 69.2 |
| 12. | BIRGUNJ | - | - | 168.6 | 10.8 |
| 13. | SIMRA | - | 0.3 | 228 | x |
| 14. | AMLEKHGUNJ | - | - | 399 | 42.5 |
| 15. | MAKWANPUR GADHI | 39 | 77.5 | 205.5 | 30 |
| 16. | NIBUWATAR | x | 256 | 380 | x |
| 17. | BELEWA | 12 | 50 | 134.5 | 23 |
| 18. | CHISAPANI GADHI | 58 | 295 | 65 | 45 |
| 19. | KULEKHANI | 5.4 | 376.8 | 54.2 | 46.8 |
| 20. | DAMAN | 5.4 | 373 | 240 | 5.2 |
| 21. | MARKHU | 4.5 | 385.6 | 43.6 | 38.2 |
| 22. | TISTUNG | 3.5 | 540 | 39 | 66 |
| 23. | THANKOT | 76 | 111.2 | 69.3 | 84.2 |
| 24. | CHITLANG | - | 202 | | 20 |
| 25. | CHAPAGAUN | 1.8 | 102.8 | 33.7 | 88.3 |
| 26. | GODAVARI | 2.0 | 84.2 | 29.0 | 113.3 |
| 27. | NALLU | 21.9 | 96.1 | 75.0 | 56.0 |
| 28. | BHAKTAPUR | 24.0 | 38.2 | 11.0 | 58.00 |
| 29. | SANKHU | 19.5 | 25.5 | 24.0 | 21.00 |
| 30. | KATHMANDU AIRPORT | 6.6 | 39.2 | 4.6 | 49.6 |
| 31. | BUDHANILKANTHA | 12.2 | 39.8 | 17.5 | 54.0 |
| 32. | KAKANI | 20 | 52 | 7.2 | 57.5 |
| 33. | GHANTI MADHI | 88.2 | 482.2 | 116.3 | 22.4 |

**Appendix 1.2 Flow Measurements on the Trek (Sept 1 - 21) 1993**

| Rivers | Mean Velocity (m/s) | Cross-sectional Area ($m^2$) | Discharge (cumec) |
|---|---|---|---|
| MANOHARI RIVER | 1.8 | 28.7 | 53.6 |
| CHITLANG *KHOLA* | 1.412 | 5.2 | 7.34 |
| LOTHAR RIVER | 1.85 | 15.57 | 26.95 |
| DHARO *KULO* | 0.65 | 0.04 | 0.02 |
| PHOOLGAUN *KHOLA* | 0.59 | 0.16 | 0.09 |
| KHANIGAUN *KHOLA* | 1.126 | 0.45 | 0.50 |
| TISTUNG + PALUNG | 2 | 3.17 | 6.34 |
| KULGAUN *KHOLA* | 1.62 | 1.09 | 1.77 |
| AGRA *KHOLA* | 1.95 | 6.51 | 12.69 |
| BISINKHEL *KHOLA* | 2.68 | 0.7 | 1.88 |
| TISTUNG | 1.62 | 0.77 | 1.24 |
| PHEDI GAUN *KHOLA* | 0.57 | 0.68 | 0.38 |
| KITINI *KHOLA* | 0.55 | 0.99 | 0.55 |
| PALUNG *KHOLA* NEAR OKHAR *BAZAAR* | 1.047 3 | 2.58 | 2.7 |
| GHARTI *KHOLA* | 1.48 | 1.06 | 1.57 |
| PALUNG RIVER NEAR SCHOOL | 2.24 | '5.55 | 12.42 |
| LUBU KHOLSO | 0.34 | 0.02 | 0.01 |
| KHAITE *KHOLA* | 0.48 | 1.28 | 0.61 |
| KUNCHAL *KHOLA* | 0.85 | .49 | 0.41 |
| 'KITINI *KHOLA*/UPSTREAM | 0.23 | 0.75 | 0.02 |
| PALUNG *KHOLA* NEAR PHOOL BARIGAUN | 1.43 | 3.43 | 4.9 |
| RAPATI RIVER | 1.57 | 38.4 | 60.3 |
| CHAKHEL *KHOLA* | 1.2 | .32 | 0.38 |

# The Geological and Geomorphological Background to the Hazards

**Background of the Area**

The Himalayan Belt can be subdivided into the following four tectonic zones from north to south respectively (Fig. 2.1).

- Tibetan-Tethys Zone
- Higher Himalayas
- Lesser Himalayas, and
- the Sub Himalayas or Siwaliks.

The Tibetan-Tethys Zone is made up of sedimentary rocks and lies in the north of the high mountains. It is followed in the south by the Higher Himalayas. The Higher Himalayas are represented by high-grade metamorphic rocks with a few granite intrusions. The Lesser Himalayas lie to the south of the Higher Himalayas. They are bordered in the north by the Main Central Thrust (MCT) and in the south by the Main Boundary Thrust (MBT). The Lesser Himalayas are made up of medium to low-grade metamorphic rocks, some igneous rocks, and sedimentary rocks. The Lesser Himalayas can further be subdivided into the Midlands and the Mahabharat Range (Fig. 2.1). The Lesser Himalayas overlie the Siwalik Belt along the MBT situated to the south. The Siwaliks (also called the Churia Hills) are composed of fragile and soft mudstone, sandstone, and conglomerates.

The Bagmati watershed (Fig. 2.2) extends south of the Higher Himalayas to the Siwaliks and the *terai* plain. The river flows from the north of Kathmandu and reaches Gaur in the *terai*. It originates from the Sheopuri Hills which form the watershed boundary at the highest elevation of 2,732 m and the river flows towards the south and south-east (Fig. 2.2). It passes through the high-grade metamorphic rocks of the Kathmandu Complex and then through the low-grade metamorphic and sedimentary rocks of the Nuwakot Complex.

A few granite intrusions (Fig. 2.3) are observed in the central part of the Lesser Himalayas. The river finally crosses the fragile Siwalik rocks and reaches the *terai*.

The Bagmati River crosses five important thrust faults (Fig. 2.2). Two of them, the Mahabharat Thrust (MT) and the MBT, pass each other very closely (Fig. 2.2) between the village of Pyutar and the Kokhajor *Khola*. Similarly, the other two faults observed in the Siwaliks pass close to each other between Jamire and Karaonje. Their proximity has created a wide crushed zone full of instabilities of various kinds. Between Pyutar and the Kokhajor *Khola*, huge rockslides prevail on the steeper slopes and debris fans are situated on the lower reaches. The two faults in the Siwaliks have contributed to the formation of the wide Bagmati Valley between Jamire and Karaonje, and they have also created a large debris fan in the Chaura Khola (Fig. 2.2).

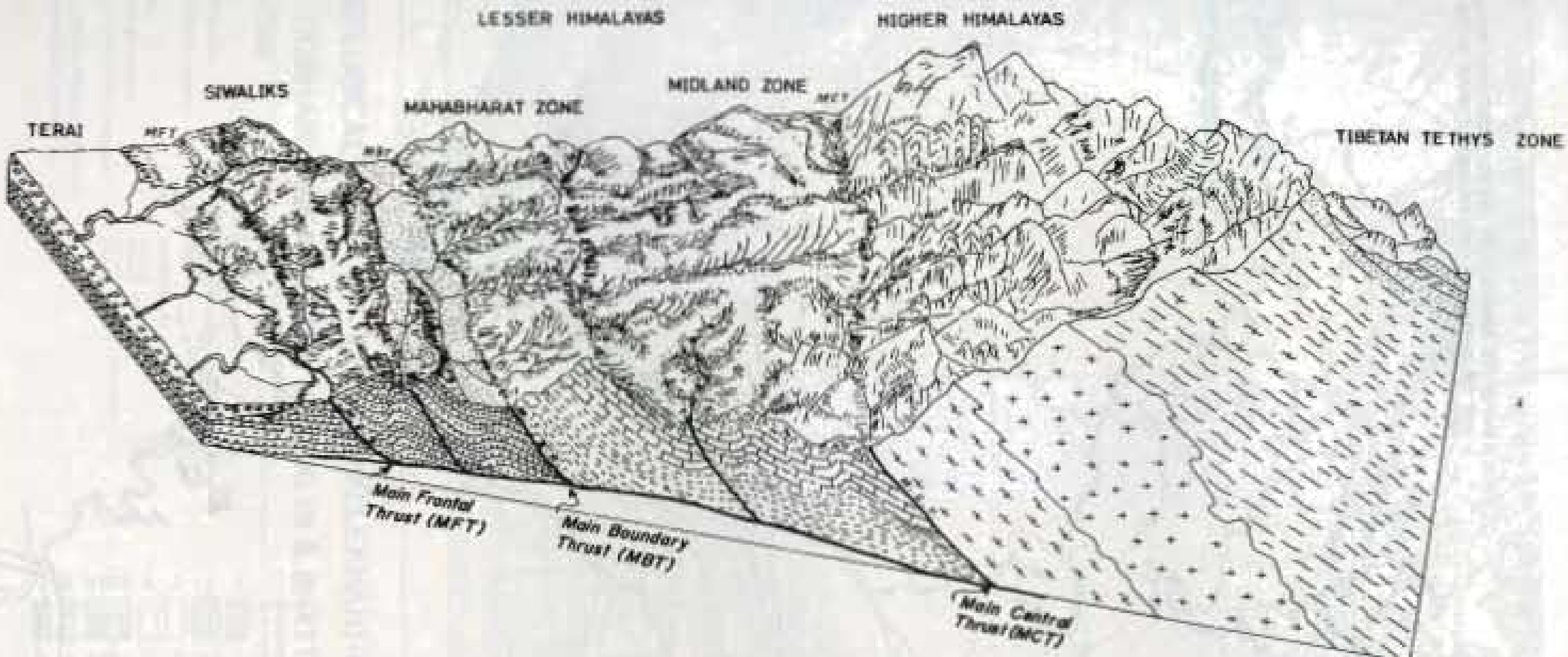
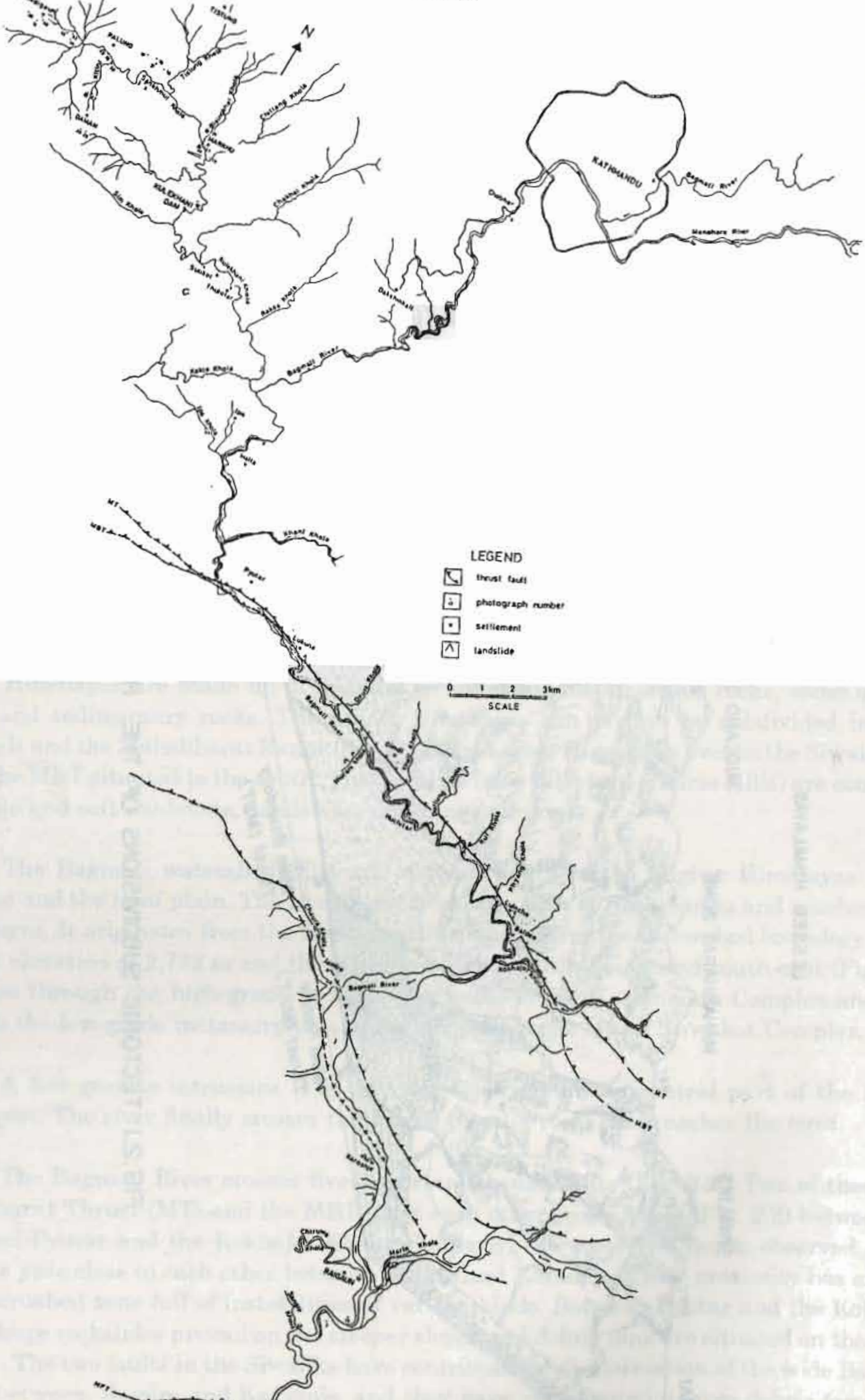



FIG.2.1: TECTONIC SUBDIVISIONS OF THE HIMALAYAS

FIG. 2.2: MAP OF THE BAGMATI RIVER AND ITS TRIBUTARIES BETWEEN KATHMANDU AND THE BARRAGE AT CANTEEN SHOWING MAJOR FAULTS, LANDSLIDES, AND SETTLEMENTS



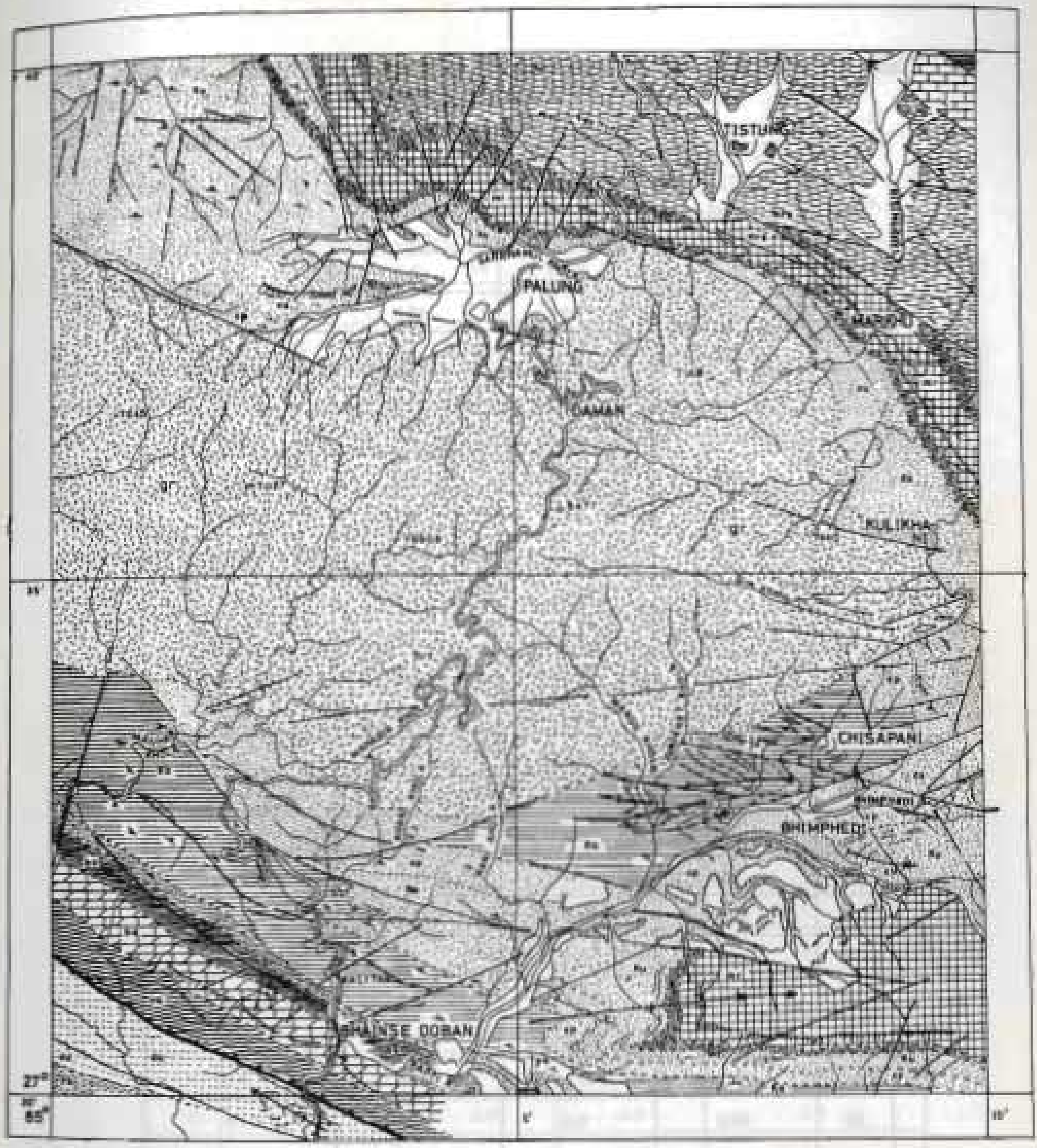



FIG.2.3: GEOLOGICAL MAP OF TISTUNG-KULEKHANI-BHAINSE DOBHAN AREA (AFTER STOCKLIN & BHATTARAI, 1978)

**Table 2.1: Daily Automatic Rainfall Records at Simlang and Tistung, July 1993**
(After Department of Soil Conservation Records)

| Date | Station at Simlang | | Station at Tistung | |
|---|---|---|---|---|
| | Rainfall, mm | Maximum intensity, mm/h | Rainfall, mm | Maximum intensity, mm/h |
| 1 | 16.0 | 7.3 | 19.0 | 8.0 |
| 2 | 18.2 | 9.8 | 12.0 | 6.0 |
| 3 | 0.5 | 0.5 | 0.0 | 0.0 |
| 4 | 0.4 | 0.4 | 1.0 | 1.0 |
| 5 | 0.0 | 0.0 | 0.5 | 0.5 |
| 6 | 4.3 | 4.3 | 0.5 | 0.5 |
| 7 | 4.2 | 2.0 | 5.5 | 5.5 |
| 8 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 5.5 | 3.5 | 3.5 | 3.5 |
| 12 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | 4.5 | 2.0 | 10.0 | 4.0 |
| 15 | 0.5 | 0.5 | 0.0 | 0.0 |
| 16 | 8.8 | 3.7 | 7.0 | 2.5 |
| 17 | 59.0 | 25.0 | 47.5 | 21.0 |
| 18 | 4.2 | 3.0 | 7.5 | 7.0 |
| 19 | 4.5 | 2.0 | 3.5 | 1.5 |
| 20 | 389.0 | 67.0 | 539.5 | 70.0 |
| 21 | 50.0 | 12.0 | 39.0 | 7.0 |
| 22 | 40.0 | 6.0 | 66.0 | 21.5 |
| 23 | 28.0 | 13.5 | 30.0 | 18.0 |
| 24 | 28.0 | 10.0 | 9.5 | 4.0 |
| 25 | 3.5 | 1.6 | 0.0 | 0.0 |
| 26 | 9.2 | 4.8 | 27.0 | 18.0 |
| 27 | 0.0 | 0.0 | 0.0 | 0.0 |
| 28 | 8.9 | 4.0 | 13.0 | 6.0 |
| 29 | 0.4 | 0.4 | 2.5 | 2.0 |
| 30 | 0.0 | 0.0 | 1.0 | 0.5 |
| 31 | 3.0 | 2.8 | 1.0 | 0.5 |

**Table 2.2: Daily Automatic Rainfall Records at Simlang and Tistung, August 1993**
(After Department of Soil Conservation Records)

| Date | Station at Simlang | | Station at Tistung | |
|---|---|---|---|---|
| | Rainfall, mm | Maximum intensity, mm/h | Rainfall, mm | Maximum intensity, mm/h |
| 1 | 11.7 | 6.5 | 21.0 | 9.0 |
| 2 | 0.5 | 0.5 | 36.0 | 29.0 |
| 3 | 7.5 | 3.8 | 3.0 | 1.0 |
| 4 | 0.0 | 0.0 | 1.0 | 0.5 |
| 5 | 11.0 | 4.0 | 10.0 | 6.0 |
| 6 | 2.8 | 1.0 | 4.5 | 2.5 |
| 7 | 5.0 | 3.0 | 8.5 | 5.0 |
| 8 | 3.0 | 1.0 | 10.0 | 2.5 |
| 9 | 32.2 | 16.0 | 25.0 | 11.5 |
| 10 | 157.0 | 28.0 | 227.5 | 45.0 |
| 11 | 38.5 | 10.0 | 41.5 | 20.0 |
| 12 | 1.1 | 1.0 | 1.0 | 0.5 |
| 13 | 7.7 | 6.0 | 5.5 | 2.5 |
| 14 | 18.5 | 10.0 | 11.0 | 7.5 |
| 15 | 32.5 | 12.0 | 9.5 | 4.0 |
| 16 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | 0.0 | 0.0 | 3.5 | 1.5 |
| 18 | 0.3 | 0.3 | 23.5 | 6.0 |
| 19 | 17.8 | 5.0 | 1.0 | 1.0 |
| 20 | 0.0 | 0.0 | 8.0 | 2.0 |
| 21 | 15.0 | 3.0 | 0.0 | 0.0 |
| 22 | 0.0 | 0.0 | 4.0 | 2.0 |
| 23 | 4.0 | 2.0 | 0.0 | 0.0 |
| 24 | 0.0 | 0.0 | 22.5 | 15.0 |
| 25 | 37.5 | 10.0 | 34.0 | 13.0 |
| 26 | 21.8 | 8.0 | 2.0 | 1.0 |
| 27 | 0.0 | 0.0 | 0.0 | 0.0 |
| 28 | 4.5 | 1.0 | 3.5 | 2.0 |
| 29 | 1.0 | 1.0 | 6.5 | 4.0 |
| 30 | 2.5 | 1.0 | 6.5 | 2.5 |
| 31 | 7.5 | 5.5 | 6.0 | 4.5 |

The longitudinal profile of the Bagmati River (Fig. 2.4) exhibits several breaks in slope. Owing to the presence of gneisses, the river gradient is rather steep between the Sheopuri Range and the Kathmandu Valley. The gentler slope around the valley is due basically to the lacustrine and fluvial deposits in the basin. Steeper slopes south of the valley (between Dakshinkali and the Khani *Khola*) are related to the resistant rocks of the Lesser Himalayas. The gradient of the river becomes remarkably steep, especially while crossing the granite intrusion (Fig. 2.4). The Bagmati River flows onwards along the MBT and the MT with an almost uniform slope. Finally, it crosses the Siwaliks along a gentler gradient and reaches the *terai* with very gentle slopes.

Geomorphologically, the Bagmati watershed and its adjacent region can be subdivided into the following tectonic landforms: the Mid-hills, the Mahabharat Range, the Siwalik Hills, and the *terai*. Apart from these, such features as intermontane valleys, alluvial fans, river terraces, and floodplains are the other important secondary landforms observed in the region.

*Mid-hills*

The Mid hills (or Midlands) range in altitude from 1,000m to 3,000m. They are represented by a rather dissected topography with dendritic, centripetal, and sub-parallel drainage patterns. Residual soils are observed on the ridges, whereas colluvial soils and talus deposits are seen on the slopes. Occasionally river terraces and alluvial fans are developed on the lower gentler slopes (Plate 1, Part II)*.

The Midlands are made up of metamorphic and igneous rocks (Fig. 2.4, Plate 2). Granite is extensively distributed around Palung, Daman, Mandu, and between the Kulekhani Dam and Ipa. The territory covered by granite is deeply weathered to yield sand, pebbles, cobbles, and boulders. Generally, randomly-oriented joints are observed in the granite and the joint spacing varies from 20 cm to three metres. In most places, four sets of joints prevail. The groundwater percolates through the joints down to depths of from five to 10 metres and considerably increases the pore-water pressure leading to debris and rockslides.

As a result of chemical weathering along the joint surfaces, the large boulders are formed by the intersecting joint sets (Plates 2 and 3). The granite is made up of potash feldspar, plagioclase, quartz, biotite, muscovite, and tourmaline. Generally it is coarse-grained and occasionally a mixture of very coarse-grained and fine-grained.

The intensely fractured and folded phyllite and slate of the Tistung, Sopyang, Kulekhani, and Chitlang formations are the other important zones of instability. Huge rotational and translational slides are triggered off on them. One of the massive sliding areas lies in the catchment of the Agra *Khola*. The villages of Chisapani, Agra, and Chaubas are severely damaged by rock and soil slides. Large landslides also occur to the south of Khanikhet in the Ipa *Khola*, the Deuta *Khola*, The Kul *Khola*, the Niureni *Khola*, and the Kokhajor *Khola* (Fig. 2.2).

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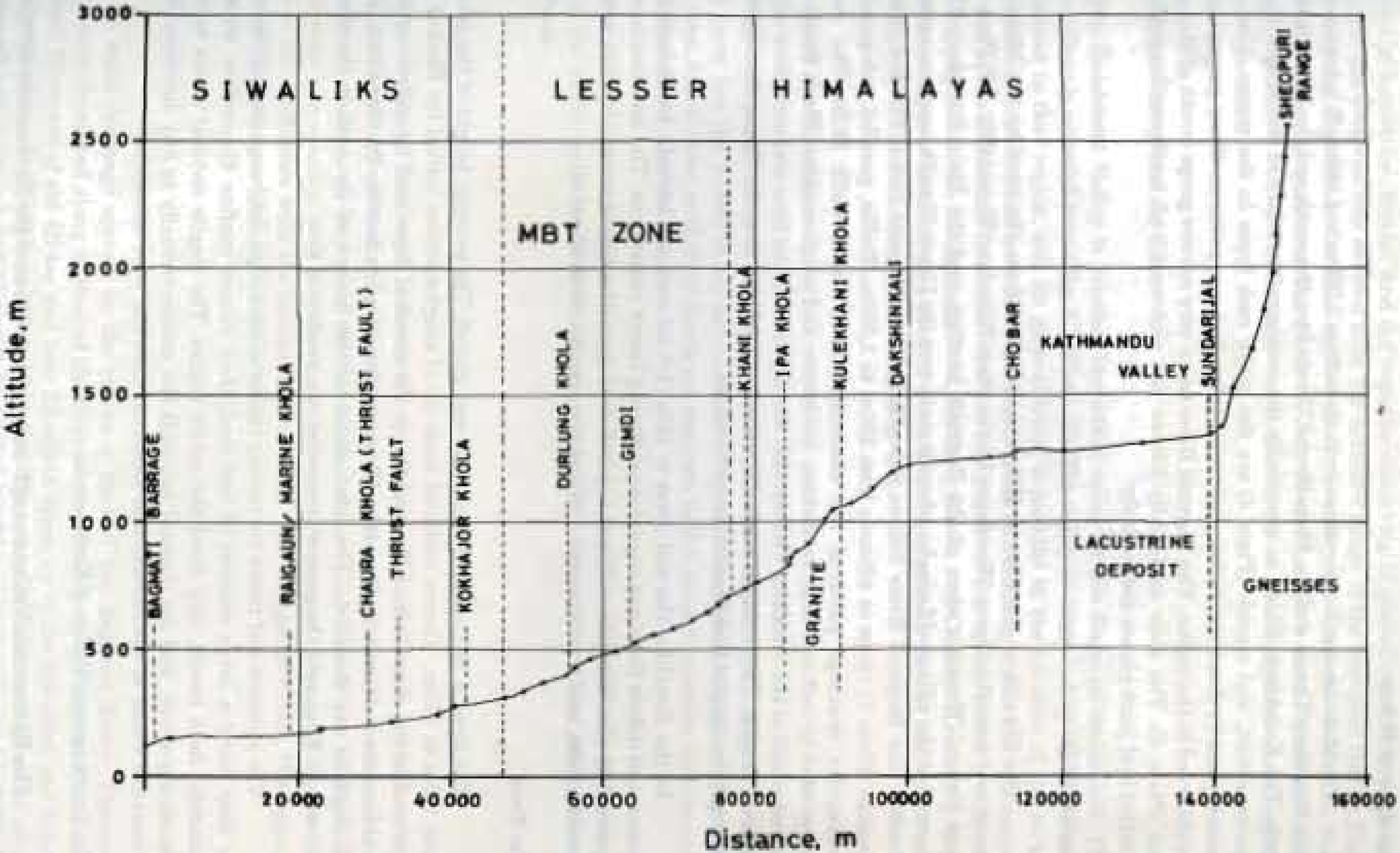
* Unless otherwise stated, all plates from this section are to be found in Part II of the Plates' Section at the end of the document.

FIG.2.4: LONGITUDINAL PROFILE OF THE BAGMATI RIVER



*Mahabharat Range*

The Mahabharat Range varies in altitude from 2,000m to 4,000m. It is bounded by the Main Boundary Thrust and the Mahabharat Thrust from the south and the Mid-hills from the north. The Kulekhani *Khola* is essentially the northern boundary of the range. Quartzite, granite, schist, and marble (Plate 4) are the major rock types in the region. The range is characterised by dendritic, radial, and rectangular drainage patterns. Steep gorges and banks are observed in the region. The Bagmati River has a very narrow gorge (south of Malta) in the area (Plate 5). The river essentially follows the east-west and north-south trends of the foliation and joint planes respectively.

*Siwalik Hills*

The Siwalik or the Churia Hills are delimited from the *terai* by the Main Frontal Thrust and from the Lesser Himalayas by the Main Boundary Thrust (Fig. 2.2, Plate 6). The Main Frontal Thrust is seen at the Bagmati barrage, and the Main Boundary Thrust is observed at the village of Luinche where it rests over the Upper Siwalik conglomerates. In the Siwaliks, the Bagmati River follows essentially the south-east trend. The low hills of the Siwaliks (Plate 7) range in altitude from 200m to 1,500m. Trellis, parallel, sub-parallel, and rectangular drainage patterns are characteristic of the Siwalik Hills. The rocks are represented by soft and loose sandstone, mudstone, and conglomerates. Flash floods are also characteristic of the Siwaliks. The streams are dry most of the time and are active only in the monsoon season. They bring reworked boulders and pebbles from the Upper Siwaliks and also undercut the fragile Middle and Lower Siwaliks.

In the Siwaliks, the soil cover is thin (1-3 m) and, the bedrock being loose, intense erosion and debris flows are experienced during heavy rainstorms. The intermontane basins observed in the Siwaliks suffered a great deal from the recent event. In that area, sheet flooding, fans, and river channel shifting phenomena were common.

The *Terai*

The *terai* is composed of sand, silt, and gravel. The average height of the *terai* varies from 100m to 150m. Coarse material made up of conglomerates (called the Bhabar Zone) is observed in the Siwalik foothills, and this is the result of deposition by coalescing fans. The boulder sizes in them vary from tens of centimetres to a few metres. Further south, sand and silt deposits are observed. The most characteristic feature of the *terai* is the rapid river channel shifting, and the present low relief is a product of this.

The streams and rivers traversing the *terai* have high discharge during the monsoon. As they carry a large amount of bed load, they cannot confine themselves within their channels. As a result, they flood the entire region. The fragile natural levees may breach almost anywhere, and the channel can shift the course virtually in any direction. Recently, almost the whole of the Sarlahi and Rautahat districts were inundated.

*The Intermontane Valley of Kathmandu*

The Kathmandu Valley is a syn-tectonic depression of the Kathmandu Synclimorium. The Valley has an oval shape with a typical centripetal drainage pattern. The Bagmati River and its tributaries originate from the hills surrounding the valley. The valley is filled by a thick series of lacustrine, fluvial, and fan deposits consisting of gravel, sand, silt, peat, and clay. Most of the material was derived from the northern range of the Sheopuri Gneiss Zone. However, the fan deposits to the east and south of the valley are made up of detritus from limestone, phyllite, and quartzite. The floods on July 19 and August 9 also affected the valley considerably (Plates 8 and 9). The damage was concentrated on the floodplains and along the terraces of the rivers.

*The Kulekhani Valley and the Dam*

The Kulekhani Valley is another important valley in the Bagmati watershed. The Kulekhani Dam is situated here (Fig. 2.2, Plate 10). The valley is controlled by the joints and faults present in that region, and its general trend is parallel to the foliation of the rocks. Slates, phyllites, marbles, and quartzites are found in the surrounding areas. The submerged surface area of the Kulekhani Reservoir (*Indrasarobar*) is about 2.2 sq.km. Water is collected from the Palung *Khola*, the Bisingkhel *Khola*, Chitlang *Khola*, and Chakhel *Khola* (Fig. 2.2). The Kulekhani Dam is situated on a faulted contact between granite (south) and schist and quartzite (north) of the Kulekhani Formation (Fig. 2.3).

*The Valleys in the Siwaliks*

Wide valleys are seen in the Marin *Khola* and the Chaura *Khola* (Fig. 2.2). The Bagmati River has the widest valley between the villages of Jamire and Raigaun (Fig. 2.2). Alluvial fans, debris flows, and sheet floods are common in this area. Numerous mid-channel bars and islands are also observed.

The ability of the streams to transport debris increases during the time of flooding. Erosion of the valley walls by slides and flows provides thousands of tonnes of debris during such periods.

*Alluvial Fans*

Several alluvial fans were active in the granites, in the slates and phyllites of the Midlands, and in the Siwaliks during the rainstorm. The fans are situated where mountain streams change gradient as they reach the flat surface of the valley floor (Plate 11, Fig. 2.2). As the streams lose velocity, they also lose their capacity to transport debris and deposit the material at the confluence with the mainstream or river. The villages of Kitini, Phedigaun, Palung, and Karaonje are situated on these fans.

*River Terraces*

The main drainage system in the region is that of the Bagmati River. Terraced landforms have developed along it. Most of the terraces observed in the Kulekhani *Khola* and the Bagmati River are of old fill-top and new fill-strath types up to the Siwaliks; and below them, they become new fill-top and fill-strath types. There are at least four levels of river terraces between the villages of Malta and Baldeo. Villages such as Malta, Pyuitar, Gimdi, and Huchitar are situated on old fill-top terraces. The terrace height for old fill-top terraces generally varies from 75 m to 150 m, and often they are about 100 m higher than the present river bed, whereas the recent fill-strath and fill-top terraces range in height from three to 25m. Severe damage to the recent terraces can be observed almost all along the Bagmati River (Plates 7 to 11).

*Floodplains and Channel Bars*

Rather wide floodplains are observed along the Bagmati River below the village of Baldeo (Fig. 2.2). They are the most vulnerable areas for flooding (Plate 12). Often they contain paddy fields. A huge amount of debris brought by the tributaries is observed to rest on the floodplains. The mid-channel bars of the Bagmati River are often cultivated (Plate 13) and suffer from serious flood hazards. Occasionally, the schools are built on the point bars and floodplains which are the areas at very high risk (Plate 14). During flooding, the schools may be surrounded by floods and could even be washed away.

**Mass Movements and Floods**

Geological processes, such as landslides, debris flows, sheet flooding, river bank scouring, river and stream channel shifting, inundation of settlements and cultivated lands, and deposition of sediments, were active during the recent rainstorms and flooding. Short descriptions of the most important types of processes operating during the recent event are given in this part.

*Landslides*

The term landslide is used to denote the downward and outward movements of slope-forming materials along surfaces of separation (Varnes 1978). Landslides are rather quick, mass-wasting processes. The landslides were widespread and contributed to the loss of hundreds of lives in the study area. Moreover, the slides were the source not only of gravel and fines but also of huge amounts of wood debris (Plate 15). Landslides caused extensive damage to dry cultivated land, roads, and settlements. The total damage caused by the slides and debris flows is difficult to assess owing to the short duration of the present study. But the fact that more than 2,000 small and large (from 25 square metres to more than a square kilometre) landslides occurred along the Tribhuvan highway as well as hundreds in the Bagmati Watershed means that the damage was substantial.

Large slides were especially common on the north-facing dip-slopes, whereas shallow slides were observed on the counter dip-slopes and on the slopes of granite. Mass movements were mainly of four types: debris slides (Fig. 2.5, Plate 16), rockslides (Fig. 2.6, Plate 17), debris flows (Plate 18), and deep-seated rotational slides (Fig. 2.7). Plane rockslides occurred on steep slopes where bedrock was close to the surface (Fig. 2.6, Plate 17). Debris and soil slides occurred on slopes that were either deeply weathered or covered by colluvium and/or residual soils of thicknesses ranging from one to six metres (Plate 16). River bank scouring (Fig. 2.8) was the main cause of road washouts.

The most severe damages occurred in zones of intense precipitation (i.e., the Tistung, Agra, and Daman areas), on alluvial fans, around the Bagmati River banks, and on the gently dipping *terai* plains.

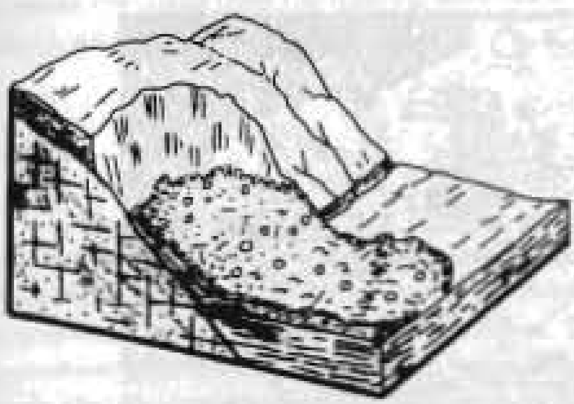


Figure 2.5: Sketch of a Debris Slide

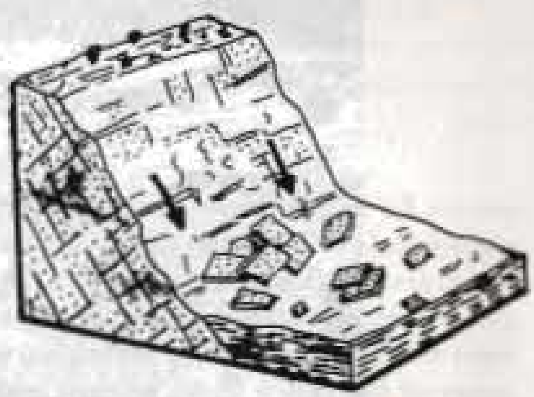


Figure 2.6: Sketch of a Plane Rockslide

*Causes of Mass Movements*

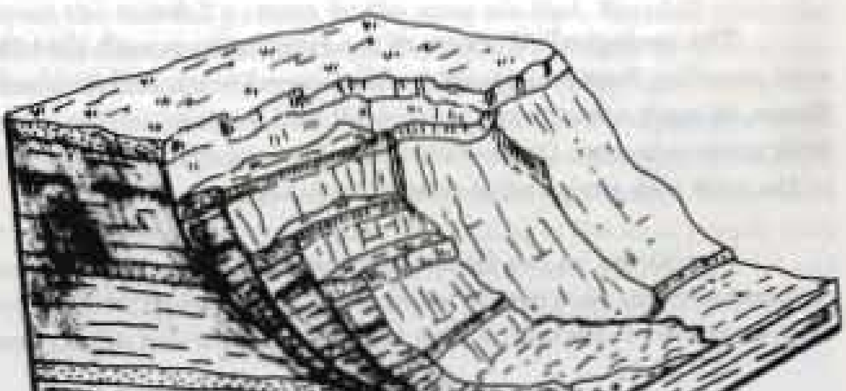


Figure 2.7: Sketch of a Rotational Slide

The most important factor leading to landslides and debris flows was the heavy rainstorm. Because of intense precipitation, the slopes around Jhapre, Tistung, Phedigaun, Agra, Palung, Chisapani, Daman, Gimdi, Baldeo, Karaonje, Mahabhir, Jurikhet, Bhimphedi, Mandu, Bhainse, Malekhu, Belkhu, Mahadev Besi, and Raigaun failed in several places leaving numerous landslide and erosion scars (Plates 1 and 2). River scouring and gully erosion were the other secondary factors leading to slope failures.

The factors which are more or less steady and inherent in the constituent rocks and soils can be grouped into the *primary causes* of failure. The basic primary cause is the force of gravity. But, apart from this, many other factors may play their roles. Some of the most important of them are: rock and soil types and their strength, rock structure (folding, faulting, jointing, foliation, bedding), soil depth, porosity, and permeability.

The factors that are either variable or very short-lived can be grouped into the *secondary causes* or *triggers*. They are seismicity; intensity of precipitation; land use; natural slope conditions; rock and soil weathering conditions; presence or absence of gullies, streams, and rivers; and groundwater conditions.

**Figure 2.8: Sketch of bank scouring by a river**

The geological structure of the Himalayas is such that there are several roughly east-west trending fractures (faults) with several weak and crushed zones (Figures 2.1 and 2.2). Hence, in such areas, numerous small and large landslides aligned along, or parallel to, the fault zones are seen. On the other hand, orientation of fold axis, bedding, foliation, and joints in the rock also play a vital role in landsliding.

Landslides in the Himalayas are very often complex and with more than one factor governing them. As a result, we observe a complex landslide. For example, a plane rockslide may be followed downslope by a wedge rockslide and debris flow.

**Vegetation** plays a vital role in slope stability and in the processes of soil erosion. The erosivity of rainfall increases during the monsoon, but the ability of vegetation to protect the topsoil also increases, resulting in reduced rates of surface erosion as the monsoon progresses. However, the mass wasting probability increases during the monsoon because the subsoil becomes saturated with moisture (Galay 1987). Generally, the vegetation cover increases the shear strength of the soil through its root network and protects the slope from landslides. However, if the landslide is deeper than the root penetration depth, the vegetation can no longer stabilise the slope.

**Pore-water pressure** is another important factor leading to slope failures. The most important aspect of pore-water pressure in rock and soil is that it reduces normal stress but does not affect shearing stress.

*Flash Floods and Debris Torrents*

**Flash floods** are events with very little time lapsing between the start of the flood and peak discharge. They are often associated with short intervals between storm incidence and arrival of the flood wave, but this is not always the case. Floods of this type are particularly dangerous because of the suddenness and speed with which they occur. Flash floods are more common with isolated and localised intense rainfall originating from thunderstorms. Debris torrents resulting from flash floods were observed at Kitini, Palung, in Mandu *Khola*, Jurikhet *Khola*, and in Kul *Khola*.

*Floods*

The basic cause of river flooding is the occurrence of heavy rainfall. Not all serious inundations of land or damage from floods, however, are due to this hydrological phenomenon alone. Often other factors operate either to exacerbate an already occurring flood problem or to create an entirely separate flood problem. These factors are associated most often with the promotion of hydraulic surcharge in water levels. They include the presence of natural or man-made obstructions in the flood path such as bridge piers, floating debris wires, and barrages. Also induced are the generally unforeseen river-surge events caused by sudden dam failure, land-slip, or mud flow (UNDRO 1991).

*A Note on Rainfall Pattern and Flood Travel Time*

Tables 2.1 and 2.2 depict the rainfall pattern in the area studied. Rainfall of similar magnitude was also recorded at the Daman, Markhu, and Kulekhani stations. From the data available, and from the present field visit, it was discovered that floods and landslides occurred between July 19 and 20 in the upper reaches of the Bagmati River, especially in the watersheds of the Kulekhani, Bhimphedi, Mandu, Malekhu, Belkhu, and the Agra *Khola*. On the other hand, floods and intense rainfall were observed between July 20 and 21 in the area between Gimdi and the lower reaches of the Bagmati River. According to the local people from the upper catchment, the flood on August 10, 1993, was bigger than that during July 19 and 20. However, the devastating flood in the lower catchment occurred during the night of July 20-21. A flood of lesser magnitude occurred in the morning of July 20.

These observations indicate that there were at least two separate areas with different cloudburst timings (i.e., the Kathmandu-Palung-Kulekhani-Bhimphedi-Malekhu and the Baldeo-Raigaun-Marin *Khola*-Canteen areas). It seems that the thunderstorm producing the intense rain was gradually moving from north to south almost at the same pace as that of the flood. Probably the cumulative effect of the rainfall event resulted in the catastrophic floods in the lower reaches of the Bagmati and other rivers reaching the *terai*.

## Field Assessment of Damages by Mass Movements and Floods

*Mass Movements on Highways and Adjacent Regions*

The floods and heavy rain caused severe damage to the roads. The damage was confined to the gullies, steep soil slopes, and slopes with highly weathered rock. Rockfalls, plane and wedge rockslides, debris slides, and rotational soil slides were most common, whereas gully erosion and alluvial fans either destroyed or blocked the road in several places. The road very close to the river channel also suffered from bank scouring, whereas, in several places, small debris fans debouched on to the road. The landslides were triggered off, either by extensive bank scouring in the gully or by increase in the pore-water pressure in the weathered rock. Generally, a perched water table was formed at the interface between the impervious granite and the weathered upper layer of rock and soil.

River bank scouring was most common around Jogimara, near Bishal Tar, west of Malekhu, on the right bank of the Malekhu *Khola*, in the vicinity of Belkhu, Galchhi, Mahadev Besi, and Naubise. A short description of the damage to the road is presented below.

*Damage to the Tribhuvan Highway and Adjacent Area*

There were more than 2,000 landslides (with major landslides in more than 200 places) ranging in size from tens of square metres to thousands of square metres. There were about 20 places with severe washouts. Areas where heavy damages occurred were Naubise (Km 26), around Jhapre (Km 49 to Km 53), between Sikharkot and Daman (Km 71 - Km 76), between Aghor and Mahabhir (Km 89-98), around Bhainse Dobhan, and at Bulbule (Km 122-123). More than 100 metres of retaining walls and 23 culverts were damaged. The bridges at Mahabhir, Bhainse (Plate 19), and Trikhandi (Plate 20) were completely washed out, and the bridges over the Sopyng *Khola* and the Sankhamul *Khola* were partially damaged.

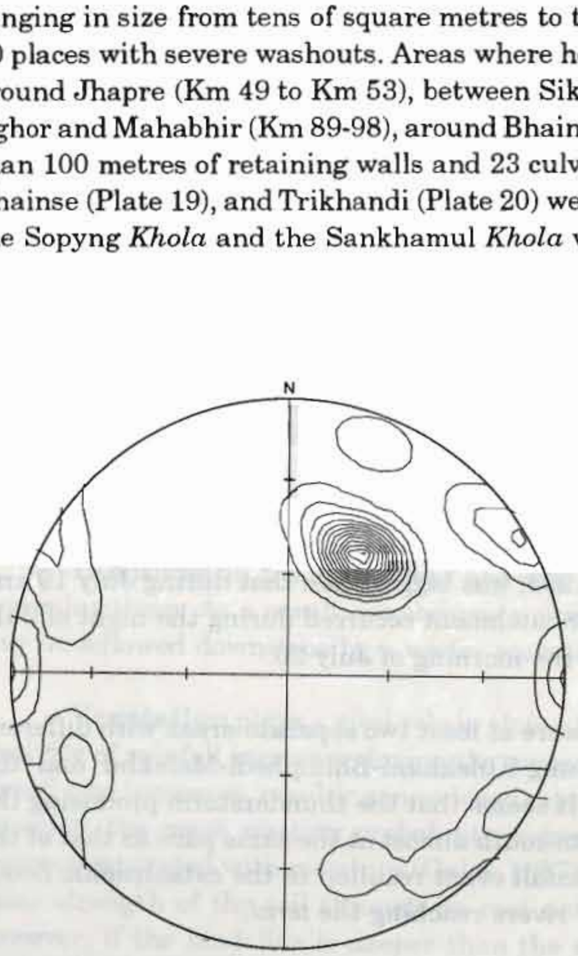



**Figure 2.9: Stereographic projection of joints, Km 64 on the Tribhuvan Highway. Upper hemispherical projection.** (See also Plate 9)

*Plane Rockslide North of Okhar Bazaar*

A large plane rockslide can be seen at Km 64 on the Tribhuvan Highway (Plate 21). The slide is on the Tistung Formation where the rock consists of highly fractured slate and quartzite. There are four distinct sets of joints developed in it (Fig. 2.9). The stereographic projection of joints (Fig. 2.9) clearly reveals that the basic mechanism of failure was caused by sliding along the bedding/foliation plane. The same type of plane rockslides and wedge rockslides can be observed around Jhapre (Km 51-52). Some of them also seem to be rotational slides in the rock.

*Landslides and Gully Erosion on the Slope North of Okhar Bazaar*

The study of landslides on the counter dip slopes near the village of Okhar *Bazaar* (Fig. 2.10) revealed that the total soil displaced by slides and gully erosion was about 6,700 cubic metres within an area of 21,400 square metres; which works out at 0.31 cubic metres per square metre (i.e., 1680x0.31=520 kg/m$^2$) of the total area. The total landslide area was about 8,500 square metres; which works out at 40 per cent of the total surface area. The average natural slope was about 35 degrees, whereas the central part of the failed slope was about 41 degrees. The contoured stereographic projection (Fig. 2.11) shows the distribution pattern of the joints.

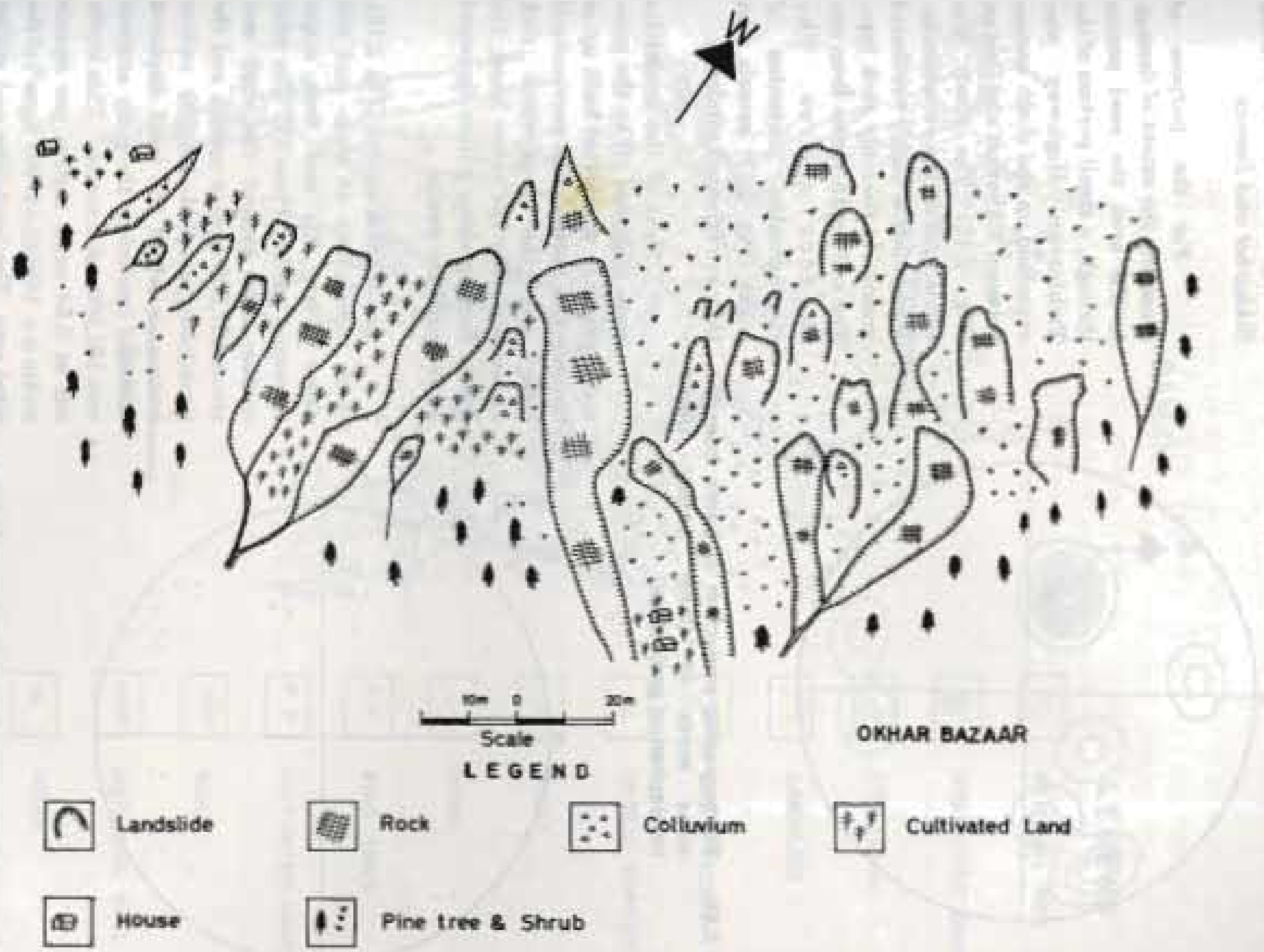



FIG.2.10: ENGINEERING-GEOLOGICAL MAP OF A WESTERN PART OF OKHAR BAZAAR

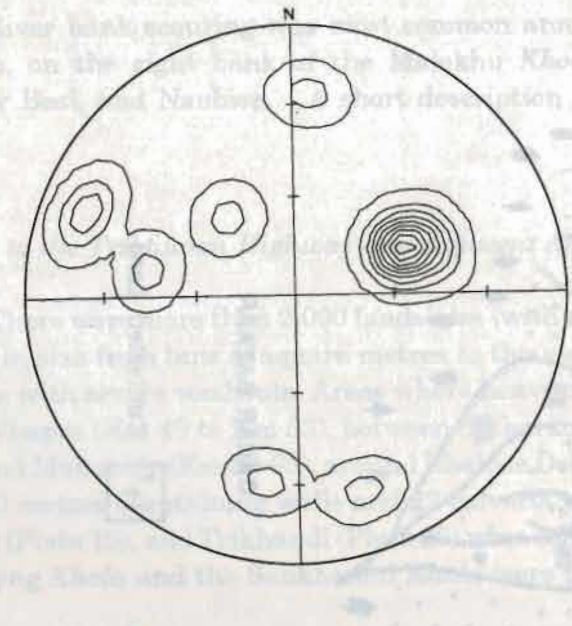



**Figure 2.11:** **Stereographic projection of joints from the slope north of Okhar *bazaar*. Upper hemispherical projection.**

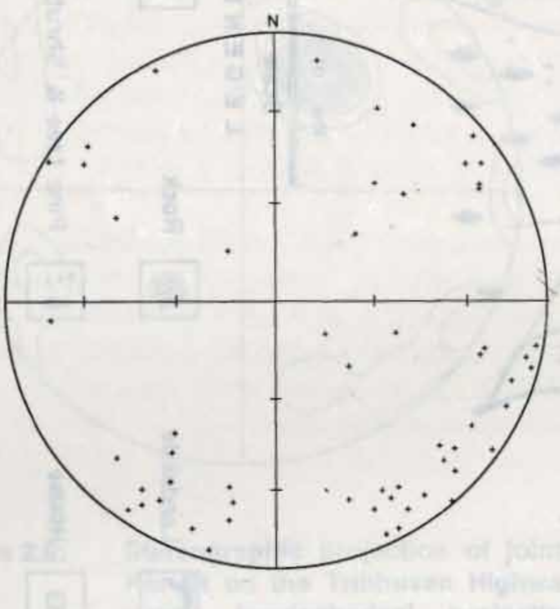



**Figure 2.13:** **Stereographic projection of joints from the road section between Sikharkot and Daman. Upper hemispherical projection.**

*Damage to the Road between Sikharkot and Daman*

For the purpose of assessing the extent of damage in the area the road passes through, a small portion of the Tribhuvan Highway was examined on the climb section between Sikharkot and Daman (Fig. 2.12). The study was carried out on the switchbacks. Moderately to highly weathered granite is the only rock type. The soil depth varies from one to four metres. The stereographic projection of joints (Fig. 2.13) reveals that they are oriented randomly.

Most of the landslides were triggered off by the pore-water pressure which had built up at the interface between the pervious soil layer and the impervious rock underneath. On the other hand, the debris flowing along gullies damaged and scoured the banks.

In a 2,185m stretch (Fig. 2.12), there were about 44 rock- and soil slides (Plate 22) and four major torrential gullies (Plate 23). The total surface area around the road was about 297,500 square metres and the landslides occupied 109,200 square metres, in which the total displaced material (excluding the gully erosion) was 161,000 cubic metres. This works out at 0.54 cubic metres per square metre (i.e. 1680x0.54=907 kg/m$^2$) of the total area. The landslides and gullies occupied about 36 per cent of the total surface area. The average depth of failure was 1.5 m, whereas the average natural slope was 31 degrees and the failed slope in the central part was 41 degrees. The total length of damaged road section (including the damages on the adjacent slopes) was 828 m (i.e., 38% of the total road length).

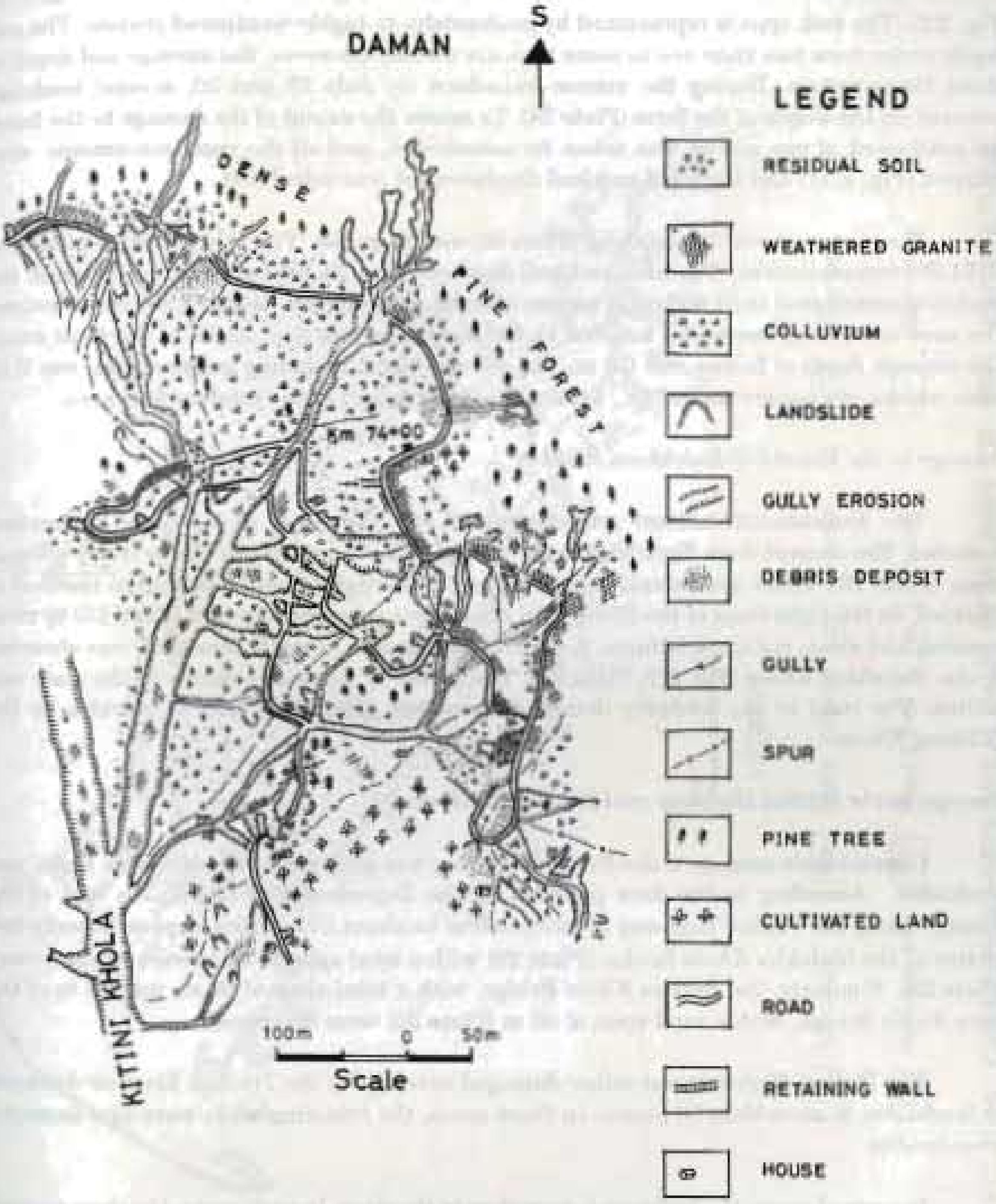



FIG.2.12: ENGINEERING-GEOLOGICAL MAP OF A PART OF THE TRIBHUVAN HIGHWAY BETWEEN SHIKHARKOT AND DAMAN

*Mass Movement at the Daman Horticultural Farm*

The Daman Horticultural Farm is located on the ridge at an altitude of about 2,300m (Fig. 2.2). The rock type is represented by moderately- to highly-weathered granite. The soil depth varies from less than one to more than six metres. However, the average soil depth is about three metres. During the intense rainstorm on July 19 and 20, several landslips occurred on the slopes of the farm (Plate 24). To assess the extent of the damage to the farm, the catchment of two gullies was taken for assessment, and all the mass movements were mapped (Fig. 2.14) and the total rock/soil displacement was calculated.

There were about 73 landslides (Plate 25) and 12 gullies (Fig. 2.14) within a total area of 51,600 square metres. The total rock/soil displaced was 34,100 cubic metres, of which the landslide contributed to 31,800 cubic metres and the gully erosion yielded 2,300 cubic metres. The area covered by landslides totalled 11,650 square metres (i.e., 22.6% of the total area). The average depth of failure was 0.8 m. The soil displaced (including gully erosion) was 0.61 cubic metres per square metre (i.e., $1,680 \times 0.61 = 1014$ kg/m$^2$) of the total surface area.

*Damage to the Kunchhal-Kulekhani Road*

The Kunchhal-Kulekhani gravelled road was damaged considerably on several stretches. The descent from Kunchhal to the village of Tistung is one of the severely affected areas (Plate 16). There are several soil slides and torrential gullies. The road to the east of Taukhel, on the right bank of the Bisingkhel *Khola*, was severely damaged (Plate 26) by river scouring and steep, cut slope failures. A small landslide dam (already breached) was observed in the Bisinkhel *Khola* (Fig. 2.2, Plate 27). The failure is a plane rockslide in the slate and marble. The road is also severely damaged about two kilometres east of Markhu by the Chitlang *Khola*.

*Damage to the Prithvi Highway and Its Surroundings*

Considerable damage to the Prithvi Highway was incurred by floods, debris flows, and landslides. According to the data provided by the Department of Roads, the cost of the damage along the Prithvi Highway is estimated to be about 572 million rupees. Twenty-two metres of the Malekhu *Khola* Bridge (Plate 28) with a total span of 44 m were washed away (Plate 29). Similarly, the Belkhu *Khola* Bridge, with a total span of 66 m, and 66 m of the Agra *Khola* Bridge, with a total span of 88 m (Plate 30) were destroyed.

The Prithvi Highway was either damaged severely by the Trishuli River or damaged by landslides in more than 50 places. In those areas, the retaining walls were also damaged considerably.

In several areas, the highway is very close to the river. In such areas, the river scoured the road and deposited from one to three metres of sand and gravel (Plate 31). Several suspension bridges were also either washed away or severely damaged during the same event. On the other hand, the flood, and rock- and soil slides damaged the road and adjacent slopes at Naubise, Galchhi (Plate 32), around Mahadev Besi, Belkhu, Gajuri, Malekhu, Benighat, Bishal Tar, and Jogimara. During the same event, the Blue Heaven Restaurant, situated on the left bank of the Trishuli River, about 500 m west of Malekhu, was washed away completely. A long stretch of the river terrace on the right bank of the Trishuli River to the west of Belkhu was scoured (Plate 33).

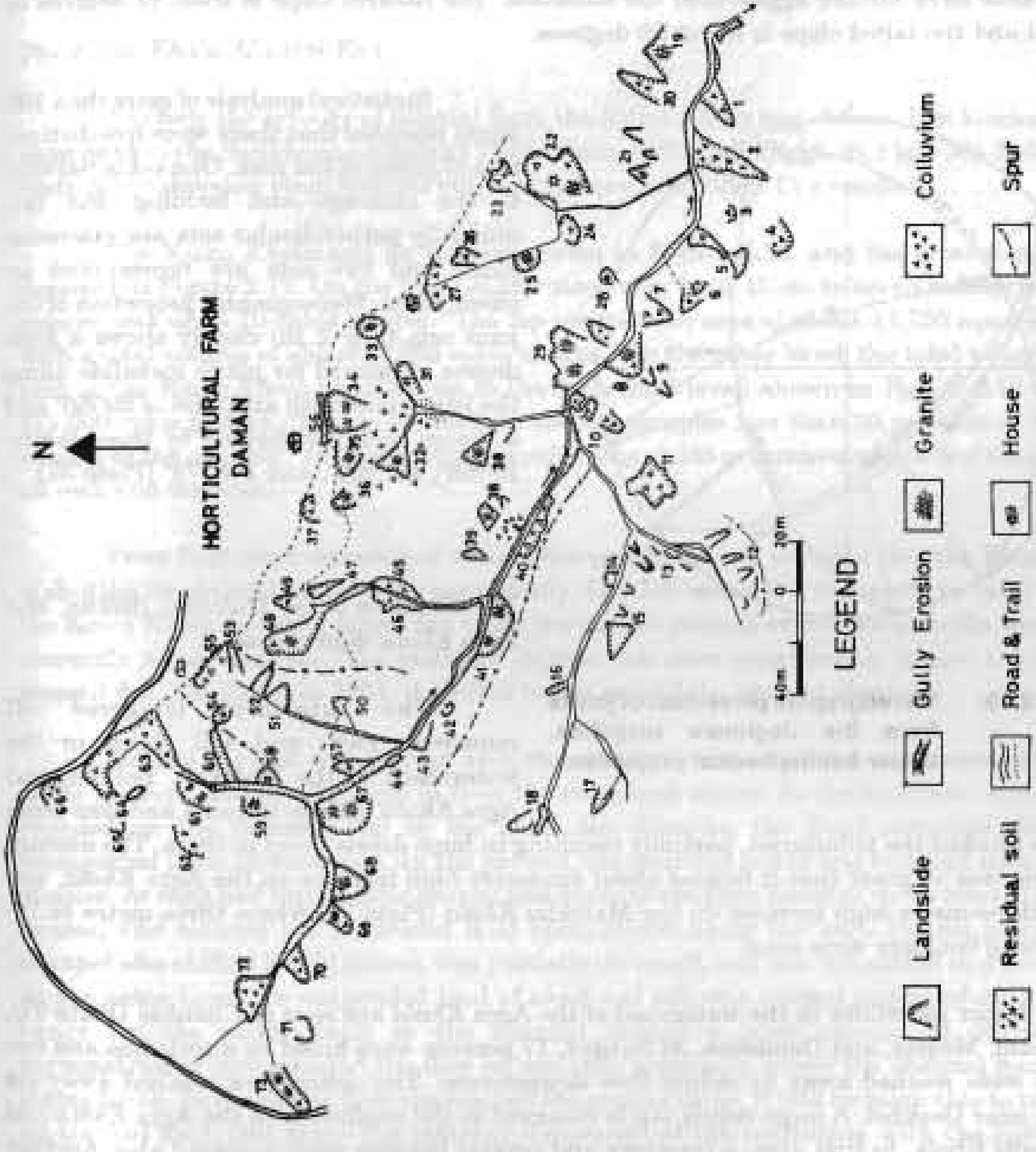



FIG. 2.14: ENGINEERING-GEOLOGICAL MAP OF A PART OF THE HORTICULTURAL FARM, DAMAN

*The Jogimara Landslide and Its Triggers*

The Jogimara landslide (Plate 34) is probably the most hazardous landslide on the Prithvi Highway. It has carried several buses into the Trishuli River and hundreds of people have lost their lives. The slide is located on the left bank of the Trishuli River on the Benighat Slates and Jhiku Limestone bands. The rocks are extremely jointed and the joint spacings vary from a few centimetres to tens of centimetres in the slate and from tens of centimetres to a few metres in the limestone. The approach road to the limestone quarry and the blasting in the area have further aggravated the situation. The natural slope is from 40 degrees to vertical and the failed slope is about 30 degrees.

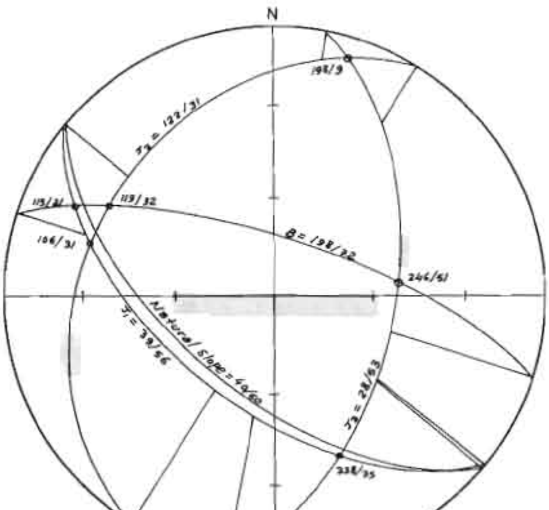



**Figure 2.15: Stereographic projection of joints from the Jogimara rockslide. Upper hemispherical projection.**

Statistical analysis of more than 100 joints revealed that there were five distinct sets of joints in the rock. One set is parallel to the cleavage and bedding, the two mutually perpendicular sets are extension joints and two sets are represented by shear joints. Stereographic projection of the joint sets (Fig. 2.15) clearly shows a high degree of hazard for plane rockslide along the joint plane with attitudes of 39°/56° and a wedge rockslide formed by three joints: 39°/56°, 122°/31°, and 198°/72° (Plate 35).

*The Situation in the Malekhu, Belkhu, and Agra Khola Watersheds*

The rainstorm triggered off numerous rock- and soil slides in the watersheds of the Malekhu, Belkhu, and Agra *Khola*. Debris torrents and fans seem to have blocked the tributaries, partially resulting in huge debris flows in them. The amount of debris was so great that it formed about six-metre high terraces on the Agra *Khola*, and about three-metre high terraces on the Malekhu *Khola* (Plate 36) where three-metre to 10-metre long boulders were seen.

Major rockslides in the watershed of the Agra *Khola* are seen at Chaubas (Plate 37), Chisapani, Mouria, and Dandabas. At Sulikot, 17 persons were killed by a rockslide and two houses were washed away by debris flow downstream. The debris flow washed away six houses near Deokhel. A large debris fan is observed at the confluence of the Agra *Khola* and the Chalti Khola. In that area, a cemetery and several temples were damaged also. Another big fan is observed to the west of Devithan where two houses were washed away.

The bridges over these rivers were washed away completely or partially. The basic reason for bridge collapse was low bridge height and narrow span. Generally, the river channel upstream is from 1.5 to two times wider than at the bridge site. The huge tree trunks brought by the rivers were entrapped by the piers and thus also contributed to collapse of the bridge.

## Field Study of Alluvial Fans

Numerous small and large alluvial fans were active during the rainstorm. They caused extensive damage to the villages, cultivated land, and infrastructure. The sediment load transported by them was variable, depending upon the rock and soil types from which they originated and upon flow velocity. Huge boulders were observed in the channel and on the fan originating from such resistant rocks as granite, quartzite, marble, and limestone. Smaller fragments are to be found on fans consisting of slate, phyllite, schist, and shale.

### *The Kitini Khola Alluvial Fan*

To study the activity of alluvial fans, the Kitini *Khola* was chosen. It is located on the right bank of the Sankhamul *Khola* at Thana *Bazaar* (Fig. 2.2, Fig. 2.16, Plate 38). Debris flow destroyed cultivated land, washed out nine houses, and killed 11 persons.

The Kitini *Khola* and its fan are shown in Figure 2.16, and the cross-sections are depicted in Figure 2.17. On the fan, boulder sizes vary from 10 cm to seven metres and their volume was up to 70 cubic metres. The fan occupies an area of about 11,750 square metres with a total volume of about 58,750 cubic metres. On the other hand, the total volume of the part of the Kitini *Khola* channel (up to the high flood level) shown in Figure 2.16 is about 179,000 cubic metres. This indicates that the fan occupies less than 30 per cent of the total volume of the channel. The longitudinal profile (Fig. 2.18) is concave with a few steep slopes on rock and terraces.

From field observations and aerial photographs, it was revealed that the Kitini *Khola* is shifting its channel and the fan periodically. In 1915 (according to reports by local people), the Kitini *Khola* formed a larger fan (than during the present event) towards the west of the currently active channel. The boulders in that fan were considerably bigger than in the present fan. Similarly, in 1954, it shifted to the east of the present channel.

Most of the load was derived from the previously deposited fan or terraces, and some of the material was also brought in from the steep rock slopes. As the boulders were already rounded on the terraces and in the older fan deposits, the flood reworked them and transported them downstream. In the process, the boulders rolled and bounced making a lot of noise. As they had high kinetic energy and momentum, they knocked down trees, destroyed houses, and scoured the cultivated land encountered along the way. In this process, the channel also shifted its old course, was partially dammed, and was bifurcated in a few places. At the same time, the suspended load of sand and silt was ejected or spilled over the low banks (on the paddy field) as the channel carried a large amount of debris which asymmetrically concentrated the flow on one side, especially where the channel made short zigzag turns. As the debris flow approached the gentler slope, it was no more able to transport all the bed load, and hence the material debouched at the confluence with the Sankhamul *Khola* where the fan is about 200 m wide and five metres thick (Fig. 2.16, Cross-section A-A' of Fig. 17).

### *The Phedigaun Alluvial Fans*

Phedigaun (Fig. 2.2, Plate 39) is located at an elevation of about 1,830 masl. It is one of the most severely damaged areas where 52 houses were destroyed (Plates 40, 41, 42) and 62 persons were killed.

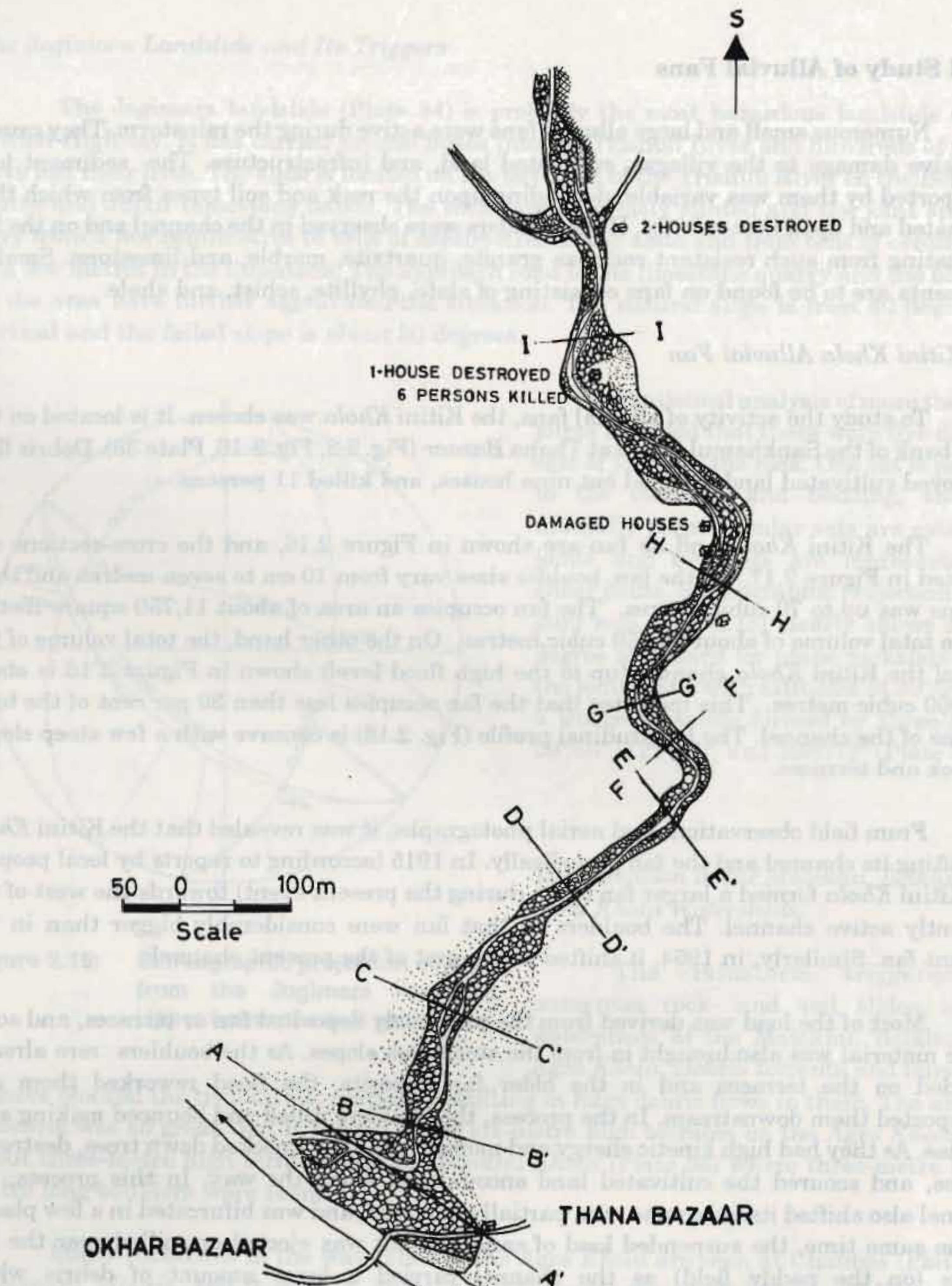



FIG.2.16: THE KITINI KHOLA FAN AT PALUNG

FIG. 2.17: CROSS-SECTIONS OF THE KITINI KHOLA

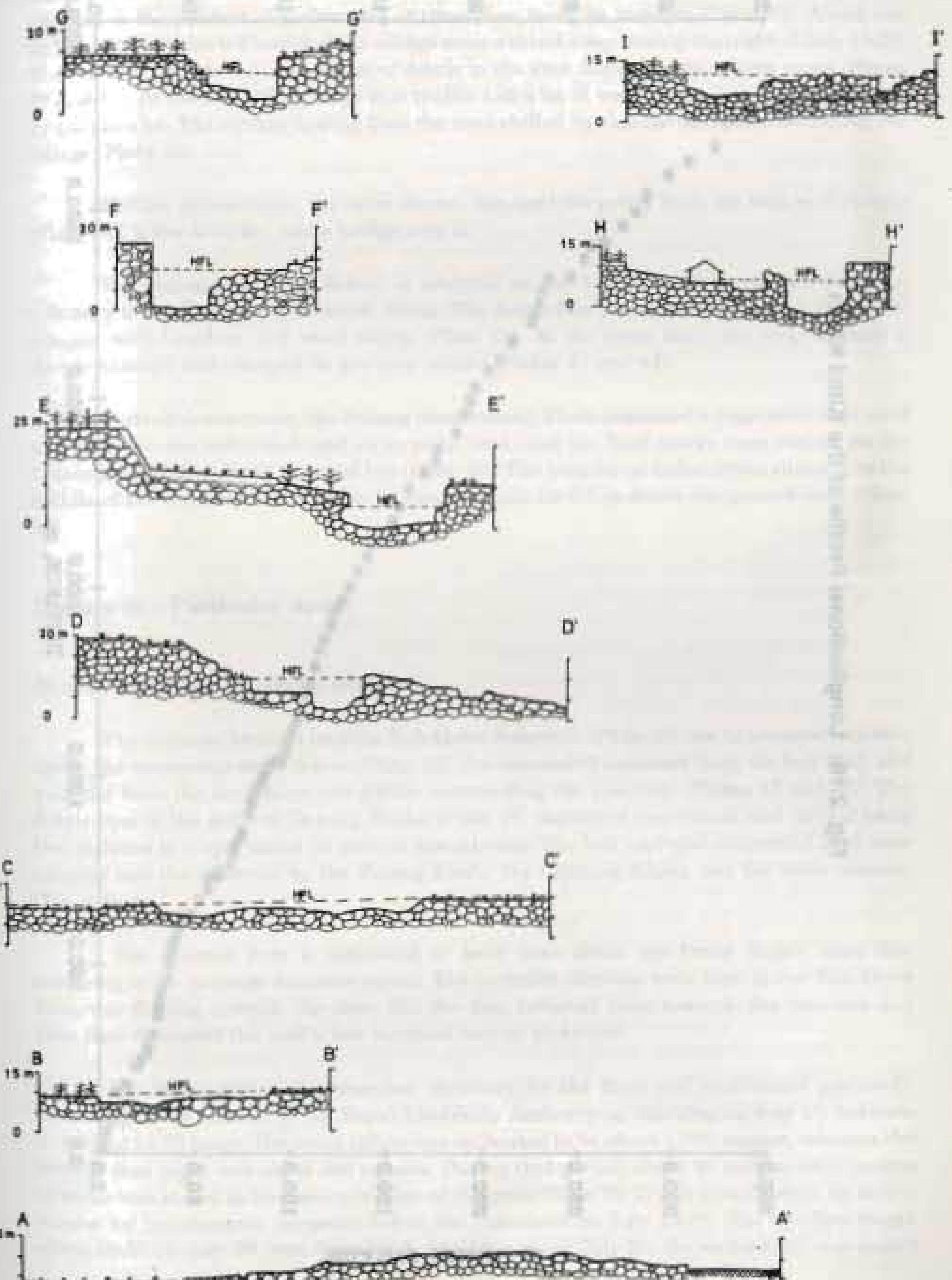
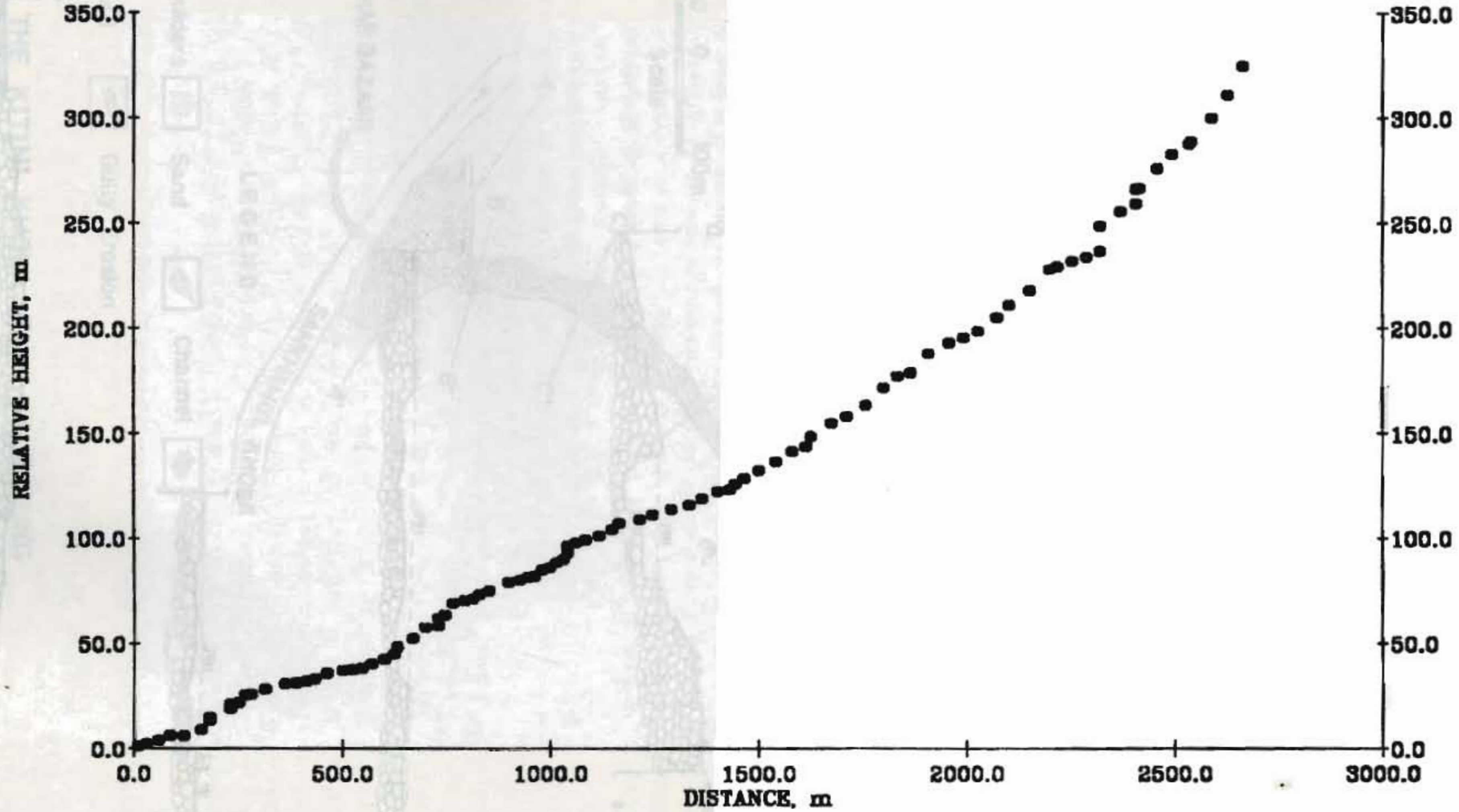


Fig. 2.18: Longitudional Profile of the Kitini Khola



The mountain slopes are steep and vary from 30 degrees to 40 degrees. There is a large plane rockslide on the northern slope south of Phedigaun. Similar soil and rockslides are also observed in the catchments of the tributaries. The alluvial fan on which the village was situated is the product of coalescence of three fans from the streams (Plate 39). About two sq.km. of the cultivated land and the village were washed away during the night of July 19-20. The streams brought a huge amount of debris in the area during the rainstorm event (Plates 39 and 40). At the same time, large tree trunks and a lot of wood debris were also brought in by the streams. The stream flowing from the west shifted its channel abruptly, destroying the village (Plate 39).

Further downstream, the same stream damaged the paddy field, the village of Palung (Plate 42), a few temples, and a bridge over it.

The Janakalyan High School is situated on the left bank of the Gharti *Khola*, a tributary to the Palung (Sankhamul) *Khola*. The debris flow in the stream filled up the school campus with boulders and wood debris (Plate 43). At the same time, the river scoured a deeper channel and changed its previous course (Plates 43 and 44).

Further downstream, the Palung (Sankhamul) *Khola* deposited a huge amount of sand and gravel on the cultivated land on its right bank, and the flood marks were noticed on the houses about 70 cm above the sand bar (Plate 45). The temples at Indrenithan situated in the middle of the terrace were filled up by sand and silt for 0.7 m above the ground level (Plate 46).

**Damage in a Particular Area**

*Damage around the Kulekhani Reservoir*

The material brought into the Kulekhani Reservoir (Plate 10) can be grouped into four types: the suspended wood debris (Plate 15), the suspended sediment load, the bed load, and material from the landslides and gullies surrounding the reservoir (Plates 47 and 48). The debris flow in the gully at Dalsing Pakha (Plate 47) destroyed two houses and carried away two children to a spot about 75 metres downstream. The bed load and suspended load were brought into the reservoir by the Palung *Khola*, the Chitlang *Khola*, and the other streams (Fig. 2.2).

The siltation rate is estimated to have been about ten times higher than that occurring in the average monsoon period. The turbidity currents were seen in the Kulekhani Reservoir flowing towards the dam. But the dam reflected them towards the reservoir and then they deposited the load a few hundred metres upstream.

The dam acted as the retention structure for the flood and contributed positively. According to the officials of the Nepal Electricity Authority at Markhu, on July 19, between 21:00 and 24:00 hours, the mean inflow was estimated to be about 1,000 cumecs, whereas the outflow that night was about 300 cumecs. During that period, about 45 million cubic metres of water was stored in the reservoir. One of the gates (Gate No 2) was already open up to five metres for maintenance purposes before the rainstorm on July 19-20. The overflow began about 00:30 on July 20 from Gate No 2. At 9:00 a.m. on July 20, the water level was raised by 26.37 metres, relative to that of 16:00 hrs on July 19. Owing to this alarming situation of a very rapid rise in water level, the second gate (Gate No 1) was opened at 9:00 am. The details of the gate opening are given in Table 2.3.

**Table 2.3: Details of Gate Opening and Closing at Kulekhani Dam**

| Date/ Major events | Water level, m | Time |
|---|---|---|
| July 19, 1993 | 1498.63 | 9:00 |
| | 1499.33 | 16:00 |
| The penstock pipe at Jurikhet was destroyed at 21:40 | | |
| July 20, 1993 | 1524.62 | 7:00 |
| | 1524.70 | 8:00 |
| Gate No 1 was open up to 15 cm at 9:00 a.m. | 1525.05 | 9:00 |
| | 1525.02 | 10:00 |
| Gate No 1 was open up to 35 cm at 11:30 a.m. | 1524.90 | 11:00 |
| | 1524.86 | 12:00 |
| | 1524.58 | 13:00 |
| The intake gate was closed manually between 10:00 and 14:00 | 1524.40 | 14:00 |
| | 1523.90 | 16:00 |
| | 1523.46 | 20:00 |
| | 1523.34 | 24:00 |

*Kulekhani Khola between the Dam and the Confluence with the Bagmati River*

Many landslides and debris flow deposits are observed along the Kulekhani *Khola* below the dam. Plane rockslides are observed on the right bank of the Kulekhani *Khola* about 500m west of the confluence with the Chakhel *Khola* (Fig. 2.2). These slides have been active for quite a long time. One of the largest landslides and the resulting fan was observed between the villages of Thulo Tar and Sulikot (Fig. 2.2, Plate 11). The joint pattern is presented in Figure 2.19 and it shows that the failure was a wedge slide.

Field observation of the confluence of the Bagmati River and the Kulekhani *Khola* showed that there was no damming effect by the Kulekhani *Khola*.

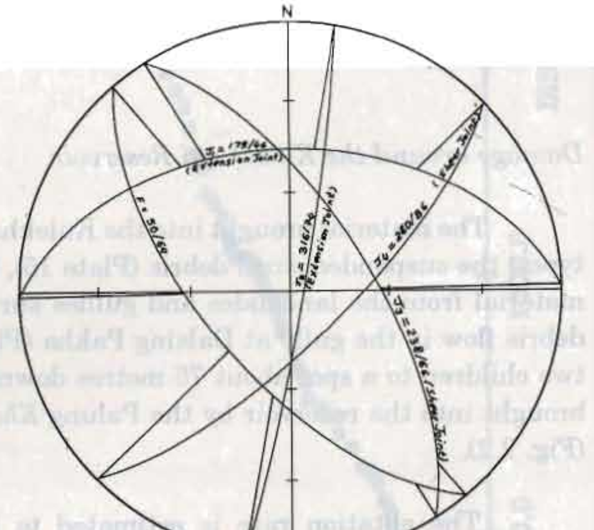



**Figure 2.19: Stereographic projection of joints from the area between Sulikot and Thulotar. Upper hemispherical projection.**

*The Bagmati Valley between Ipa and Gimdi*

The Bagmati Valley between Ipa and Gimdi is characterised by the presence of a deep entrenched gorge in marble and granite (Plate 5). At Baguwa (about 1 km north of the confluence with the Khani *Khola*), on the Kanti Rajpath, it can be inferred that there was a past landslide dam. A huge landslide zone is seen at the Ipa *Khola* (Plate 49) with a large debris fan below. It is the Mahabharat Thrust zone (Fig. 2.2). Landslides and debris flows were also observed at the Deuta *Khola* and the Neureni *Khola*.

*The Bagmati Valley between Gimdi and Kokhajor Khola*

The Bagmati River between the Gimdi and the Kokhajor *Khola* essentially follows the Main Boundary Thrust and the Mahabharat Thrust (Fig. 2.2). The Siwaliks are seen along the right bank of the valley, whereas the schists, marble, and quartzites are exposed along the left bank. Several soil and rockslides can be observed on the river banks and hillslopes. Large slides and slumps can be seen at the Kul *Khola* and the Phyang *Khola*. Alluvial and debris fans formed by smaller rivers are characteristic of the region. They have partially dammed the Bagmati River. There is a large rockslide on the left bank of the Kokhajor *Khola*, about one kilometre upstream from the confluence. According to the local people, the landslide occurred on July 21, 1993. However, there was no evidence of damming by it on the Bagmati River.

*Sheet Flooding in Karaonje*

The village of Karaonje (Fig. 2.2) is situated on the right bank of the Bagmati River on the alluvial fans (Plates 50 and 51). Most of the material was derived from the Upper Siwalik conglomerates. The gullies reworked and transported the pebbles downstream. During the period of intense rainfall, the channel could not contain the water within its very low banks and the sheet flood spilled over the entire alluvial fan. As a result, the houses were buried or destroyed by the debris.

*Damage to Raigaun*

Raigaun is situated on the right bank of the Bagmati River, opposite the confluences of the Marin *Khola* and the Chiruwa *Khola* (Fig. 2.2). Ward No 6 of the village (Plates 12 and 52) was severely affected by flooding on the Bagmati River during the night of July 20-21. The highest water level occurred between 1:00 and 6:00 a.m. on July 21, and the flood subsided between 6:00 and 7:00 a.m. During the flooding, several houses were washed away or inundated, resulting in heavy loss of cattle, cultivated land, and property.

The settlement was on the floodplain within the natural levees. The high water level was about 20m above the present river level. Probably the backwater flow from the barrage was one of the factors contributing to the unprecedented rise in water level. There was clear evidence of backwater flow in the Chiruwa *Khola* (Fig. 2.2). However, there was no evidence of damming of the Bagmati River by the Marin *Khola*.

*Damage below Raigaun*

The area below Raigaun suffered from inundation along the Bagmati River and from the debris flows, landslides, and gully erosion on the upper slopes. The backwater flow from the Bagmati River was seen in the Sangle *Khola* (Plate 53) situated to the south of Raigaun (Fig. 2.2), where the high flood level was from 1.5 to two metres above the present stream level. The channel was evenly filled up by medium to fine sand, making the bed almost horizontal (Plate 53).

*Damage to the Bagmati Barrage*

The Bagmati Barrage at Canteen is situated just on the Main Frontal Thrust (Fig. 2.2) which separates the Siwaliks from the alluvial deposits of the *terai*. The adjacent Siwalik rocks are intensely folded and are represented by grey, green, red, yellow, and brown mudstones and sandstones. The barrage was severely affected by the flood, and a loss worth more than 150 million rupees is estimated.

The dimensions and other technical parameters of the barrage (Plate 54) are presented in Table 2.4. There is a large mid-channel bar upstream from the barrage (Plate 55) and it continues downstream. The total volume of the channel bar downstream from the barrage was 148,400 cubic metres. The channel bar upstream from the barrage was almost three times larger, and, therefore, the total gravel deposit in the bar is estimated to be about 550,000 cubic metres.

**Table 2.4: Details of the Bagmati Barrage**

| | |
|---|---|
| Barrage length | 403.5 m |
| Dam site elevation | 125.0 m |
| Barrage crest level | 126.0 m |
| Barrage road level | 134.7 m |
| Pier width | 2.0 m |
| Barrage gate width | 9.0 m |
| Number of gates | 50 |
| Number of head regulators | 12 |
| Design flood | 8000 cumecs |

After a flood of smaller magnitude (about 4,000 cumecs) on the morning of July 20, the gates were opened. The catastrophic flood came during the night of July 20-21 between 1:00 and 6:00 a.m.

Large trees (more than 30 m long) and wood debris (Plates 55, 56, 57) were some of the underestimated loads. The large tree trunks blocked the barrage as the gates were too narrow to let the wood debris pass through them. As a result, the entire barrage became clogged by the sediment and wood debris. It acted as a large dam and the flood started overflowing the raised gates (Plates 57 and 58). In this process, the eastern and western guide bunds were washed away. The flood and debris destroyed the control tower on the eastern bank at 5:30 a.m. (Plate 59) and washed away the settlements and cultivated land downstream (Plate 60).

The sediment sluices were buried by the sediment, being unable to carry away the bed load. As there were no sediment ejectors, a lot of sand and gravel was deposited in the canals (Plate 59). Neither were there any log-catching structures upstream. The western sediment sluice contained less sediment than the eastern one, indicating uneven flow of the bed load.

Such factors as the damming effect of the barrage by wood and sediment debris and subsequent backwater flow, as well as the morphology and size of underwater channel bars and other larger bed forms, should be taken into consideration in estimating the peak discharge. It is extremely difficult to assess the exact slope of the channel floor and the amount of bed load at the time of high flood. It is important to notice that, after the flood, there was a large amount of sediment load on the gates (Table 2.5). The preliminary calculations showed that more than 20 per cent of the total gate outlet area was covered by debris.

*Damage to the Kulekhani Penstock Pipe*

The Kulekhani penstock pipe was damaged by the debris torrent from the Jurikhet *Khola* (Plate 61) at 21:40 on July 19. The damage amounted to about 200 million rupees of equipment. The Jurikhet *Khola* is a tributary to the Mandu *Khola*, whereas the Mandu *Khola* itself joins with the Bhimphedi *Khola*.

The penstock bridge over the Jurikhet *Khola* was very low. There were heavy bank protection and debris retention structures (retaining walls) in the stream, most of which were also washed away. The huge amount of debris was derived from a large landslide upstream. The outflowing water from the destroyed pipe was insignificant in comparison to the debris torrent from the Jurikhet *Khola*.

**Table 2.5: Siltation of the Bagmati Barrage after the Flood of July 21, 1993**

| Gate No | Depth of sediment, m |
|---|---|
| 7 | 2.04 |
| 8 | 2.76 |
| 9 | 3.02 |
| 10 | 3.19 |
| 11 | 3.52 |
| 12 | 3.66 |
| 13 | 3.47 |
| 14 | 3.63 |
| 15 | 4.02 |
| 16 | 3.73 |
| 17 | 3.62 |
| 18 | 3.69 |
| 19 | 3.16 |
| 20 | 3.21 |
| 21 | 3.12 |
| 22 | 2.45 |
| 23 | 2.13 |
| 24 | 2.30 |
| 25 | 3.16 |
| 26 | 2.75 |
| 27 | 1.33 |
| 28 | 1.50 |
| 29 | 1.65 |
| 30 | 1.00 |

## Damage to the Kulekhani I

*Tailrace Tunnel and Intake of Kulekhani II*

The portal of the Kulekhani I tailrace tunnel and the intake of the Kulekhani II are located in the Mandu *Khola* (Plate 62). During the night of July 19-20, cloudburst in the catchment of the Mandu *Khola* (around the village of Aghor) and the Bhimphedi *Khola* (around Chisapani) gave rise to debris torrents in the streams. The result was severe damage to the tailrace tunnel and intake site at the Mandu *Khola* and to the road, settlements, and cultivated land downstream. The village of Mandu was almost completely destroyed by landslides. A mother and her child were buried in a landslide and rescued after 24 hours.

A 15 m long and 10 m high 'Indreni' boulder of granite (Plate 63) was lying about 25m upstream from the intake canal of the Kulekhani II, hence it did not contribute directly to the destruction. Other old boulders of smaller dimensions (6-10 m long) were observed on the terraces downstream, indicating similar debris flow in the past.

The road between Bhainse and Bhimphedi was almost completely washed away and numerous landslides occurred on the slopes.

*Damage by the Manohari Khola*

The Manohari *Khola* (Plate 65) breached the dykes about 150 m downstream from the bridge on the East-West Highway and entered into the cultivated land of the Chitwan Valley.

Further downstream, the Burhi Rapti *Khola* also shifted its course, resulting in extensive damage to villages and cultivated land.

## Conclusions

The number of landslides and the extent of inundation during the rainstorm from July 19-21, 1993, were extraordinarily high for that region. There were more than 2,000 landslides along the Tribhuvan Highway alone. Apart from heavy rainfall; inadequate design of the barrage; inappropriate location of the powerhouse and the penstock; as well as deforestation; steep slope cultivation and encroachment on to highly hazardous areas were other factors leading to the heavy loss of infrastructure, lives, and property. On the other hand, the Kulekhani Dam acted as a retention structure and played a positive role during that event. Steep rock slopes followed by a flat valley provided ideal conditions for the occurrence of debris torrents and flash floods. Floods and torrents led to the forming of alluvial fans. Some of the alluvial fans seem to be active from time to time. For example, the debris flow in the Kitini Khola alluvial fan also occurred about 41 and 78 years ago.

In the hills of the country, natural slopes have been modified by the people without sound knowledge of their stability. In other instances, infrastructures have been designed without taking the extent and power of natural processes into account. Hence, it is clear that the extensive damage was exacerbated by them.

PART III

# Assessment of Land Use Changes and Their Impact

### An Introduction to Land Use

On the basis of **use intensity** the land in the area can be divided into two types -- *charchit* (used) and protected or inaccessible forest land (Fig. 3.1). *Charchit* land can be divided into three subtypes on the basis of use. They are agricultural land, pastoral land, and accessible degraded forest. These *charchit* lands, apart from *galbari* (fertile alluvial land) *tar* (river terraces), and *gairibari* (gently sloping unirrigated [*pakho*]) are more susceptible to landslide hazards than protected or inaccessible forest lands. Agricultural land can again be divided into two types on the basis of its production potentials or the land system; i.e., (i) marginal and (ii) productive land. Marginal lands can also be divided into three principal types - *bagar*, *dhaden*, and *bhote khorea*. *Bagar* is an active floodplain which is covered mostly by cobbles, pebbles, and sands. Old to recent fans, which are formed by materials brought by debris flow, locally known as *dhaden*, are composed of large boulders, cobbles, and pebbles. Cultivated steep slopes are called *bhote khorea*. Because of the very steep slopes, ploughing with oxen is not possible. All these marginal lands are vulnerable to landslides and flood hazards.

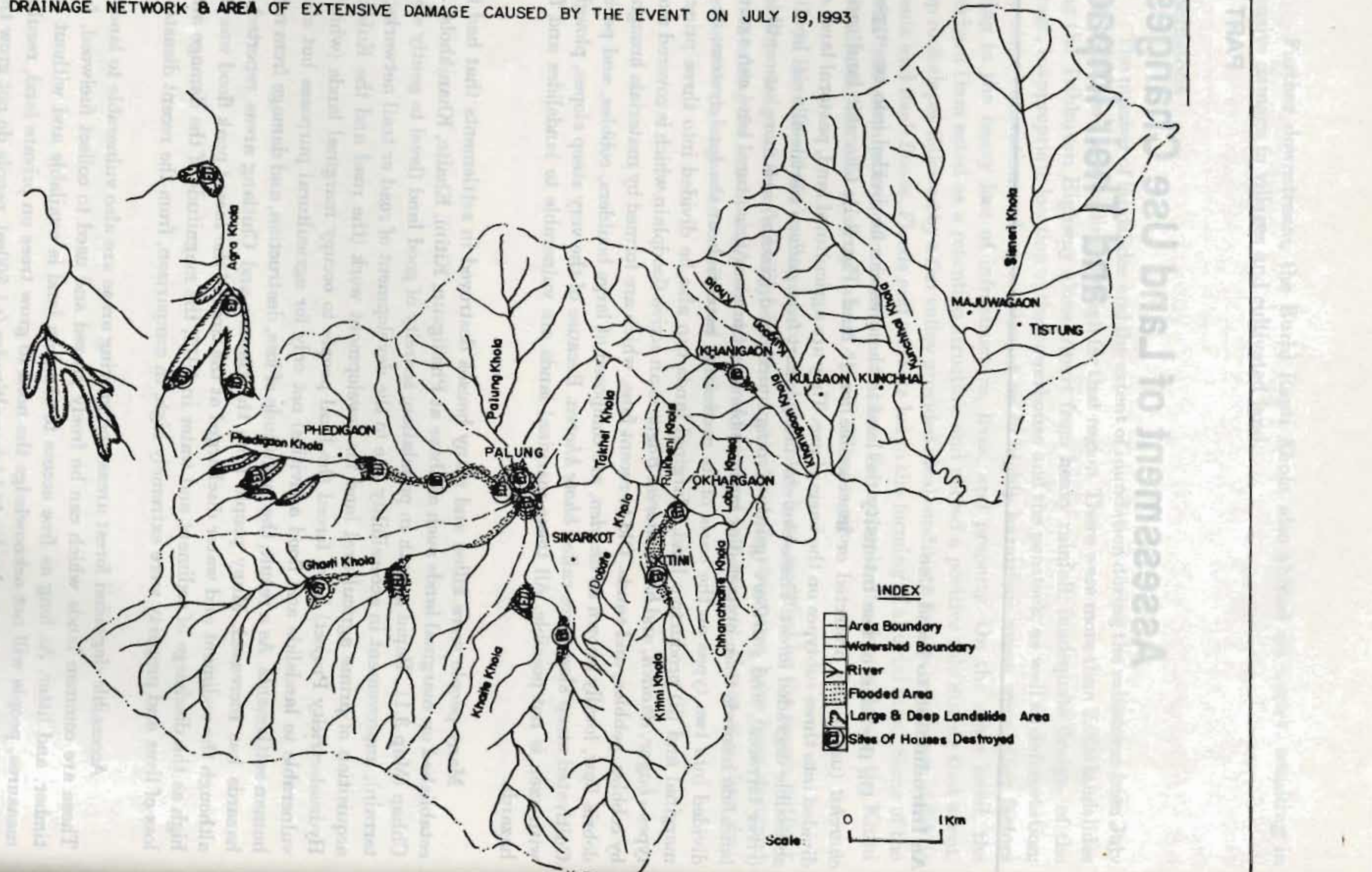
Many people were killed and many houses destroyed in settlements that had been established on marginal lands such as those at Phedigaun, Kitini, Khaite, Khanikhola, and Chhap (Map 3.1). Rapid growth in population; scarcity of good land (level to gently sloping terrain); improvement in accessibility due to the development of road or trail networks; and acquisition of prime agricultural land for development work (the road and the Kulekhani Hydroelectricity Project) have forced the local people to occupy marginal lands (which are vulnerable to landslide and flood activities) not only for agricultural purposes but also for human settlements. As a result, the magnitude of loss, destruction, and damage from natural hazards has increased. Many people from the Daman and Chitlang areas reported that, although the sediment and water discharged at the time of the recent peak flood was not as high as the discharge of sediment and water in 1915, the magnitude of the damage and the loss of lives and property were extremely high, in comparison, from the recent disaster.

Accessible degraded forest areas and grazing areas are also vulnerable to landslides. These are common lands which can be freely grazed and used to collect fuelwood, fodder, timber, and litter. As long as free access to common land is available and without control measures, people will not acknowledge the need to grow trees on private land, resulting in more pressure on common lands. At higher altitudes (>1,500m), people do not grow trees in maize fields. They state that "maize under the trees and a son in debt" are not productive. Because of free access to common lands, the people are not under pressure to change their cropping practices nor to plant trees on private land.

Map 3-1

DAMAN, PALUNG , TISTUN AREAS

DRAINAGE NETWORK & AREA OF EXTENSIVE DAMAGE CAUSED BY THE EVENT ON JULY 19, 1993



In order to reduce the use intensity of common land and eventually to minimise the damage from hazardous events, it is essential to encourage local people to plant permanent tree crops instead of maize crops, particularly on very steep mountain slopes (>30°), on the one hand, and to develop a community forestry programme on common lands on the other.

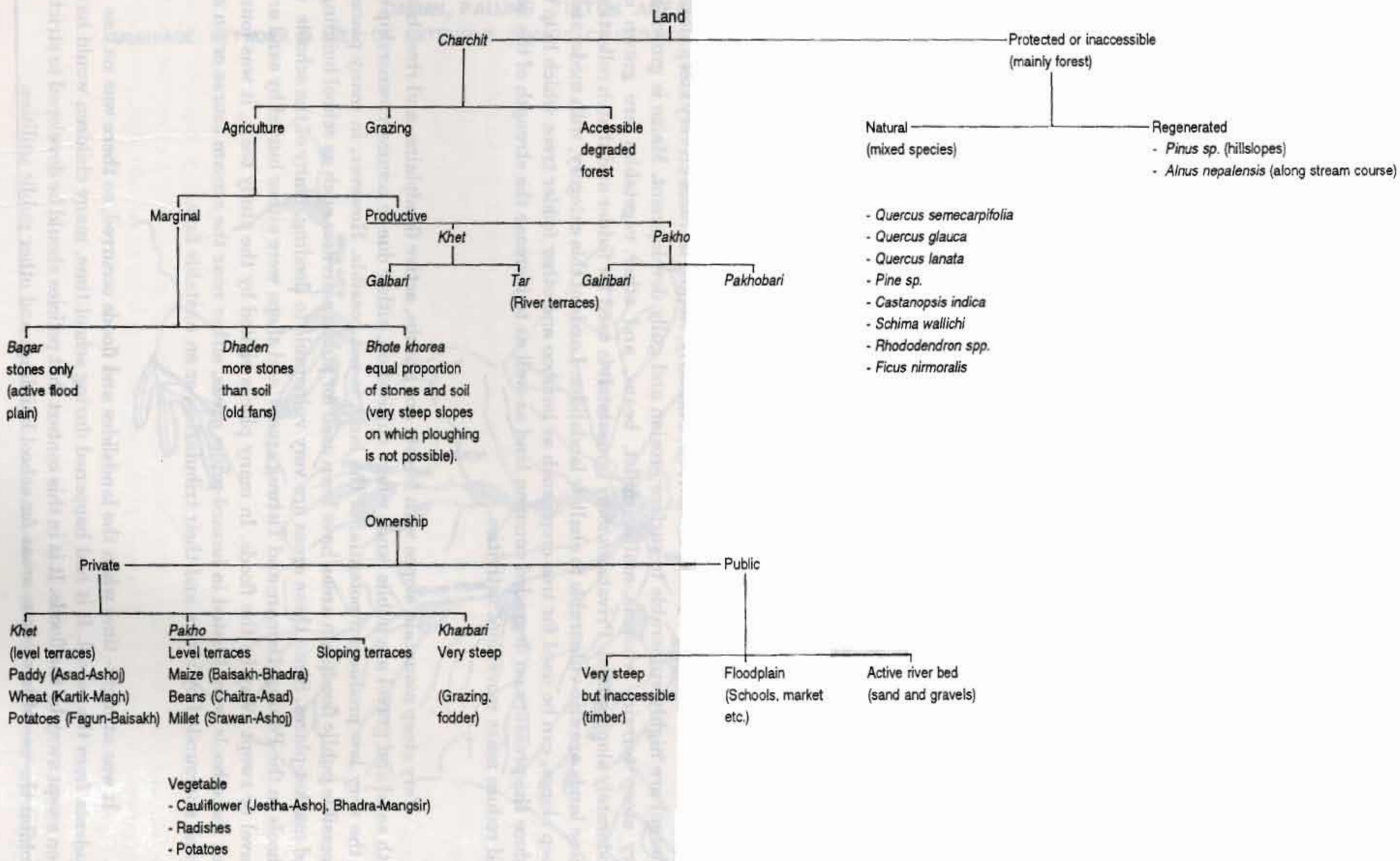
In protected or inaccessible forest areas, it is found that regenerated pine forest (both planted and protected) areas are much more vulnerable to landslide hazards than forests with mixed species, such as *Quercus* sp., *Castanopsis indica*, *Schima wallichi*, *Rhododendron* spp and *Ficus* spp, which have dense and deep root systems and where the undergrowth of other species is high. In pine forests there is no undergrowth, resulting in high surface runoff, gullies, and landslide scars. Tree species, such as pine and *Alnus nepalensis*, need less water and nutrients and grow more rapidly than other species. It is in this context that emphasis has been given to planting these species by the forestry development agencies working in this area, in order to achieve good results (to show greenery in the area) within a short period. The present afforestation strategies should be reviewed and emphasis should be given to mixed species rather than pine in order to minimise the damages of rainfall.

On the basis of **ownership**, the land can be divided into two types- private and public (Chart 3.1). Private land can be divided into three major types - *khet*, *pakho*, and *charbari* (grassland). *Khet* is irrigated land on which paddy, wheat, potatoes, and vegetables are grown. Except in places where rivers have shifted their channels, no major damage was found on this land. *Pakho* can be divided into two types - level terraces and sloping terraces. Both level terraces and sloping terraces on very steep natural slopes (>30°) are much more vulnerable to landslides. Many of the landslides occurred on very steep *pakho* where the risers are very high and the widths of the terraces are narrow. Similarly, sloping terraces on very steep slopes (*khorea*) are highly vulnerable to surface erosion and gully development. Maize is grown on very steep terrain, whereas maize, millet, beans, and other vegetables are grown on moderately sloping land. Private *khabari* (grassland) is used for fodder and thatch collection. These lands are also vulnerable to shallow landslides. Lands of this category, with moderately steep slopes, can be used for tree crops such as bamboo and other fodder trees which help to reduce the pressure on degraded common land as well as to increase the strength of the soil and reduce mass movement activities.

Very steep mountain slopes with forests and shrubs, active floodplains, and river beds with sand and gravel are public lands where cultivation, either due to common ownership or to the very low production potential of the land, is not possible. However, in many places, accessible public floodplain areas have been used for public activities such as school buildings and market-places. Since these areas are very vulnerable to flooding, many of the schools (6 schools in the Palung, Daman, and Tistung areas) and shops were either buried by sand and gravel or swept away by the floods. In many places visited by the study team, it was found that the schools were located in hazard-prone areas, either near the stream course or on an island surrounded by rivers and their tributaries, or on unstable fans.

It was at night- time when the landslides and floods occurred, so there was no loss of students from the school. If it had happened during school time, many children would have been swept away by the floods. It is in this context that policies should be developed to strictly prohibit the use of hazardous areas for school buildings and other public utilities.

## CHART 3.1: LAND TYPES AND THEIR USES



**Land, Land Use, and Landslide Activities in the Daman-Palung Area**

An attempt was made to count the number of landslides by major land-use types, as accurately as possible, in 14 sub-watersheds in the Daman-Palung Area at the time of field work. The basin area of these watersheds and areas, according to principal land use types, was calculated from the toposheet (1:50,000) and Land Utilisation map (1:50,000), prepared by the Land Resources' Mapping Project based upon air photographs taken in 1979 and the changes identified at the time of the current field work. The result is presented in Table 3.1. The frequency of landslides in these watersheds ranges from only 15 per square kilometre in Phedignun *Khola* to 151 per square kilometre in the Takhel *Khola* watershed with an average of 47 landslides per square kilometre. A similar picture of landslide densities was reported from the Lele watershed (46 landslides per square kilometre), triggered by the cloudburst on September 30, 1981 (Manandhar and Khanal 1988). It should be noted that only the frequency of landslides was counted, without keeping in mind their magnitude in terms of length, depth, and width, and this only indicates the extent of the degradation of land by its use type rather than the actual rate of overall degradation of mountain slopes. Landslides located in drainage depressions, seepage hollows, and along major streams were found to be very large and deep, producing a huge volume of materials and destroying large areas on the footslopes and floodplain areas. For example, although the frequency of landslide scars per unit of area is comparatively very low in the Phedignun watershed, the volume of sediment produced by these landslides was much higher. The loss of lives and property in lowland areas was significantly higher than in the Takhel *Khola* watershed where the frequency per unit of area is very high, where most of the landslides are small and shallow, and the loss of lives and property is comparatively very low.

**Table 3.1 Frequency of Landslides by Land Use Types**

| Name of watershed | Total no. of landslides | No. of landslides per km$^2$ | Cultivated land per km$^2$ | Grazing shrub degraded forest (per km$^2$) | Forest |
|---|---|---|---|---|---|
| Phedigaun | 85 | 15 | 8 | 80 | 20 |
| Gharti *Khola* | 175 | 19 | 4 | 101 | 11 |
| Palung *Khola* | 95 | 24 | 10 | 63 | 3 |
| Takhel *Khola* | 168 | 151 | 126 | 212 | na |
| Rukbeni *Khola* | 35 | 58 | 30 | 82 | na |
| Lobu *Khola* | 106 | 103 | 53 | 483 | na |
| Khaite *Khola* | 153 | 23 | 12 | 100 | 19 |
| Dobate *Khola* | 23 | 20 | - | 105 | na |
| Kitini *Khola* | 134 | 67 | 28 | 140 | na |
| Chhanchhane *Khola* | 144 | 127 | 57 | 216 | na |
| Khanigaun *Khola* | 441 | 136 | 137 | 156 | 54 |
| Kulgaun *Khola* | 148 | 86 | 60 | 200 | na |
| Kunchhal *Khola* | 355 | 102 | 86 | 209 | na |
| Sisneri *Khola* | 421 | 37 | 47 | 39 | 11 |
| Average | | 69+47 | 47+42 | 168+102 | 20+16 |

Source: Field Survey

The density of landslides on cultivated land ranges from less than four per square kilometre in Dobate *Khola* and Gharti *Khola* watershed, where valley cultivation and footslope cultivation are comparatively intensive, to 127 per square kilometre in Takhel and 137 per square kilometre in Khanigaun *Khola* where the proportion of sloping terraces on steep slopes is very high. The number of landslides per unit of grazing land, including shrubland and degraded forests (with crown densities of less than 40%), is significantly high, ranging from 80 landslides per square kilometre in Phedigaun to more than 200 in Lobu *Khola*, Takhel *Khola*, Chhanchhane *Khola*, Kulgaun *Khola*, and Kunchhal *Khola* watersheds. The number of landslides per square kilometre of forest area (crown densities >40%) ranges from three in Palung *Khola* watershed to 54 in Khanigaun *Khola* watershed. On an average, the number of landslides per square kilometre of land ranges from 47 with a standard deviation of 42 on cultivated land to 168 with a standard deviation of 102 on grazing land, including shrubland and degraded forest areas, and 20, with a standard deviation of 16, in dense forest areas. Overgrazed areas, including grazing land, shrubland, and accessible degraded forest areas are much more vulnerable to shallow landslides than inaccessible, dense forests with mixed tree species and cultivated land. However, the number of landslide scars, even on cultivated land on steep hillslopes, and particularly on sloping agricultural fields, is very high.

A detailed study was carried out on four hectares of maize fields in the Kunchhal area and the results are presented in Table 3.2.

**Table 3.2: Landslides in a *Pakho Bari* (maize field) near Kunchhal Village**

1. Total area of the study plot : 3,9732 square metres (3.9732 ha)

2. Size of the Landslides:
   Range: 1.25-787 square metres
   Mean : 109 square metres

| Size class: | Size | No. of landslides | Percentage |
|---|---|---|---|
| | <20m² | 23 | 47 |
| | 20-59 | 8 | 16 |
| | 60-99 | 2 | 4 |
| | >100 | 6 | 33 |
| | Total | 49 | 100 |

3. Total area occupied by landslides: 5325.37 square metres
4. Percentage of area covered by landslides: 13.4
5. Total volume of materials eroded: 7676.19 cubic metres
6. Average volume of materials eroded from one landslide: 156.7 cubic metres
7. Total volume of materials transported from the area: 4771.29 cubic metres
8. Soil loss from the study plot: $0.12m^3/m^2$ or $1201m^3/ha$

9. Natural slope of the landslide area: >30°

| Slope category | No. of Landslides |
|---|---|
| 30-35° | 24 |
| 36-40° | 23 |
| >40° | 2 |

Source: Field Survey

There was a total of 49 landslides with sizes ranging from 1.25 square metres to 787 square metres. The average size of these landslides was 109 square metres. Out of these 49 landslides, the average size of 23 landslides was less than 20 square metres, whereas the average size of 16 landslides was more than 100 square metres. The natural slope of these landslides was more than 30°. Hillslopes of more than 40° have been brought under cultivation, and these lands were found to be much more vulnerable to landslides. Nearly 13 per cent of the total maize field is occupied by landslides. Nearly 7,676 cubic metres of soil was removed from the terraces of which 4,771 cubic metres ( 62%) was transported from this area. In this way nearly 1,201 cubic metres of soil were eroded from one hectare of maize field because of this single event. The heights of the risers of such maize fields ranged from 1.3m to 4.5m, with an average of 2.5m, and the widths of the terraces ranged from 1.9m to 5.7m, with an average of 3.2m.

The area occupied by landslide scars was found to be slightly higher, i.e., 18 per cent on agricultural and grazing land in Lobu *Khola* watershed near Okhar *Bazaar*.

An attempt was also made to examine whether there is a relationship between the density of landslides and geology and land use types. As mentioned earlier, the study area consists of two major geological units - one of more resistant granite in the south west of Palung *Khola* and another of less resistant rocks of slate, quartzite, phyllites, and marble. The number of landslides observed and the area of different rock types are presented in Table 3.3. The number of landslides per square kilometre of land as a whole is 47, whereas it is only 31 in the granite area and 57 in areas with comparatively less resistant rocks such as slates, quartzite, phyllites, and marble. Although the frequency of landslides per unit of land is comparatively very low in the granite area, the size of boulders in the river bed in this area is comparatively very large compared to the size of boulders in the area of slates, quartzite, phyllites, and marble, and most of them have round shapes.

**Table 3.3: Frequency of Landslides and Geology**

| Geology | Total no.of landslides | Area $km^2$ | No of landslides per $km^2$ |
|---|---|---|---|
| Granite | 629 | 20.26 | 31 |
| Slate,quartzite, phyllites, and marble | 1854 | 32.27 | 57 |
| Total | 2483 | 52.53 | 47 |

$x2$ value: 4.71

Source: Field Survey

The percentage of grazing, shrub, and degraded forest on the total land area; percentage of hillslope cultivation on the total cultivated land area; percentage of sloping terraces on cultivated hillslopes; percentage of degraded forests in total forest land; percentage of shrubland and pine forests in total forest and shrubland, which are thought to be much more vulnerable to landslide scars, its average score by watersheds; and the frequency of landslides per square kilometre are presented in Table 3.4. It indicates that there is a close relationship (with a correlation coefficient of 0.77 ) between the average score of these land use parameters and the frequency of landslides. It is in this context that, if the land is managed properly, the magnitude of damage can be minimised.

**Table 3.4: Frequency of Landslides and Land-use Characteristics**

| Watersheds | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Phedigaun | 5.71 | 15 | 84 | 9 | 7 | 66 | 100 | 55 | 0 | 46 |
| Gharti *Khola* | 9.42 | 19 | 36 | 11 | 53 | 62 | 11 | 17 | 11 | 22 |
| Palung *Khola* | 3.94 | 24 | 49 | 29 | 22 | 81 | 100 | 57 | 54 | 64 |
| Takhel *Khola* | 1.11 | 151 | 70 | 30 | 0 | 94 | 100 | 100 | 100 | 85 |
| Rukbeni *Khola* | 0.60 | 58 | 45 | 55 | 0 | 28 | 100 | 100 | 100 | 77 |
| Lobu *Khola* | 1.03 | 103 | 88 | 12 | 0 | 74 | 100 | 100 | 100 | 77 |
| Khaite *Khola* | 6.56 | 23 | 23 | 8 | 70 | 87 | 0 | 10 | 100 | 41 |
| Dobate *Khola* | 1.15 | 20 | 81 | 19 | 0 | 58 | 0 | 100 | 100 | 55 |
| Kitini *Khola* | 2.0 | 67 | 65 | 35 | 0 | 71 | 0 | 100 | 100 | 61 |
| Chhanchhane | 1.13 | 127 | 55 | 45 | 0 | 79 | 0 | 100 | 100 | 65 |
| Khanigaun *Khola* | 3.19 | 138 | 53 | 40 | 7 | 100 | 100 | 84 | 84 | 82 |
| Kulgaun *Khola* | 1.72 | 86 | 81 | 19 | 0 | 100 | 100 | 100 | 21 | 68 |
| Kunchhal *Khola* | 3.47 | 102 | 80 | 14 | 0 | 81 | 100 | 100 | 100 | 79 |
| Sisneri *Khola* | 11.5 | 37 | 50 | 27 | 23 | 66 | 100 | 54 | 59 | 61 |

1. Basin area in square kilometres
2. No of landslides per $km^2$
3. Percentage of cultivated land
4. Percentage of grazing land including shrub and degraded forest (crown densities of less than 40%)
5. Percentage of dense forest (crown densities of more than 40%)
6. Percentage of hillslope cultivation in total cultivated land
7. Percentage of sloping terraces in total hillslope cultivation
8. Percentage of degraded forest in total forest area
9. Percentage of pine forest, including shrubland, in total forest area
10. Average score of 4,6,7,8, and 9.

Correlation coefficient between the frequency of landslides (2) and use type (10): 0.77

Source: Field Survey and Land Utilisation Map prepared by LRMP

## History of Land-use Change

Increasing demands for fuelwood, fodder, and timber, as well as for land for agricultural use and housing as a result of population growth have been leading to encroachment on to forest and marginal lands such as very steep hillslopes, active floodplains, and unstable fans. In addition, development works, such as the construction of the Tribhuvan Highway and the Kulekhani dam, and the establishment of a horticultural farm in the area, have also led to encroachment on to very steep slopes for cultivation and on forest land for timber, firewood, and fodder. It was reported that deforestation, as well as degradation of, natural forests, commenced in 1952 when the feasibility study for the Tribhuvan Highway was carried out. Before then, there was a dense religious forest of mixed species, known as the forest of Mahadev-Parbati, in the Chhanchhane *Khola* watershed. It was protected by the local people. No one was allowed to cut green trees from this forest. At the time of the feasibility survey, when the army entered the forest to collect firewood, the local people could not protect it. As a result, the traditional system of protection broke down and the forest was open to all the local people and was converted into shrubland. Similarly, many forest areas along the highway began to deteriorate from this time.

The horticultural farm was established at Daman in 1960. Nearly 72 ha of previously forested land (before 1960) was cleared for horticultural activities. It led to an increase in pressure on the remaining forest land for fuelwood, fodder, and timber.

Quite a large area of fertile agricultural land was inundated after the construction of the Kulekhani Hydroelectricity project. Although the project had provided land compensation to local people, these people could not migrate to other places with the money they had received. They were forced to settle and encroach on very steep slopes and forest land in nearby areas.

Local people used to collect medicinal plants and herbs and export them to India. According to them, nearly 50 full trucks of these medicinal plants were exported to India annually. The principal plant species include *majhito* (*Rubia cardifolia*), *chiraito* (*Swertia chiraito*), *pakhanbed* (*Bergenia Pigulata*), *jeewanti* (*Demotrichum tibritum*), *kutki* (*Picrorhiza kurroa*), *archuro*, *panisaro*, *kurilo*, *thunke*, and *jhyau* (*Lichenes* spp). The principal species on which lichens grow are *Quercus* spp., *Castanopsis indica*, and *Lithocarpus grandifolia*. In order to collect lichens one has to climb the tree and rather than doing that people would cut down the branches as well as the trees. Thus, uncontrolled collection of these medicinal plants and herbs has led to the degradation of natural forests in the area. It was reported that forest fires are frequent in the Mahabharat Range, causing degradation to forest resources. It was also reported that a large forest fire last year caused the accelerated decay of tree roots, decreasing the cohesive strength of the soil and hence leading to many landslides at the time of high precipitation.

**Summing Up**

Mountain precipitation is very complex and varies a great deal with time and space. Landslides and flood hazards associated with high intensity precipitation are not uncommon, although their impact is confined to small areas. There were two different, very high intensity precipitation events with recurrence intervals of from 80 to 150 years. The area coverage of such high intensity rainfall ranges from 500 to 800 square kilometres. Damage by landslides and flood hazards generated by high intensity precipitation was not confined to the upper catchment area where the high intensity precipitation occurred. It caused damage at least 60km downstream. The natural and man-made causes that triggered the recent hazards and damages are summarised in Chart 3.2.

It is evident that apart from high intensity precipitation, geological and tectonic activities; climatic factors, such as a wide temperature range as well as the drainage pattern network (sharp bends in channels and the merging of tributaries with the main river more or less at right angles); and the steep channel profile are other natural factors still responsible for triggering the hazards and the magnitude of the damage.

## Chart 3.2: FACTORS WHICH ARE RESPONSIBLE FOR TRIGGERING THE DISASTER OF JULY 19 AND 20, 1993

**Main Cause**: Climatic (high intensity rain with recurrence intervals from 80 to 150 years).

**Other Causes**

| Natural | Others |
|---|---|
| **Geologic:-** Tectonically very active mountain systems (the mountains are rising, resulting in very steep slopes and intensifying down-cutting activities as well as reworking previously deposited materials along the streams. Most of the large, deep landslides are located along the stream and recently formed fans are more vulnerable).<br>- Structure (jointing systems of rocks caused to produce large boulders). | - Encroachment on marginal and forest land due to rapid growth in population (cultivation on very steep slopes up to 45° and maize-based, subsistence agriculture).<br>- Free access to common lands (no need to grow trees on farmland).<br>- Deforestation and frequent forest fires.<br>- Lack of long-term experiences about the environment in recently habitated areas, particularly in *Churia*, *Bhabar*, and the inner *terai* region.<br>- Emphasis on result-oriented programmes in forestry (*Pinus* spp and *Alnus nepalensis*). |
| **Climatic:-** High range in seasonal temp. (very cold winters with frost and snow and hot summers). | - Construction of private and public buildings on unstable land, particularly in accessible areas without keeping in mind the possible risk of hazards that could be occur frequently.<br>- Abstraction of sand and gravel along streams. |
| **Drainage Network:-** Sharp bend in the river course, cause of partial damming and deposition of bed materials resulting in flooding.<br>- Areas where tributaries are merging in more or less at right angle are much more vulnerable to the flood. | - Development activities such as -<br>- Horticultural farms (previously forested area).<br>- Kulekhani hydro project (forced people to encroach marginal land).<br>- Road construction (pressure on forests).<br>- Quarrying on steep slopes and on steep river banks along the stream (rise in bed level causing lateral erosion).<br>- Lack of records about such information and lack of their application in designing major construction works (Bagmati barrage, penstock, checkdam on the Rapti and many bridges). |
| **Cumulative Effect of Past Events:-** Earthquakes, precipitation and landslide activities in the past (reinitiation of landslides). | - Lack of communication systems (information exchange and warning).<br>- Lack of scientific investigation of such events in the past. |

These mountains are rising, resulting in very steep slopes and intensifying the down-cutting activities, as well as reworking the previously deposited materials along the streams. It should be noted that high intensity precipitation, although small in magnitude, and the size of the area covered are common before such disasters. Cracks and landslides occur on the mountain slopes and, in such situations, mass movement activities are inevitable. These natural factors cannot be controlled or improved through human efforts. However, there are other factors that are responsible for triggering the hazards. These include deforestation; encroachment on marginal lands (very steep slopes, active floodplains, and fans), even for housing; unmanaged quarrying; and extraction of sand and gravel from the river bed. It should be noted that many of the settlements and houses that were destroyed by the recent event in the mountain areas (both in the Churia and Mahabharat areas) were new (within 40 years) and were located in hazard-prone areas (fans or floodplains, or near drainage depression areas, or on very steep mountain slopes). Although agricultural fields were also damaged substantially by this event, most of these fields can be repaired or reconstructed within a two- to three-year period, which is not the case for the other damage incurred.

There is little information on the environmental consequences of natural hazards (both geologic and climatic), and there is no government agency responsible for monitoring the watershed conditions and identifying potential hazard areas and warning systems. Flood-warning systems have not yet been developed. It took two to four hours for the peak flood to arrive from Bhimphedi (the high intensity precipitation area) to Bhandara and Kumroj (Chitwan) in the downstream area. If information about the flood had been communicated more speedily, the loss of life and property would have been minimised. People living in the downstream reaches from the Kulekhani dam site are concerned about the timings of the opening and closing of the dam gates, since there is no system by which this information is communicated to them.

It was also found that development projects, such as road and dam construction, and activities which are confined to forest areas, such as the horticultural farm at Daman, had neglected the environmental consequences of their activities in the past. Efforts of the forestry as well as of the agricultural development projects in the area to improve watershed conditions were found to be ineffective in minimising the impact of the event, because of their result-oriented (rather than sustainable) development programmes.

Construction of infrastructure without proper understanding of the geohydrological processes, particularly the discharge of water and sediment and discharge types, has also led to hazardous activities. For example, if the designer of the Bagmati barrage had known the size and the volume of logs that could be brought down by the river, there would have been no damming and floods would not have been so big in the downstream reaches. Similarly, if the engineer had known the size of the boulders, that could be brought down by the Jurikhet *Khola*, he would have constructed a tunnel to protect the penstock pipe from debris flow instead of constructing two checkdams in the upper reaches.

There is no scientific investigation into the magnitude and consequences of the big events occurring in the past in other areas of the country. Exchange of information among the development agencies, as well as among independent researchers, is poor. It is still difficult for interested independent researchers to find the hydrometeorological records of a particular event.

It should be noted that the discussion presented earlier is based on a relatively short field visit and consequently some of the conclusions are tentative, to be confirmed by further research in the future. However, in spite of various limitations, a number of issues can be identified for future action.

Because of the inherently unstable nature of mountain areas, the probability of hazardous events is very great. Reports by local people also suggest that hazard events of varying intensity have occurred quite frequently. These events will also definitely continue to occur in the future because of the nature of the environment. The present level of understanding and analysis of these natural events are very poor. No database exists. No monitoring activities are carried out on a regular basis, even in cases where such monitoring can be of direct benefit to project-related management activities.

Not all natural hazards necessarily become natural disasters. A natural hazard turns into a natural disaster when these naturally occurring hazards result in heavy loss to human lives, property, and other economic assets. This happens when human activities, on account of limitations of knowledge, resources, capacities, and alternatives, take place in natural hazard zones. Different types of natural hazards have different types of spatial manifestations, and once these are occupied by human activities, these naturally become subject to such events. The fact that a natural hazard area has been occupied increases the probability of a natural hazard becoming a natural disaster, depending upon the extent to which precautionary measures are affordable and are actually taken.

In the present case of the natural events of July 19 and 20 in the southern parts of the Central Development Region, the fact that different types of natural hazards occurred was not surprising nor unknown. Recent histories of such events are still quite vivid in people's memories. The fact that they turned quickly into a natural disaster of catastrophic proportions has a lot to do with human decisions and activities in and along the natural hazard zones in the area. Ironically, while some interventions undertaken to provide protection from such events failed and resulted in even greater damage, because of a number of critical oversights in technical decisions, other losses of economic assets were the result of technical incompetence in coping with fairly predictable and recurring natural events. No specific examples are provided because these initial indications need to be validated by a thorough technical enquiry of all the major physical assets that were damaged and destroyed during the recent natural events of July 19 and 20.

PART IV

# Overall Assessment and Needed Action

## The Workshop

### *Objectives*

The main objective of the workshop was to identify concrete measures for better flood and landslide disaster preparedness and mitigation in Nepal.

More specifically, it was (a) to synthesise the relevant and available information on different aspects of the recent floods and landslide disasters in Nepal, (b) to promote inter-agency dialogue and review of the events in order to develop a better understanding of the factors and processes involved, and (c) to identify concrete short- and long-term measures needed on different levels, by various agencies, for better disaster preparedness and mitigation.

### *Preparatory Activities for the Workshop*

(i) ***Reviews and Assessments***
- Evaluation of land-use changes and their possible impact.
- Assessment of hydrological factors and conditions and their impacts on the concerned areas.
- Landslides, debris flows, and geological conditions and their interrelationships with land use and hydrology.
- Identification of upstream and downstream linkages.
- Assessment of infrastructural damages and their possible causes (to be prepared by different sectoral line agencies).
- Critical assessment of institutional responses in post-disaster management.

(ii) ***Preparation of maps showing different events and their effects.***

(iii) ***Preparation of photo-documentation on various aspects of the natural disaster.***

### *Workshop Schedule*

The workshop was organised by ICIMOD from November 22nd to 23rd, 1993. All the concerned agencies of His Majesty's Government, a number of donor agencies, and ICIMOD participated in this workshop. Presentations were made of the different field reports, and these were extensively discussed. Different working groups were organised to identify priority areas for future attention. The following section discusses the issues identified during the discussions and by the working groups. The workshop programme and the participants have been provided in Appendices 4.1 and 4.2. Appendix 4.3 contains a selection of maps related to infrastructural installations, human and animal losses, and land affected by the disaster.

## Overall Assessment

The inherently unstable nature of mountain areas has been well recognised. Past occurrences of natural hazards, as reported by the local people, also suggest that hazard events of varying intensity have occurred quite frequently. These events will also continue to occur in the future because of the nature of these environments. The present levels of systematic understanding and analysis of these natural events are very poor. No data base exists. No monitoring activities are carried out on a regular basis, even in cases where such monitoring can be of direct benefit to project-related management activities.

Not all hazards necessarily become natural disasters. A natural hazard turns into a natural disaster when these naturally occurring hazards result in heavy losses of human lives, property, and other economic assets of society. This happens when human decisions (because of limitations of knowledge, resources, capacities, and alternatives in natural hazard zones) result in interventions. Different types of natural hazards have different types of spatial manifestations, and, once these are occupied by human activities, they naturally become influenced by these events. The fact that a naturally hazardous space has been occupied increases the probability of a natural hazard becoming a natural disaster in such locations/areas, depending upon the extent to which precautionary measures are actually taken. These measures are concerned with appropriate land use practices, construction of suitable structures, increasing awareness of potential natural hazards in hazard-prone areas, more comprehensive assessment of watershed conditions and their implications for development activities, and incorporation of these considerations into development projects and different economic activities.

In the present case of the natural events of July 19 and 20 in the southern parts of the Central Development Region, the fact that different types of natural hazards occurred was not surprising, nor unexpected. Recent histories of such events are still quite vivid in people's memories. The fact that some of these had become natural disasters of catastrophic proportion has a lot to do with human decisions and activities in and along the natural hazard zones in the area.

Some of the important human activities identified in this context were:

a) expanding cultivation on to steeper slopes;
b) increasing settlements on floodplains with no protection measures;
c) continuing deforestation of upper slopes;
d) limited reforestation of exposed slopes;
e) unregulated mining activities along upper slopes and in upstream areas;
f) establishing vital structures in hazard-prone zones without adequate review of existing information, watershed conditions, and past experience, resulting in unsuitable locational decisions, inadequate standards, and poor maintenance;
g) limited sharing of available information regarding natural events and poor infrastructure for disseminating critical information about potential hazards; and
h) lack of continuing and systematic attention to the growing problems of different types of natural hazards and their mitigation.

## Recommendations

### *Organising a High-level Technical Review*

The Government needs to organise a high-level technical review of the damaged to bridges and dams to ascertain clearly the reasons for their vulnerability. If major technical problems were involved, these have to be corrected so that they are not repeated in future. If poor design standards were used, these need to be upgraded so that future infrastructure can be better protected. If maintenance was poor, the Government should be committed to providing more resources in future. Not doing anything about this problem will cost much more in the future to society. Incorporating geological, climatic, hydrological, and land-use information in the design of infrastructural installations would improve their resistance to natural hazards. More dialogue is also needed among engineers, scientists, and local people to improve their understanding of natural events and to formulate appropriate design standards for different types of structures. If one objective is to reduce the potential dangers to these infrastructures, the other problem is to reduce the potential dangers arising out of structures such as barrages and dams. If these are not properly managed, they could trigger major disasters. This review should look into these issues and provide appropriate guidelines and decisions for safeguarding these vital installations and providing protection from adverse effects of such structures.

### *Development of Settlement Location Guidelines*

With increasing human mobility, the settlement patterns in the country are undergoing major changes, and yet there is little understanding regarding the development and hazard risks of these settlements. Many of the settlements destroyed by the natural events were those established recently along floodplains and in landslide hazard areas. The people living in these areas have a right to know the type of risks they face. Knowledge of these risks might result in preventive measures being organised on a local basis. The generation of this knowledge is also dependent on the development of suitable hazard maps for use by local and project authorities.

### *Development of Hazard Maps*

As a long-term measure, it is recommended that a preliminary hazard map on a 1:50,000 scale be prepared for the critical watersheds of the country. The map should show the level of hazard (i.e., low, medium, and high) as well as the type of hazard (i.e., landslide, gully erosion, debris flow, flooding). The data should be based on the field observations as well as on the available maps and aerial photographs. For more critical areas, the maps should be on a 1:10,000, or larger, scale, especially in areas with settlements, roads, barrages, and other infrastructures. In these areas, an inventory map of the existing and past mass movements, and the risk associated with the hazard, should also be depicted. The need for a climatic atlas of Nepal was also pointed out, and this would also be a critical input into the hazard mapping process.

### *Preparation of Land-use Guidelines and Mobilising Local Support for Their Implementation*

Land-use problems are one of the most common and serious environmental issues throughout the hill areas of Nepal. Landslides, debris flows, slope failures, and increasing sediment loads in rivers are all directly traceable to the widespread mismanagement of land resources resulting from deforestation, increasing cultivation of steep slopes, overgrazing and inadequacy of soil and water conservation measures, and haphazard growth of settlements in highly vulnerable areas. The needed measures are complex and effects will be seen and felt only in the future. However, if no efforts are made to improve land-use conditions and identify hazard zones, the situation will worsen, increasing the probability of every natural hazard turning into a major natural disaster. Uncontrolled mining activities are already beginning to trigger major landslides in many parts of the hills. Land-use guidelines have to be developed so that fragile areas are protected and degraded lands are rehabilitated. No land-use guidelines can be implemented without the participation and cooperation of the local people. Hazard mapping must also be approached from the perspective of developing suitable land-use guidelines.

*Early Warning Systems*

Some efforts must be made to establish early warning systems in order to prevent large-scale damage from floods. The advantage of lead times available, if used to warn people downstream, can save many lives. The most appropriate systems and mechanisms available should be evaluated and specific water-management related projects should be made responsible for operating these systems. Local people in downstream areas should be made aware about the early warning signals.

*Environmental Rehabilitation Work*

Environmental rehabilitation activities can help to reduce the impact of future hazards, and some of the important activities which can be supported under local and rural development activities are the following:

a) promotion of sloping agricultural land technologies on sloping terraces;
b) promotion of agroforestry techniques using multiple tree species;
c) promotion of bioengineering techniques for soil and water conservation;
d) building of protective and diversion structures along floodplains based upon the historical perspective of flood events; and
e) providing support to different types of river control activities.

All of these activities can become important sources of employment for local people and contribute towards improving the environment in the long run.

*Public Awareness of the History of Natural Events*

Local people should be encouraged to be more familiar about the history of natural disasters in their areas. Local discussions should be organised to identify different protection measures that can be undertaken by the local people. The district government should undertake this as part of its regular development agenda. The various issues related to environmental management should be highlighted through different awareness-raising programmes. Special materials that are easily understood should be widely distributed to schools and other public places.

*Problem-oriented Research*

Specific problem - oriented research is needed to improve mapping methodologies for slope, alluvial fan, and flood areas; to develop performance guidelines for building and other activities; to prepare standards and techniques for retrofitting existing structures; to improve modelling capabilities to assess the nature of risks and the impacts of development; to assist communities in preparing disaster-mitigation plans; and to develop and test mitigation strategies other than planning and regulation (e.g., warning systems, dewatering of potential mudflow areas, debris basins, and land treatment after forest fires). Field studies should be regularly conducted after hazard events to determine the precise nature and types of losses and the adequacy of mitigation approaches.

Pilot studies that are rehabilitation focussed should be conducted by different agencies, in cooperation with local agencies, to assess the practicality and feasibility of particular approaches. Such pilot or demonstration projects could also help meet immediate "on the ground" needs if conducted in communities with severe problems.

The other aspect of research deals with the monitoring and analysis of regularly occurring events, e.g., the monsoon and its effects. Little is understood about the phenomenon of cloudbursts in specific areas.

*Information Networks and Coordination*

If inadequate information was one aspect of the problem, the other even more serious handicap has been the lack of knowledge and the failure to share available information. As no one agency can possibly provide all the relevant information, there is an urgent need to establish a network among related agencies to share information that is already available with respect to different natural events. Resources are being wasted through duplicated efforts and failure to use available information. An information network is, therefore, considered essential in order to facilitate information exchange and sharing among the different agencies concerned. The National Planning Commission should play a lead role in developing such a network of concerned agencies.

*Training in Natural Hazard Mitigation and Management*

Technical skills needed in different subjects and at various levels for natural hazard mitigation, monitoring, and management are still very limited in the country. A major effort is needed to improve these technical skills in many different areas such as slope stabilisation, watershed management, hydrological and geological assessments, and problems related to risk engineering in mountain areas. Concerned departments of the Tribhuvan University and the Government should organise regular short courses in these areas.

*Improvement in Hydrological and Meteorological Stations*

Although the number of hydrological and meteorological stations have increased in recent times, there is a pressing need for more stations with substantial improvements in facilities. These stations are the only source of basic hydrological and climatic information to become an essential planning input for all major development activities. More support is needed in order to improve the quantity and quality of these stations.

*Environmental Guidelines for Specific Projects*

All development activities in hazard prone areas should be subject to environmental screening (based upon guidelines) on a mandatory basis. This will involve some costs, but these will be more than compensated for through the increased life of the project. Not enough attention has been given in past discussions to different types of natural hazards arising out of extreme weather events and mass movements or out of the geomorphological characteristics of these mountain areas. Some of these considerations should be integrated into the project screening of environmental guidelines.

*Establishment of a Multidisciplinary, Hazard Mitigation Body*

A multidisciplinary, hazard mitigation body is necessary in order to ensure that disaster preparedness does not decline over time. In most cases, as the immediate shock of disaster wears out, there is decreasing commitment in terms of resources, attention, and institutional activities. Such a body should follow up on all the recommended measures if the level of preparedness is to improve over time. There is no doubt that natural hazards of varying intensities will occur from time to time in future at different places. While these events can hardly be controlled, their adverse effects can be contained through better awareness, planning, monitoring, and coordination of different activities. Such a body should function to facilitate the development of this capacity at different levels.

*More Effective Development Policies*

It is well recognised that the slow pace of development and the failure to control rapid population growth, reduce poverty, and diversify the economy are the main compulsions behind increasing cultivation on steep slopes, colonisation of floodplains, deforestation of hillsides, and many other related activities that enhance the probability of recurring natural hazards turning into major disasters. Unless the economy can provide sustainable economic alternatives and reduce population pressures, hazard mitigation efforts alone will be tantamount to treating the symptoms rather than the basic processes underlying increasing human colonisation of hazard-prone areas.

# Appendix 4.1
# Workshop Schedule

**Day One, November 22, 1993 Monday**

| | |
|---|---|
| 10:00 - 11:30 | First Session<br>Chairperson: Dr. B. Bhadra<br>Welcome by Dr. E. F. Tacke<br>General Description of Natural Events on July 19 and 20 - Mr. Narendra R. Khanal<br>Discussions<br>Chairperson's Summary |
| 11:30 - 11:45 | Tea Break |
| 11:45 - 01:00 | Second Session<br>Chairperson: Dr. B. Bhadra<br>Extreme Weather Events - Mr. Khadga B. Thapa<br>Discussions<br>Chairman's Summary |
| 01:00 - 02:00 | Lunch Break |
| 02:00 - 03:30 | Third Session<br>Chairperson: Mr. P.L. Shrestha<br>Geology and Mass Movement - Dr. M. R. Dhital<br>Discussions<br>Chairperson's Summary |
| 03:30 - 05:00 | Tea Break |
| 3:45 - 4:45 | Fourth Session<br>Chairperson: Mr. A.L. Joshi<br>Role of Land Use Change - Mr. Narendra R. Khanal<br>Discussions<br>Chairperson's Summary |

**Day Two, November 23, 1993 Tuesday**

| | |
|---|---|
| 10:00 - 12:00 | Working Groups on Specific Policy and Institutional Responses<br>Group I. Coping with Extreme Weather Events<br>Group II. Coping with Mass Movements<br>Group III. Improving Land Use |
| 12:00 - 02:00 | Presentation of Group Recommendations and<br>Discussions<br>Chairperson's Closing Remarks - Dr. B. Bhadra |
| 02:00 - | Lunch |

## Appendix 4.2
## Workshop Participants

### National Planning Commission

1. **Dr. Binayak Bhadra**, Hon'ble Member, NPC

### Climate and Hydrology

1. **Dr. S.P. Adhikary**, Director General, Department of Hydrology and Meteorology
2. **Mr. P.B. Shrestha**, Deputy Director General, Dept. of Hydrology and Meteorology
3. **Mr. Kiran Shankar**, Deputy Director General, Dept. of Hydrology and Meteorology
4. **Mr. L.M. Acharya**, Department of Hydrology and Meteorology
5. **Mr. Adarsha Pokhrel**, Department of Hydrology and Meteorology
6. **Dr. M.L. Shrestha**, Department of Hydrology and Meteorology
7. **Prof. K.B. Thapa**, Central Department of Meteorology, Tri-Chandra Campus Building, Tribhuvan University
8. **Mr. D.D. Mulmi**, Central Department of Meteorology, Tri-Chandra Campus Building, Tribhuvan University
9. **Prof. B. P. Upadhyaya**, Department of Meteorology, Tri-Chandra Campus Building, Tribhuvan University
10. **Mr. Lochan Devkota**, Department of Meteorology, Tri-Chandra Campus Building, Tribhuvan University
11. **Mr. S.P. Sharma**, SDE, DOI

### Geology and Mass Movements

1. **Mr. P.L. Shrestha**, Director General, Department of Mines and Geology, Lainchaur
2. **Mr. T.P. Adhikary**, Department of Mines and Geology, Lainchaur
3. **Dr. Toran Sharma**, N.E.S.S., Thapathali
4. **Dr. Megh Raj Dhital**, Central Department of Geology, Tribhuvan University
5. **Dr. B.N. Uprety**, Central Department of Geology, Tribhuvan University
6. **Mr. Pradeep Mool**, Water and Energy Commission Secretariat
7. **Dr. P. Hoppe**, Department of Mines and Geology
8. **Mr. H. Oi**, JICA, CTA, D. P. T. C.
9. **Mr. Kiran Raj Poudyal**, Department of Mines and Geology
10. **Dr. D.R. Kansakar**, Department of Irrigation
11. **Mr. Barun Shrestha**, Director General, Department of Roads
12. **Prof. D.F. (Dough) Vandine**, Geologist, Canada
13. **Dr. Hiroshi Yamomoto**, Shikoku, Agri. Exp. Station, Japan

### Land Use

1. **Mr. A.L. Joshi**, Director General, Department of Soil Conservation and Watershed Management
2. **Mr. D.P. Parajuli**, Director General, Department of Forests
3. **Dr. Jibgar Joshi**, Deputy Director General, Department Housing and Physical Planning
4. **Mrs. Ram Badan Pradhan**, Department of Agriculture
5. **Dr. Mahesh Banskota**, ICIMOD
6. **Mr. Balaram Bhatta**, ICIMOD
7. **Mr. P.B. Shah**, ICIMOD
8. **Mr. Narendra R. Khanal**, Tribhuvan University
9. **Mr. Durga Bahadur Dura**, Bagmati Watershed, Soil Conservation Officer

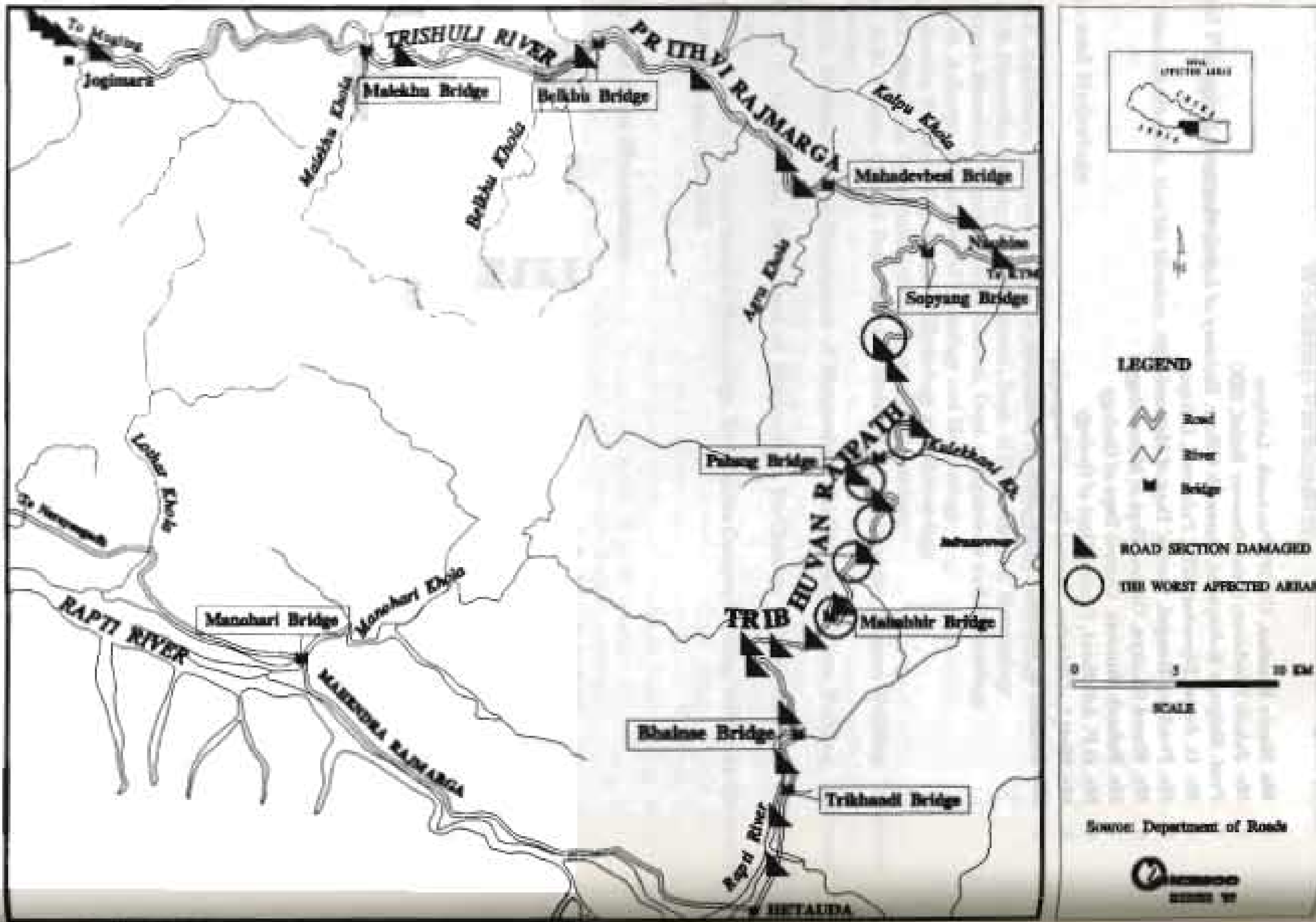
**Observers**

1. **Ms. Maria Ruedas**, UNDP, Pulchowk, Lalitpur
2. **Mr. Jakob Niederer**, Swiss Disaster Relief, SDC
3. **Prof. Shigeru Kobayashi**, Research Officer, Embassy of Japan, Prof. of Geography
4. **Mr. O. Auge, Director**, GTZ, Pulchowk, Lalitpur
5. **Mr. Pradeep Dongol**, Central Dept of Meteorology
6. **Mr. Binod Shakya**, Central Dept of Meteorology
7. **Mr. Subash Sunwar**, Central Dept of Geology
8. **Mr. D.P. Adhikari**, Central Dept of Geology
9. **Mr. Moti L. Ghimire**, Central Dept. of Geography
10. **Mr. Buddhi K. Dulaal**, Central Dept. of Geography

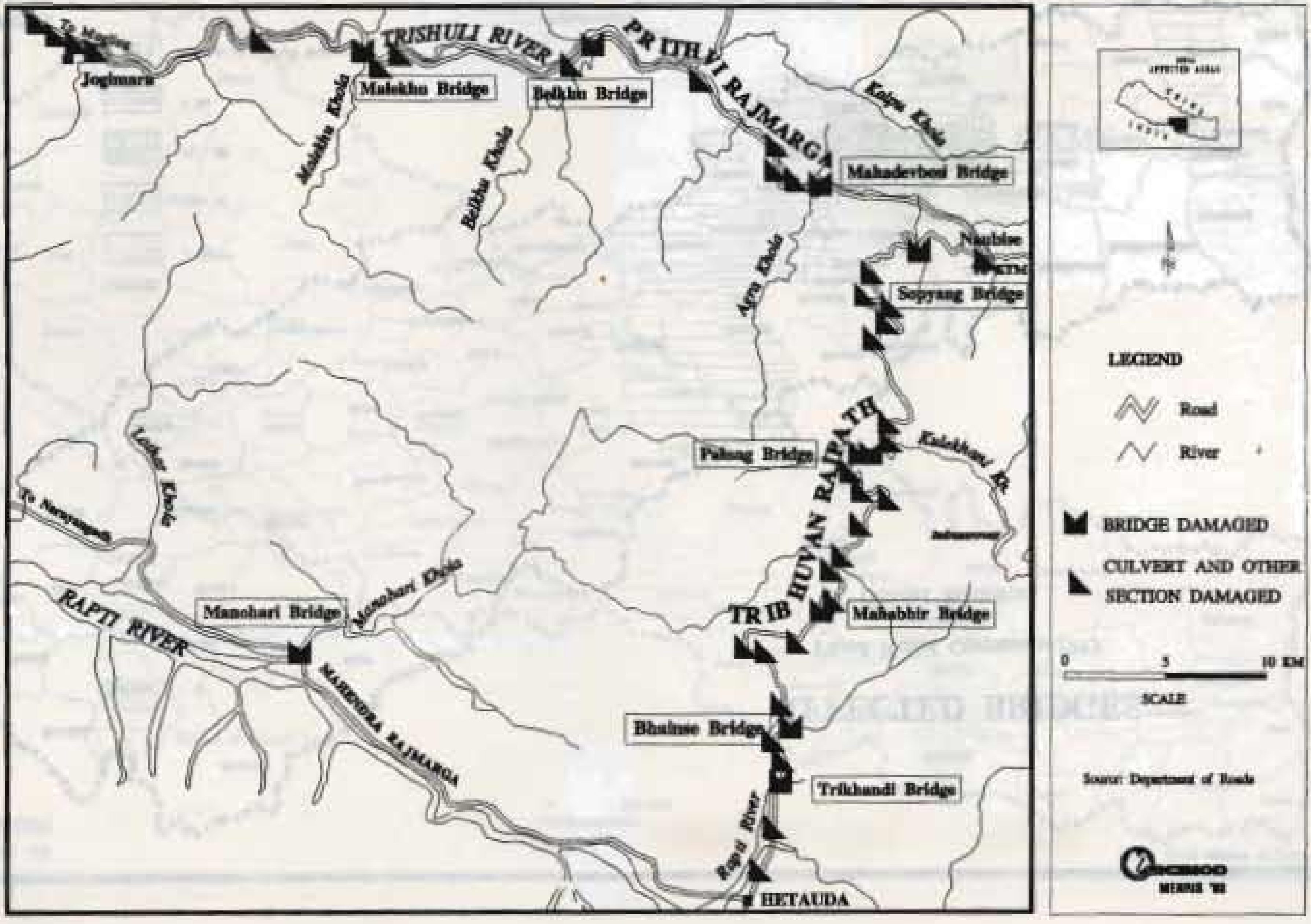
Map 4.1

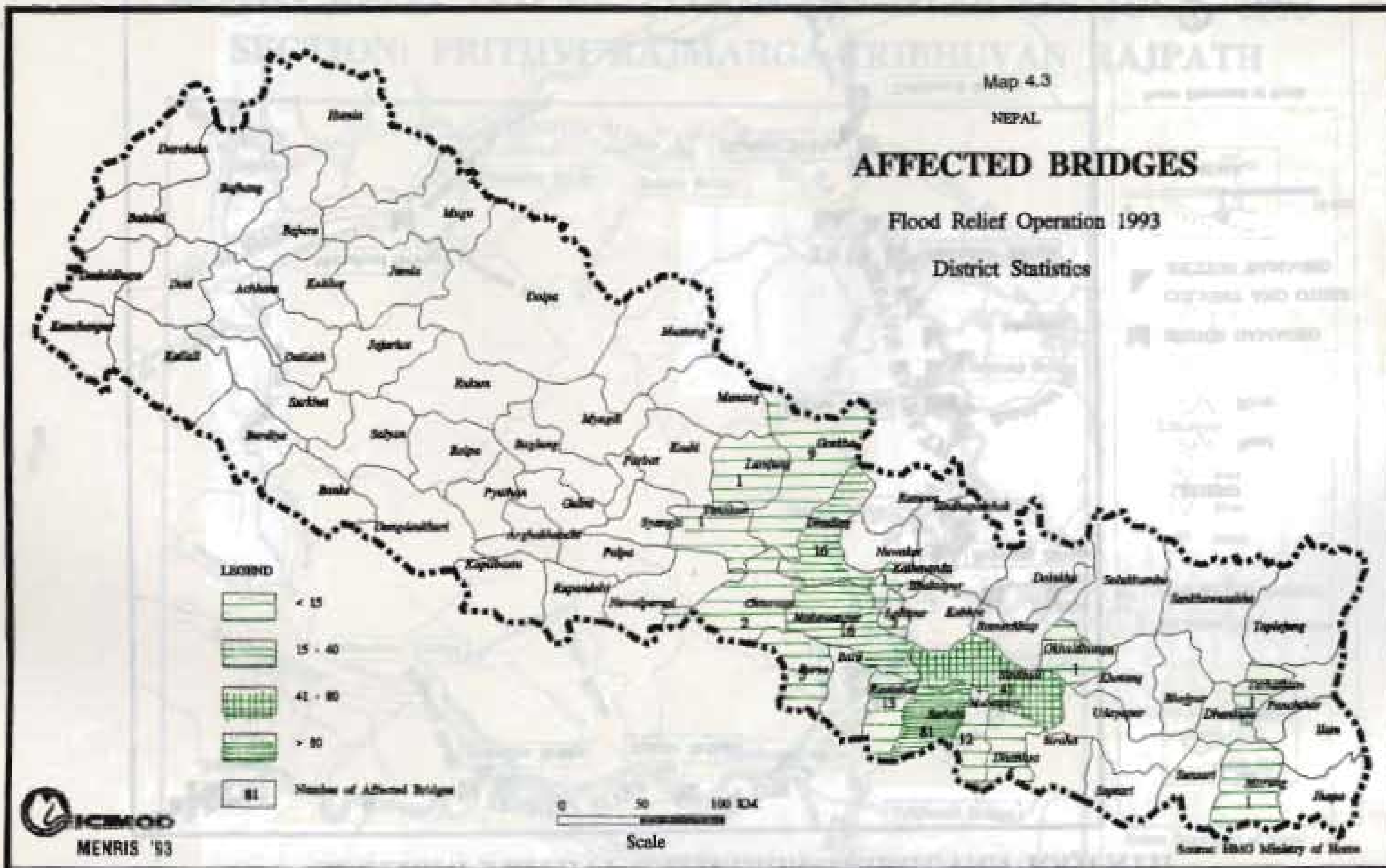
# ROADS AFFECTED BY FLOOD DISASTER ON JULY, 1993

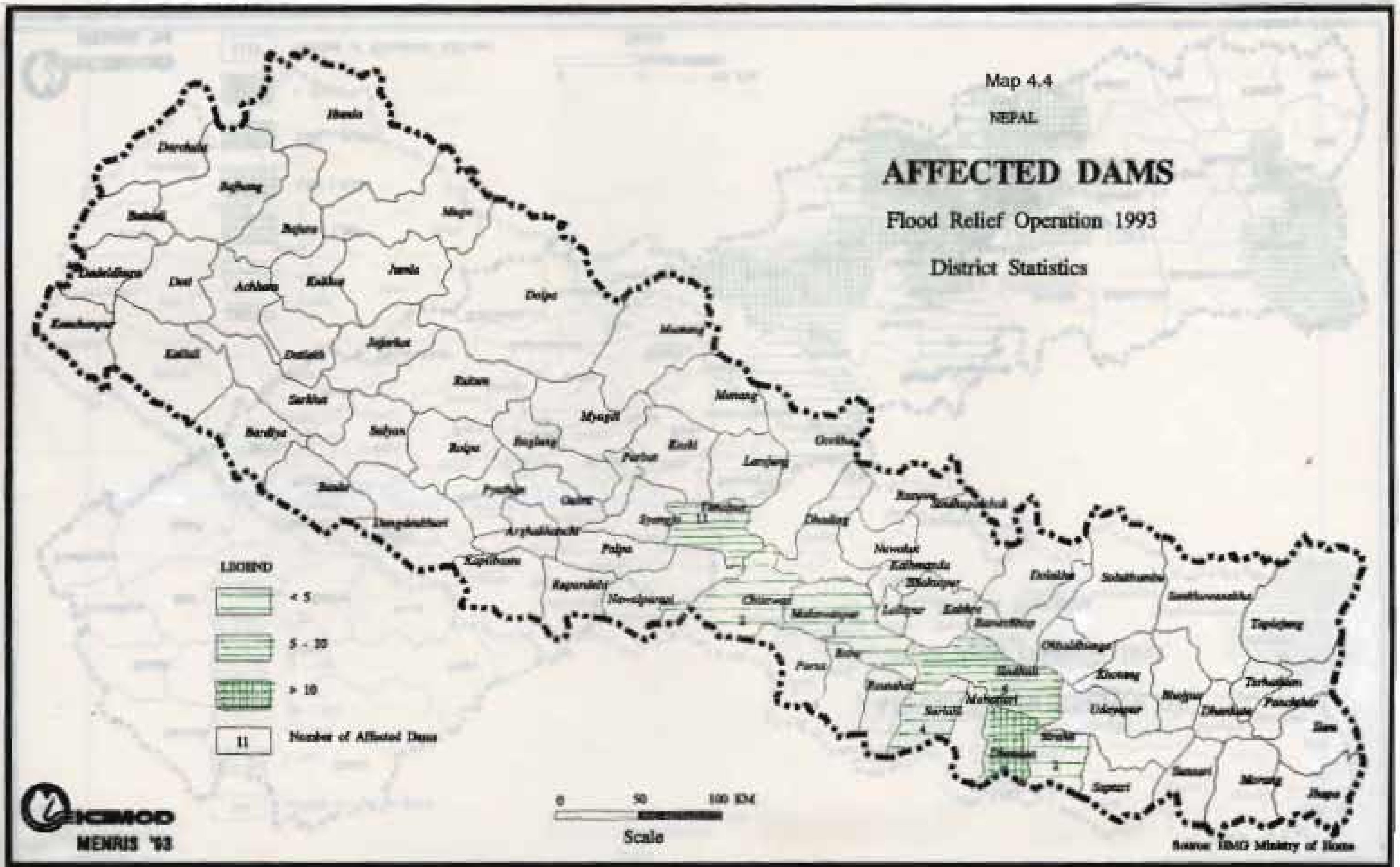
## SECTION: PRITHVI RAJMARGA-TRIBHUVAN RAJPATH

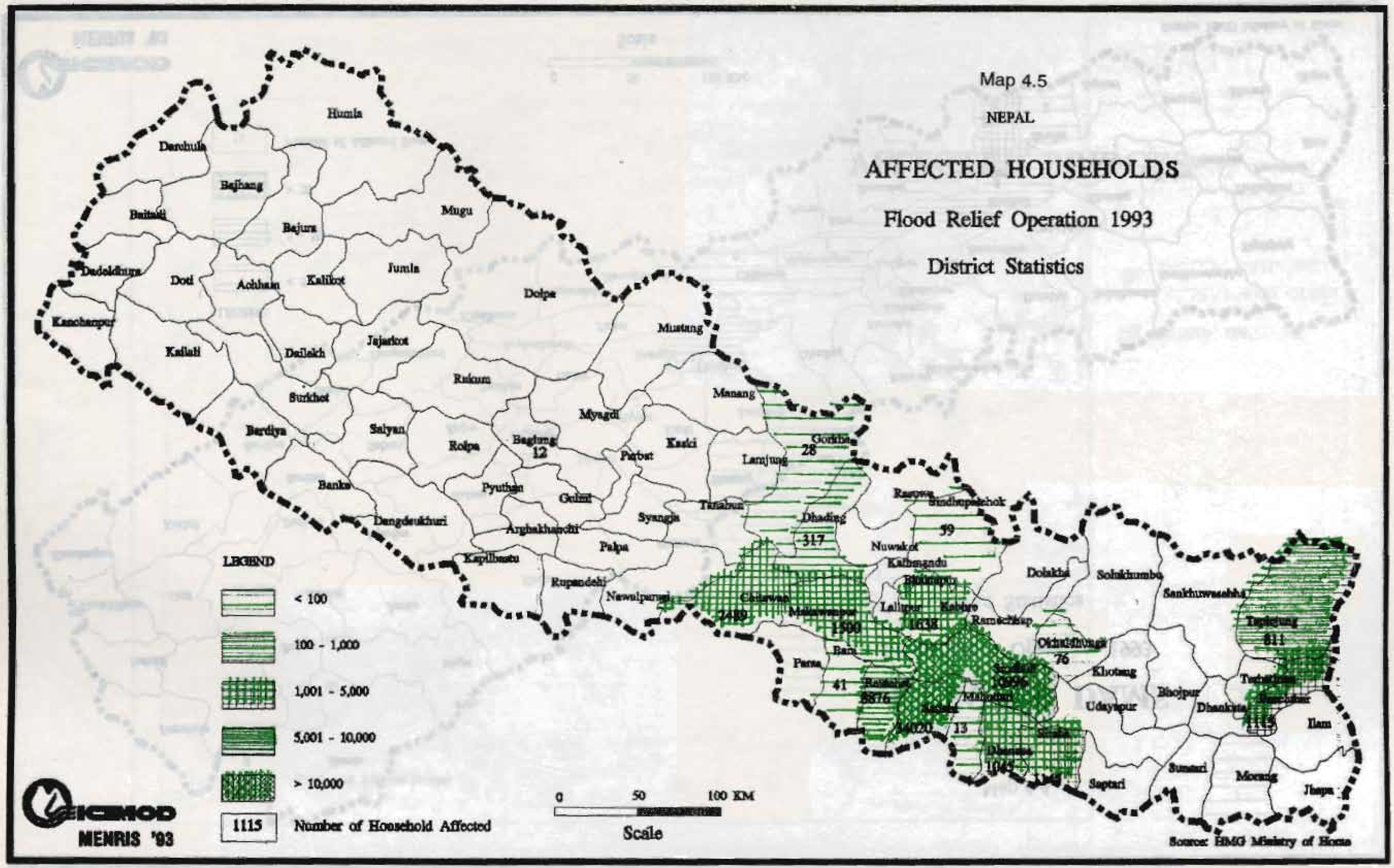


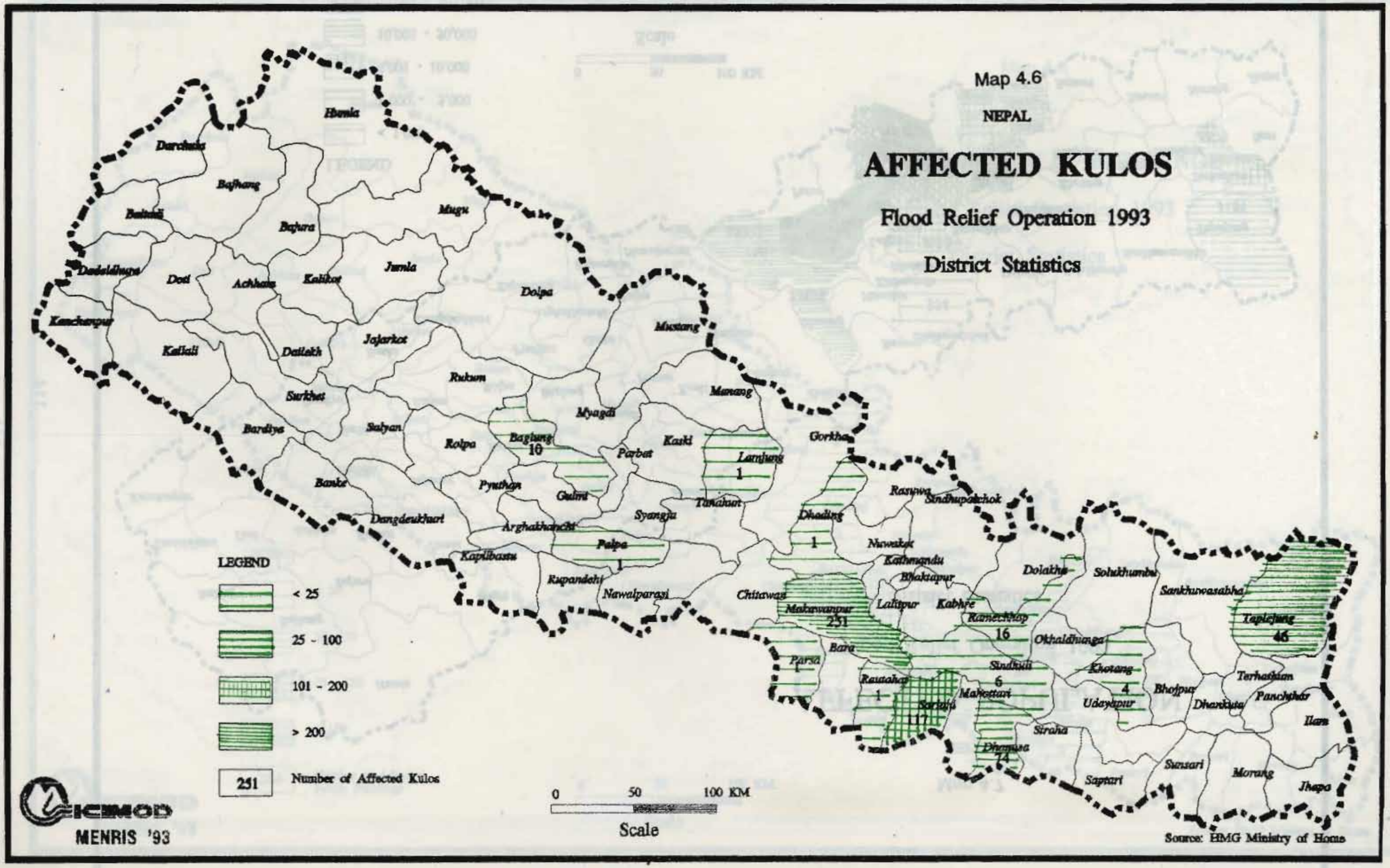
## ROADS AND BRIDGES AFFECTED BY FLOOD DISASTER ON JULY, 1993
## SECTION: PRITHVI RAJMARGA-TRIBHUVAN RAJPATH




Map 4.3
NEPAL
AFFECTED BRIDGES
Flood Relief Operation 1993
District Statistics
LEGEND
< 15
15 - 40
41 - 80
> 80
Number of Affected Bridges
0
50
100 KM
Scale
MENRIS '93
Source: HMG Ministry of Home


Map 4.4
NEPAL
AFFECTED DAMS
Flood Relief Operation 1993
District Statistics
LEGEND
< 5
5 - 10
> 10
Number of Affected Dams
0 50 100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home


Map 4.5
NEPAL
AFFECTED HOUSEHOLDS
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
12
Parbat
Kaski
Lamjung
Gorkha
28
Banke
Pyuthan
Gulmi
Dangdeukhuri
Arghakhanchi
Syangja
Tanahun
Dhading
317
Rasuwa
Sindhupalchok
59
Kapilbastu
Palpa
Rupandehi
Nawalparasi
Chitwan
2489
Nuwakot
Kathmandu
Lalitpur
Makwanpur
1500
1638
Ramechhap
Dolakha
Solukhumbu
Sankhuwasabha
Taplejung
811
Okhaldhunga
76
Bara
Parsa
41
8876
13
Khotang
Udayapur
Bhojpur
Dhankuta
Ilam
Saptari
Sunsari
Morang
Jhapa
LEGEND
< 100
100 - 1,000
1,001 - 5,000
5,001 - 10,000
> 10,000
1115
Number of Household Affected
0
50
100 KM
Scale
MENRIS '93
Source: HMG Ministry of Home


Map 4.6
NEPAL
AFFECTED KULOS
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Jumla
Dadeldhura
Doti
Achham
Kalikot
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
10
Kaski
Parbat
Lamjung
1
Gorkha
Banke
Pyuthan
Gulmi
Tanahun
Rasuwa
Sindhupalchok
Dangdeukhuri
Arghakhanchi
Syangja
Dhading
1
Palpa
1
Kapilbastu
Nuwakot
Kathmandu
Bhaktapur
Rupandehi
Nawalparasi
Dolakha
Solukhumbu
Sankhuwasabha
Chitawan
Makawanpur
251
Lalitpur
Kabhre
Ramechhap
16
Okhaldhunga
Taplejung
46
Bara
Parsa
1
Sindhuli
6
Khotang
4
Rautahat
1
Mahottari
Sarlahi
117
Udayapur
Bhojpur
Dhankuta
Terhathum
Panchthar
Ilam
Siraha
Dhanusa
74
Sunsari
Morang
Saptari
Jhapa
LEGEND
< 25
25 - 100
101 - 200
> 200
251 Number of Affected Kulos
0 50 100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home

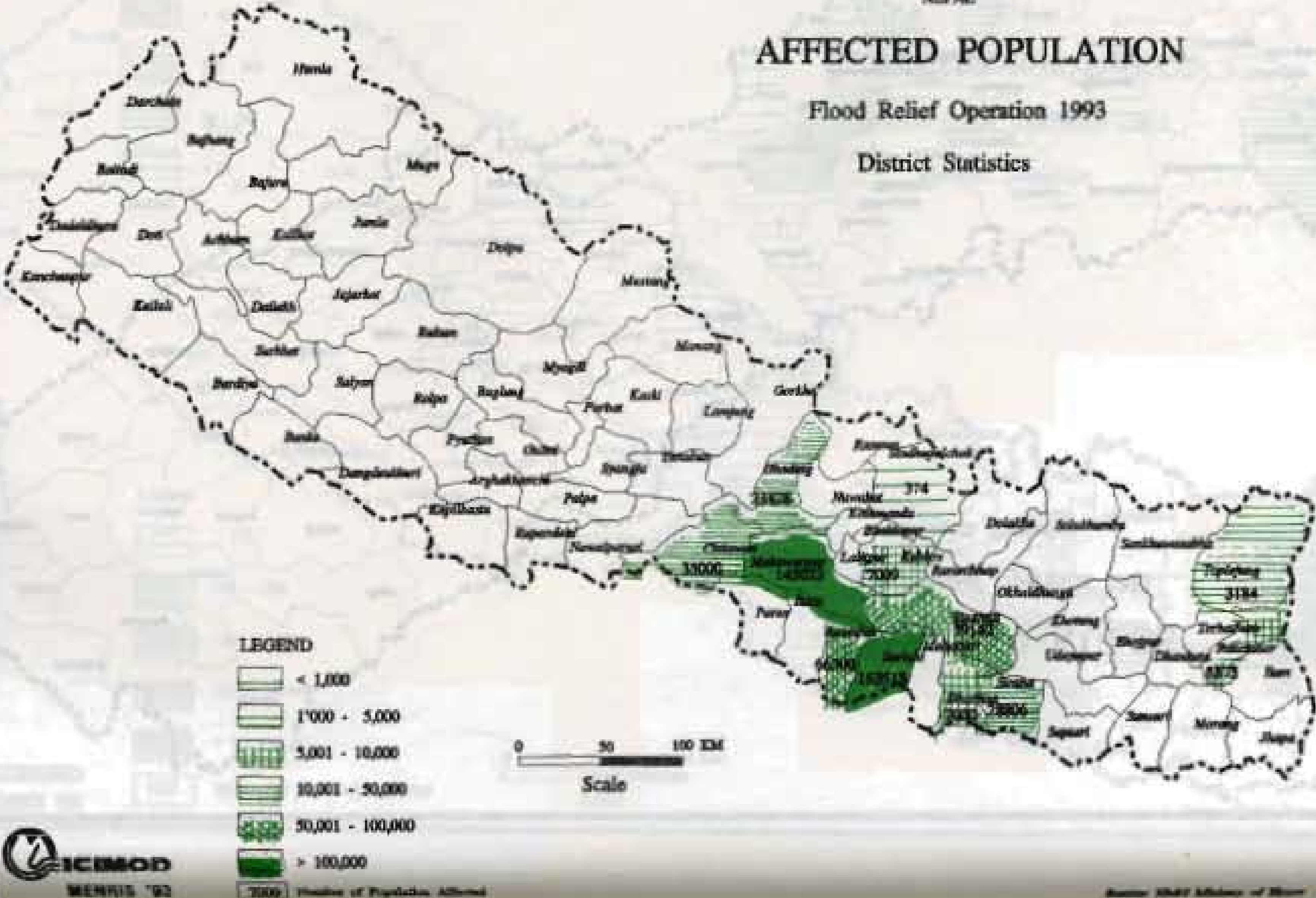
Map 4.7

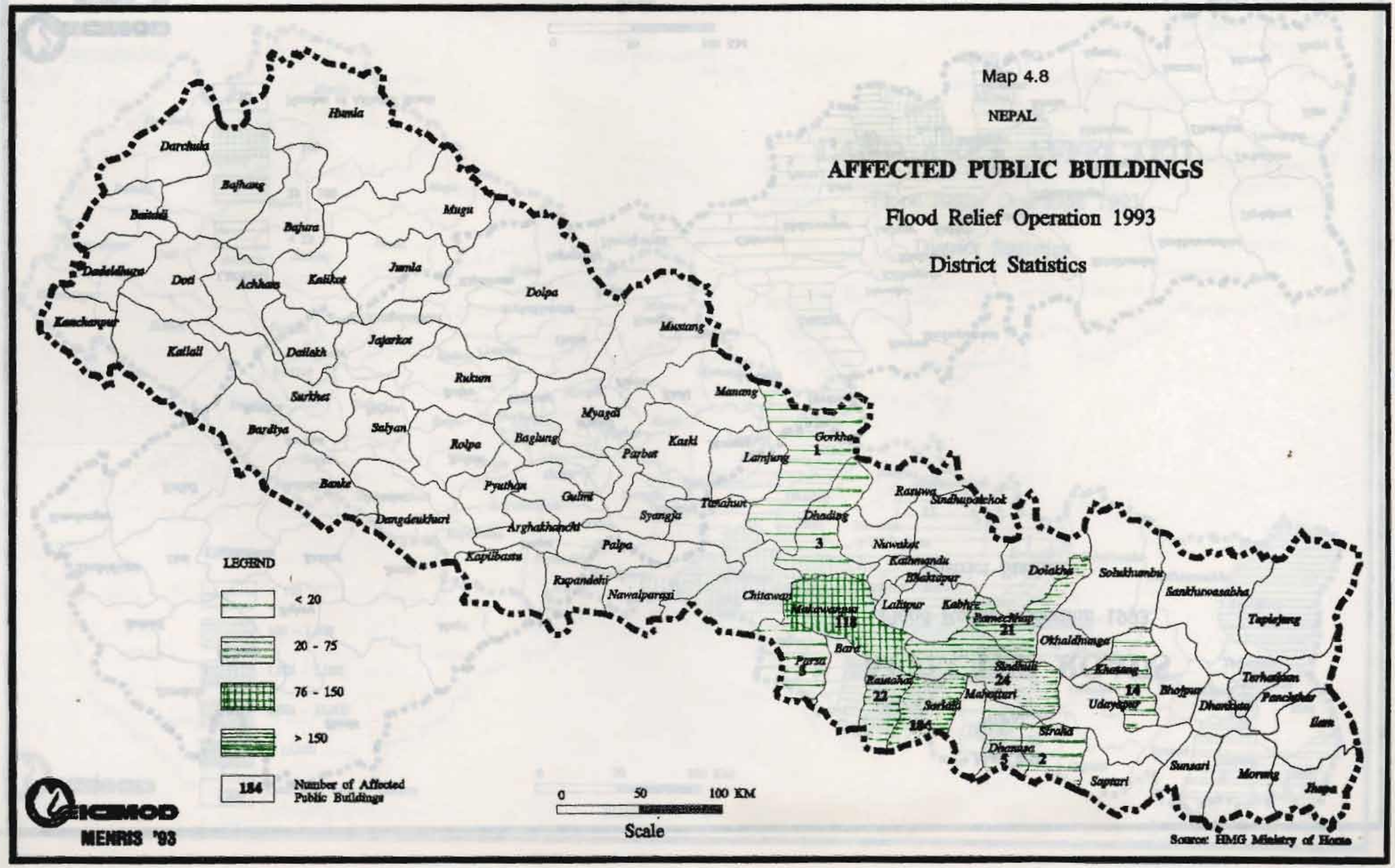
NEPAL

# AFFECTED POPULATION

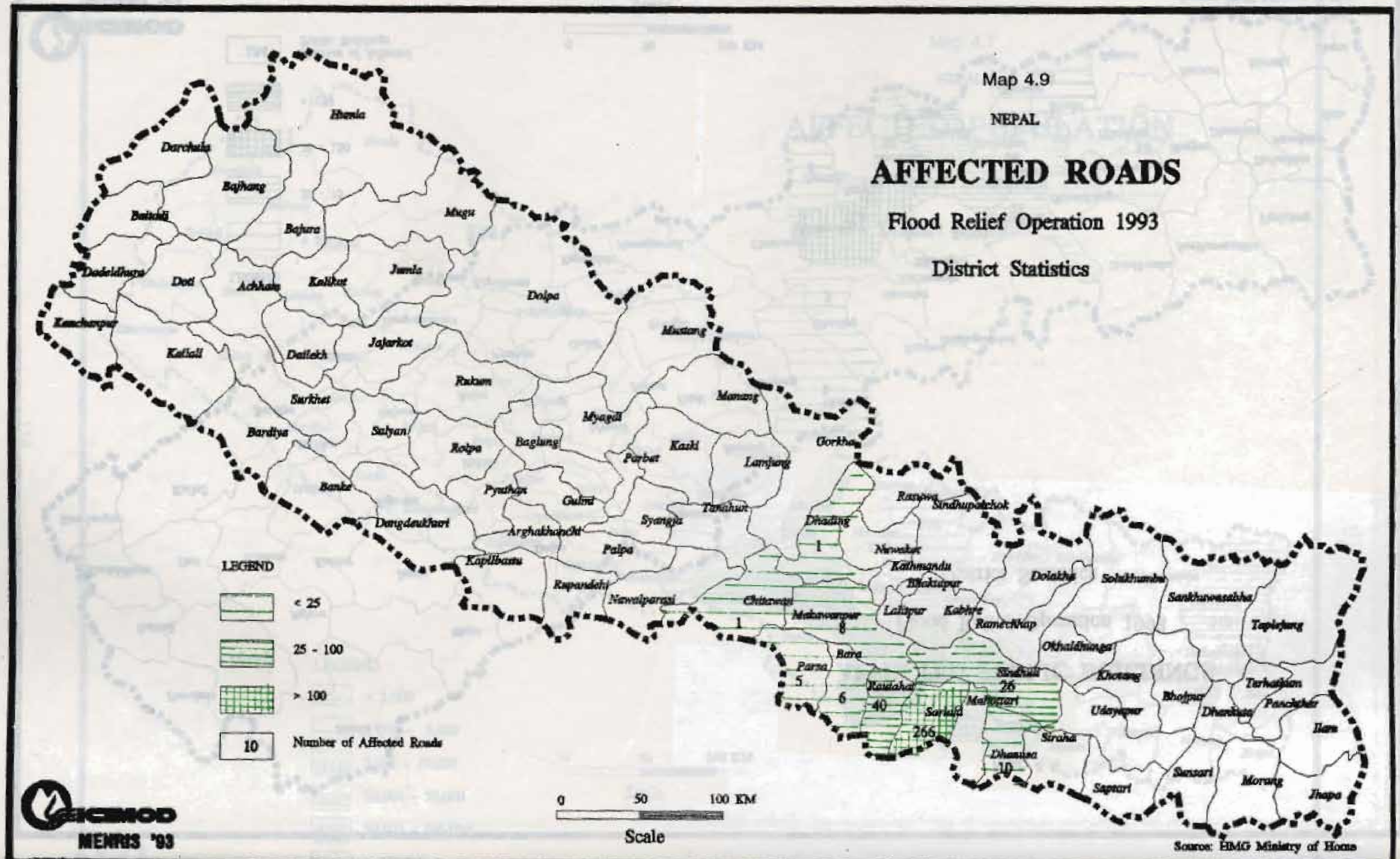
Flood Relief Operation 1993

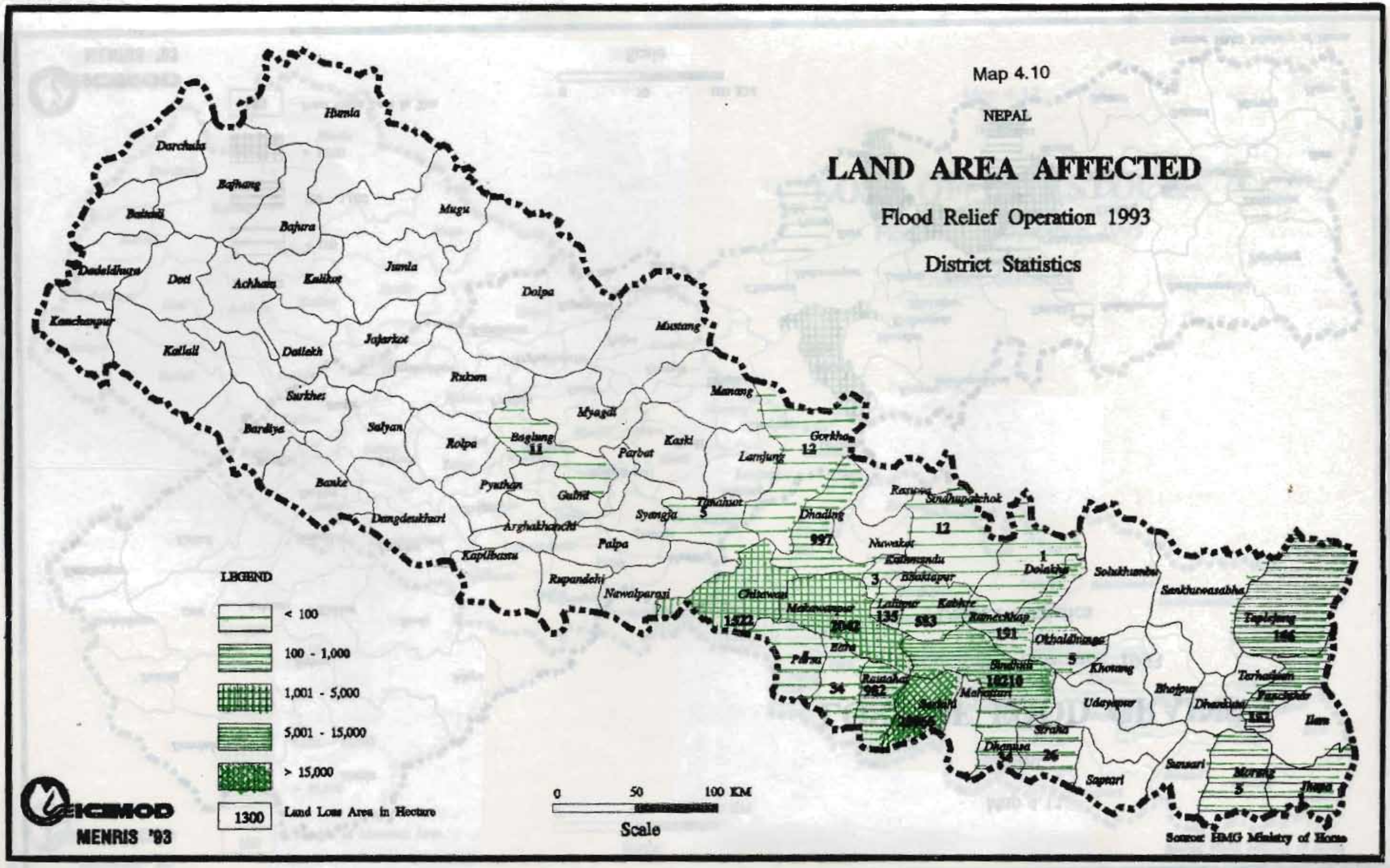
District Statistics

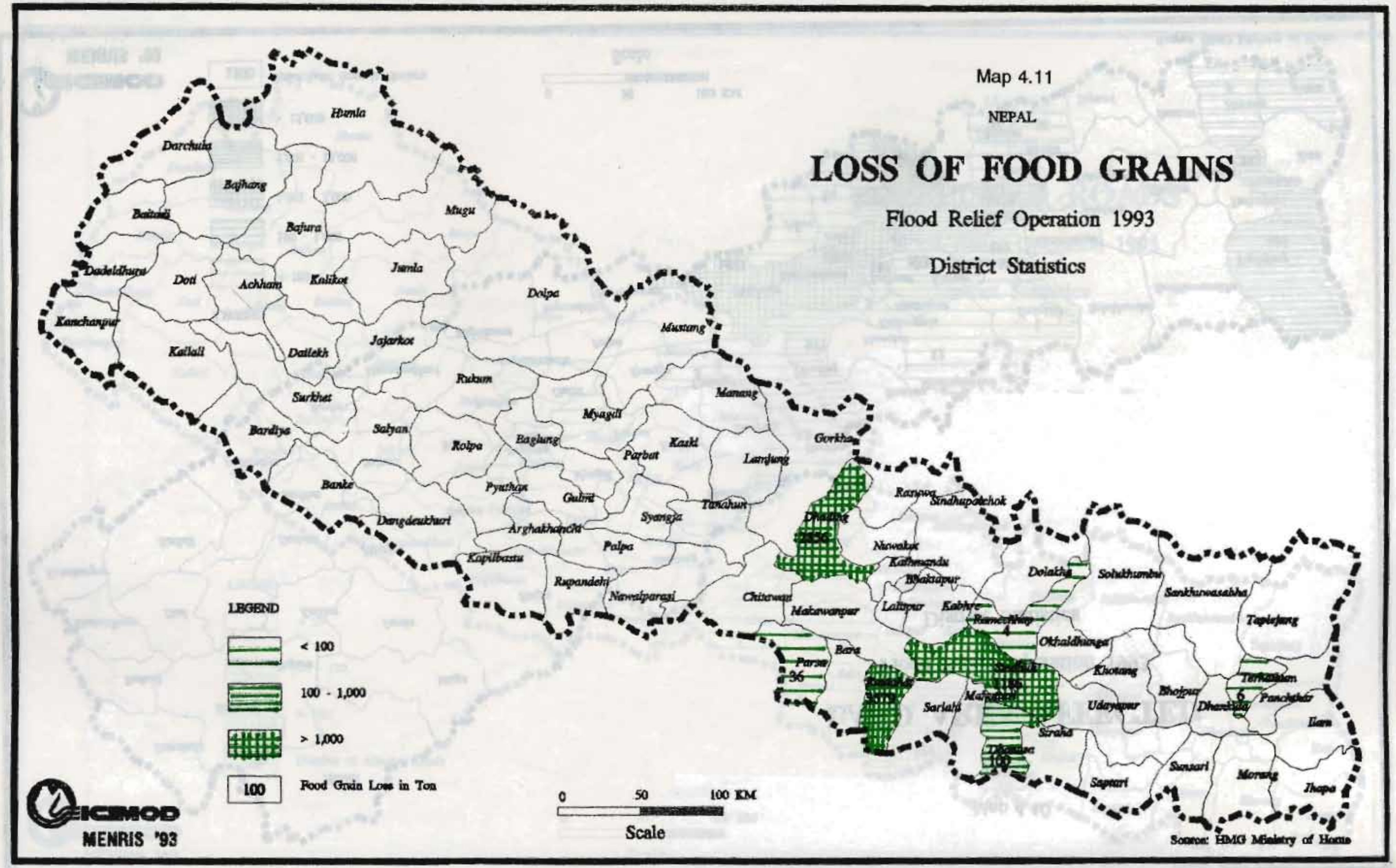


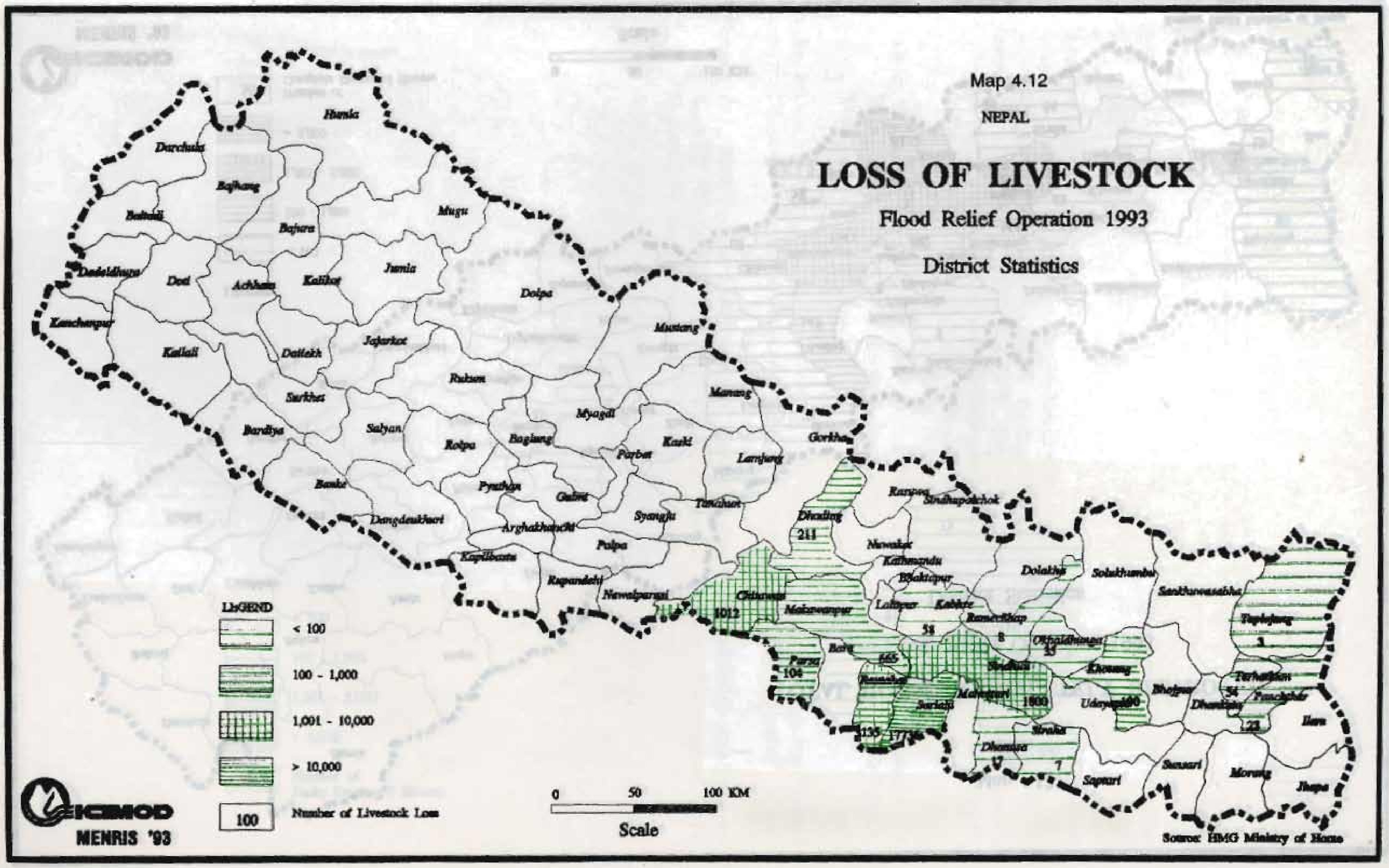


Map 4.8
NEPAL
AFFECTED PUBLIC BUILDINGS
Flood Relief Operation 1993
District Statistics
LEGEND
< 20
20 - 75
76 - 150
> 150
184 Number of Affected Public Buildings
0 50 100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home
Darchula
Humla
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Bardiya
Salyan
Rolpa
Baglung
Myagdi
Kaski
Parbat
Lamjung
Gorkha
1
Banke
Pyuthan
Gulmi
Tanahun
Rasuwa
Sindhupalchok
Dangdeukhuri
Arghakhanchi
Syangja
Dhading
3
Kapilbastu
Palpa
Nuwakot
Kathmandu
Bhaktapur
Rupandehi
Nawalparasi
Chitawan
Makawanpur
118
Lalitpur
Kabhre
Ramechhap
21
Dolakha
Solukhumbu
Sankhuwasabha
Taplejung
Okhaldhunga
Khotang
14
Udayapur
Bhojpur
Dhankuta
Terhathum
Panchthar
Ilam
Sindhuli
24
Rautahat
22
Sarlahi
184
Mahottari
Siraha
Dhanusa
2
Saptari
Sunsari
Morang
Jhapa


Map 4.9
NEPAL
AFFECTED ROADS
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Jumla
Dadeldhura
Doti
Achham
Kalikot
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
Kaski
Gorkha
Parbat
Lamjung
Banke
Pyuthan
Gulmi
Rasuwa
Sindhupalchok
Tanahun
Dangdeukhuri
Arghakhanchi
Syangja
Dhading
1
Palpa
Nuwakot
Kapilbastu
Kathmandu
Bhaktapur
Rupandehi
Dolakha
Solukhumbu
Nawalparasi
Chitawan
Sankhuwasabha
1
Makawanpur
8
Lalitpur
Kabhre
Ramechhap
Taplejung
Okhaldhunga
Bara
Parsa
5
Sindhuli
26
Khotang
Terhathum
Rautahat
6
40
Sarlahi
Mahottari
Udayapur
Bhojpur
Dhankuta
Panchthar
266
Ilam
Siraha
Dhanusa
10
Sunsari
Morang
Saptari
Jhapa
LEGEND
< 25
25 - 100
> 100
10
Number of Affected Roads
0
50
100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home


Map 4.10
NEPAL
LAND AREA AFFECTED
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
11
Parbat
Kaski
Lamjung
Gorkha
12
Banke
Pyuthan
Gulmi
Tanahun
5
Syangja
Dhading
997
Dangdeukhuri
Arghakhanchi
Palpa
Kapilbastu
Rupandehi
Nawalparasi
Chitawan
1522
Makwanpur
2042
Nuwakot
Kathmandu
Bhaktapur
3
Lalitpur
135
Kabhre
583
Sindhupalchok
12
Dolakha
1
Ramechhap
191
Okhaldhunga
5
Sindhuli
10210
Parsa
34
Rautahat
982
Sarlahi
Mahottari
Dhanusa
Siraha
26
Solukhumbu
Sankhuwasabha
Taplejung
Khotang
Udayapur
Bhojpur
Terhathum
Panchthar
Dhankuta
Ilam
Sunsari
Saptari
Morang
5
Jhapa
LEGEND
< 100
100 - 1,000
1,001 - 5,000
5,001 - 15,000
> 15,000
1300 Land Loss Area in Hectare
0 50 100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home


Map 4.11
NEPAL
LOSS OF FOOD GRAINS
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Mugu
Bajura
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Mustang
Kailali
Dailekh
Jajarkot
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
Kaski
Gorkha
Parbat
Lamjung
Banke
Pyuthan
Gulmi
Tanahun
Rasuwa
Sindhupalchok
Dangdeukhuri
Arghakhanchi
Syangja
Palpa
Nuwakot
Kapilbastu
Kathmandu
Bhaktapur
Dolakha
Solukhumbu
Rupandehi
Nawalparasi
Sankhuwasabha
Chitawan
Makawanpur
Lalitpur
Kabhre
Ramechhap
4
Tapiejung
Okhaldhunga
Parsa
36
Bara
Khotang
Terhathum
Sarlahi
Mahottari
Udayapur
Bhojpur
Dhankuta
6
Panchthar
Siraha
Ilam
100
Sunsari
Morang
Saptari
Jhapa
LEGEND
< 100
100 - 1,000
> 1,000
100
Food Grain Loss in Ton
0
50
100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home


Map 4.12
NEPAL
LOSS OF LIVESTOCK
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Kailali
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
Kaski
Parbat
Lamjung
Gorkha
Banke
Pyuthan
Gulmi
Dangdeukhuri
Arghakhanchi
Syangja
Tanahun
Palpa
Kapilbastu
Rupandehi
Nawalparasi
Dhading
211
Chitawan
1012
Makawanpur
Parsa
104
Bara
665
Rautahat
Sarlahi
Nuwakot
Kathmandu
Bhaktapur
Lalitpur
Kabhre
58
Ramechhap
8
Dolakha
Solukhumbu
Okhaldhunga
Sindhuli
Mahottari
1800
Dhanusa
Siraha
7
Saptari
Khotang
Udayapur
Bhojpur
Dhankuta
Sunsari
Morang
Jhapa
Ilam
Panchthar
Terhathum
54
Taplejung
Sankhuwasabha
123
LEGEND
< 100
100 - 1,000
1,001 - 10,000
> 10,000
100
Number of Livestock Loss
0
50
100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home

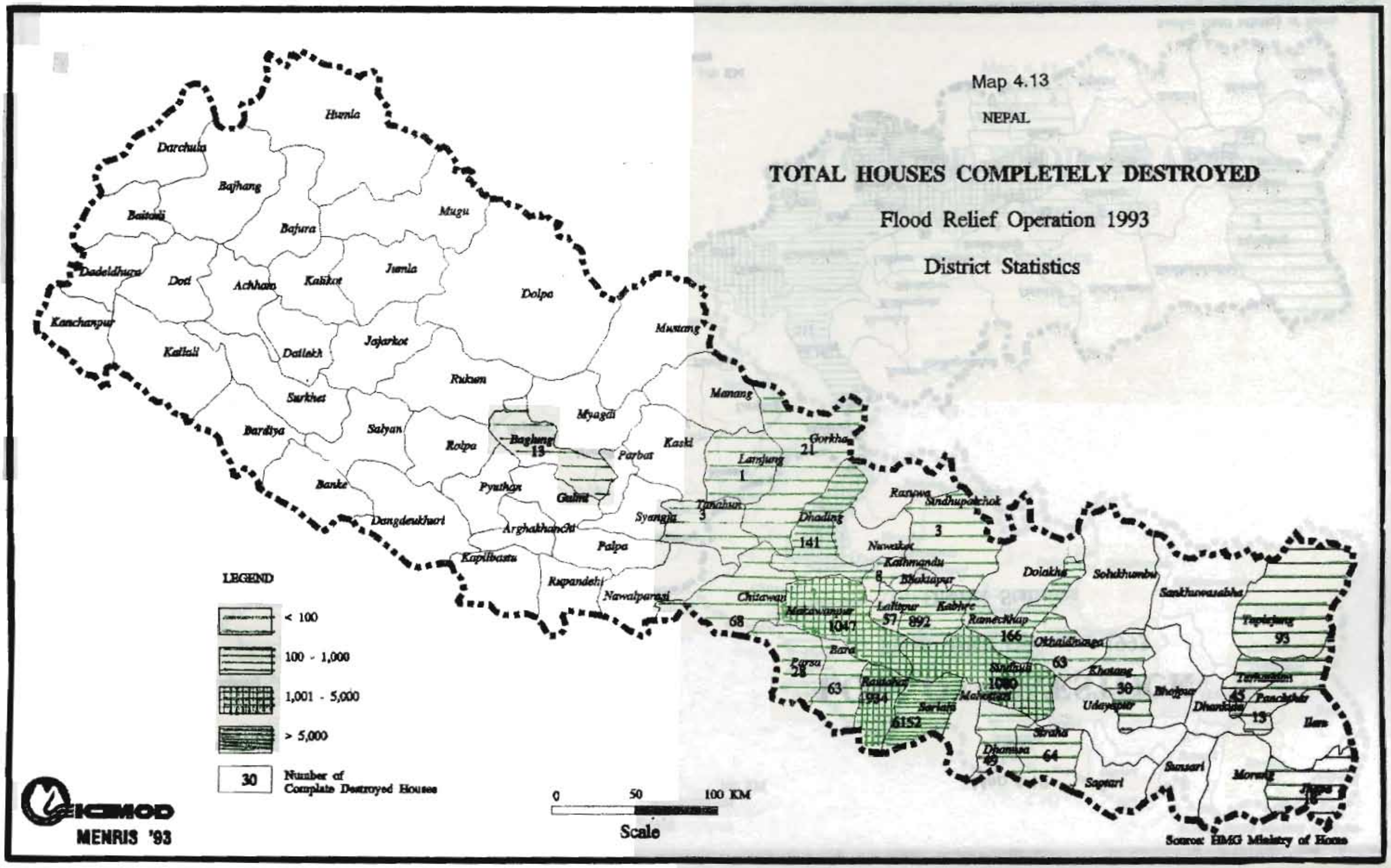
Map 4.13

NEPAL

# TOTAL HOUSES COMPLETELY DESTROYED

## Flood Relief Operation 1993

## District Statistics



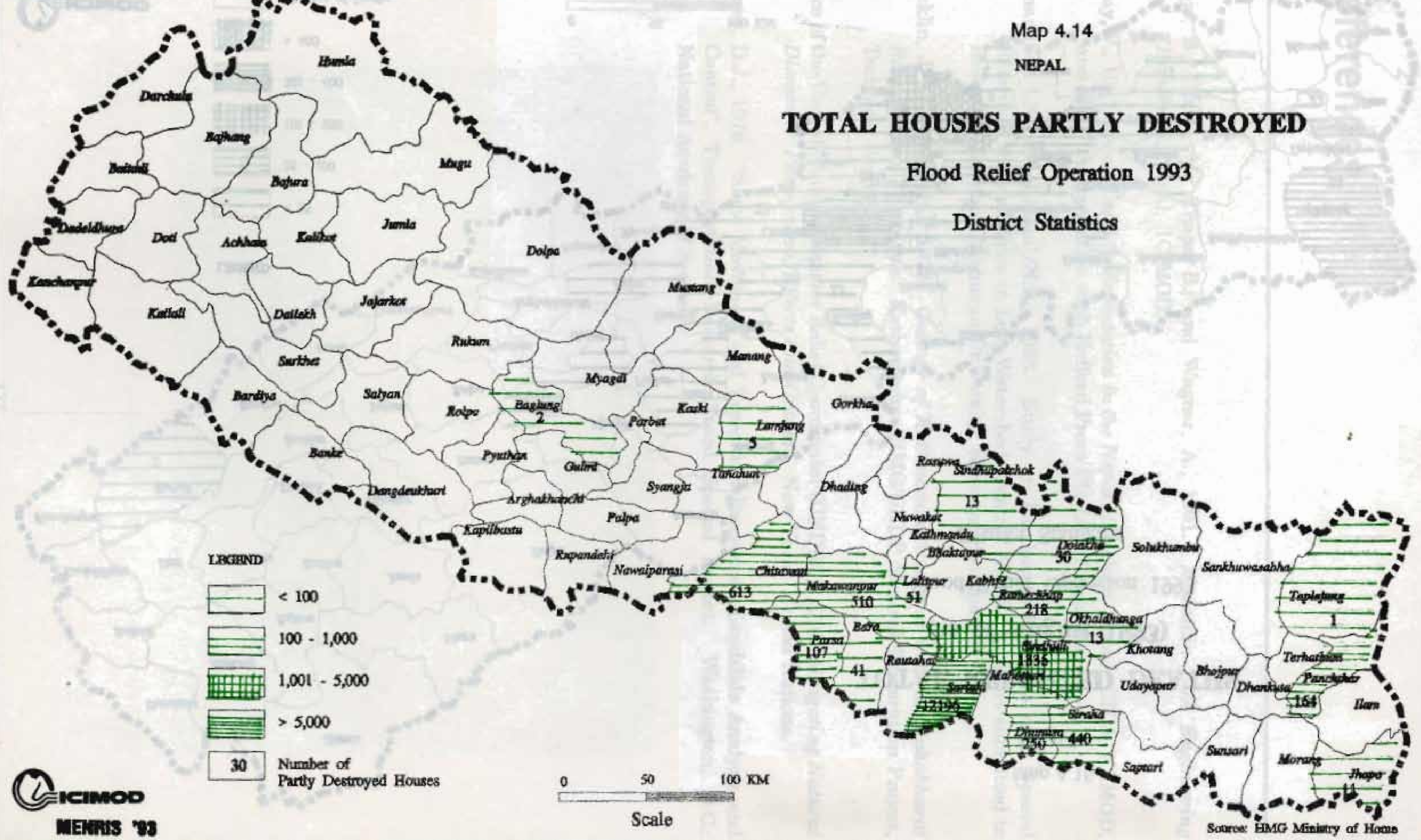
Map 4.14

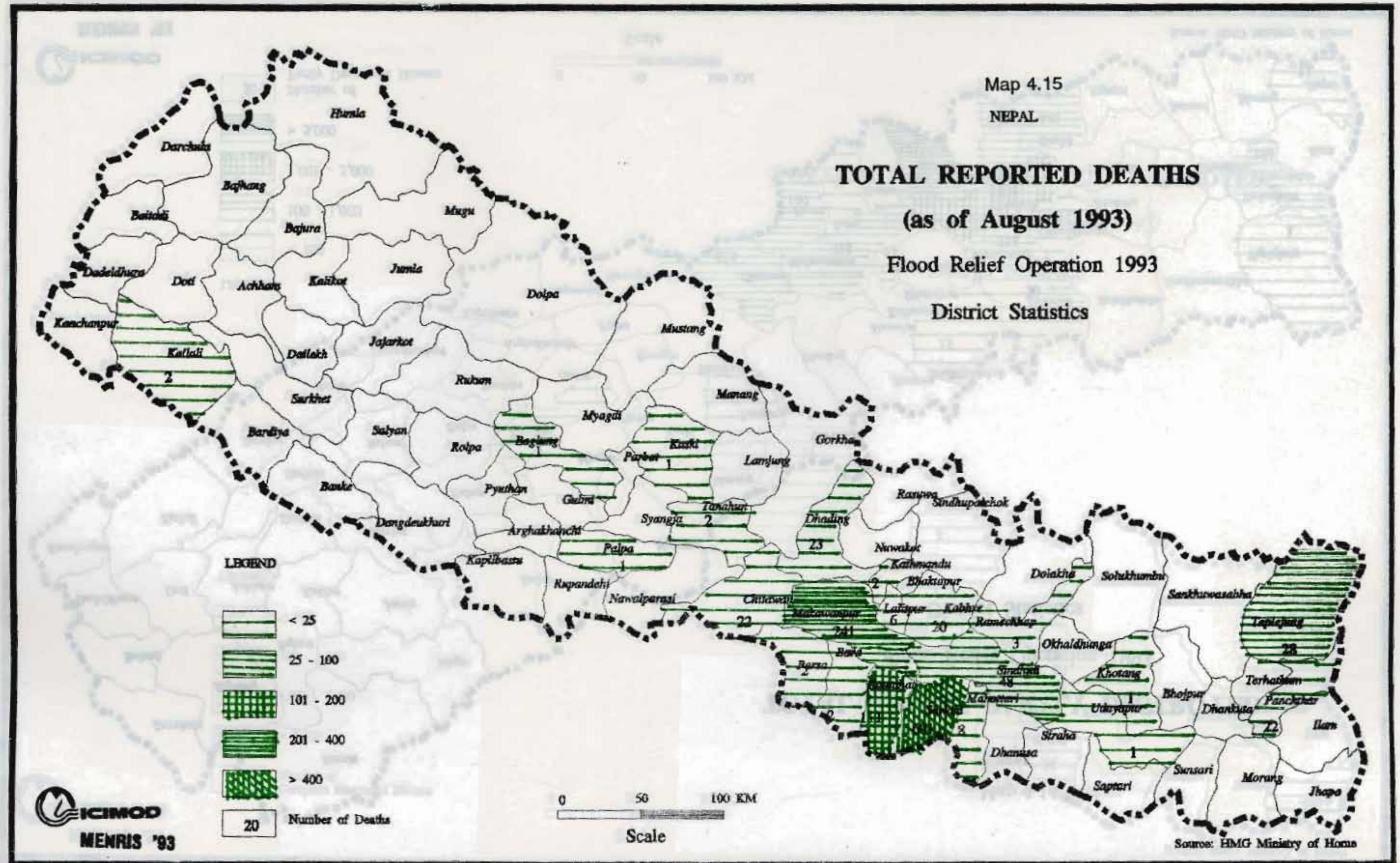
NEPAL

# TOTAL HOUSES PARTLY DESTROYED

Flood Relief Operation 1993

District Statistics




Map 4.15
NEPAL
TOTAL REPORTED DEATHS
(as of August 1993)
Flood Relief Operation 1993
District Statistics
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Dolpa
Kanchanpur
Kailali
2
Dailekh
Jajarkot
Mustang
Rukum
Surkhet
Manang
Myagdi
Bardiya
Salyan
Rolpa
Baglung
1
Kaski
Parbat
1
Gorkha
Lamjung
Banke
Pyuthan
Gulmi
Tanahun
Syangja
2
Dangdeukhuri
Arghakhanchi
Palpa
1
Dhading
23
Nuwakot
Kathmandu
2
Bhaktapur
Kapilbastu
Rupandehi
Nawalparasi
Chitawan
22
Makawanpur
241
Lalitpur
6
Kabhre
20
Ramechhap
3
Dolakha
Solukhumbu
Sankhuwasabha
Taplejung
28
Okhaldhunga
Khotang
1
Bara
Parsa
2
Sindhuli
48
Mahottari
8
Udayapur
Bhojpur
Dhankuta
Terhathum
Panchthar
22
Ilam
Dhanusa
Siraha
1
Saptari
Sunsari
Morang
Jhapa
LEGEND
< 25
25 - 100
101 - 200
201 - 400
> 400
20
Number of Deaths
0
50
100 KM
Scale
ICIMOD
MENRIS '93
Source: HMG Ministry of Home

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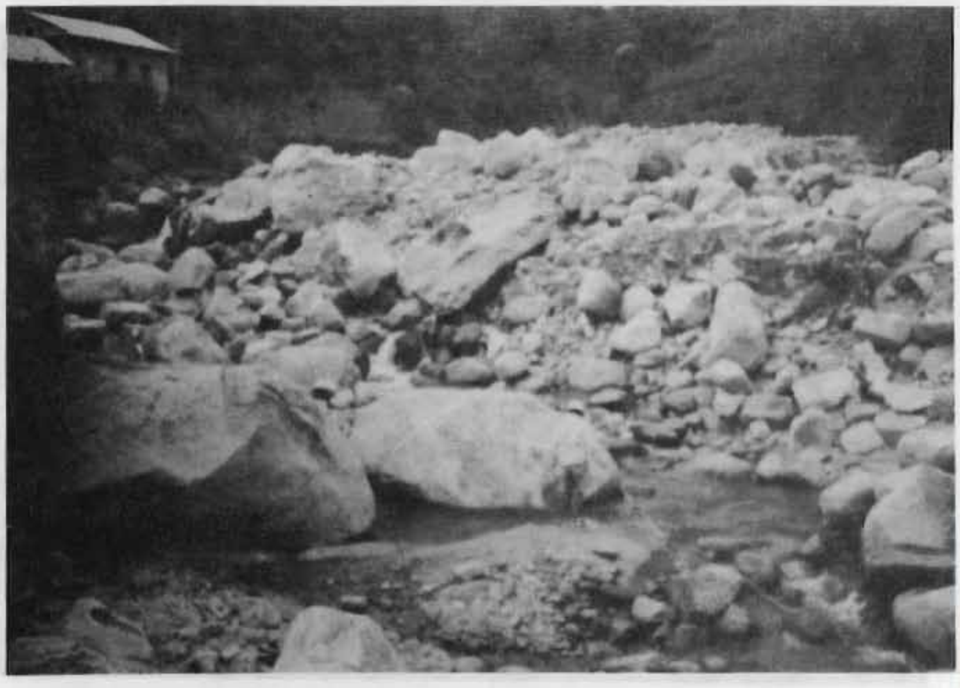
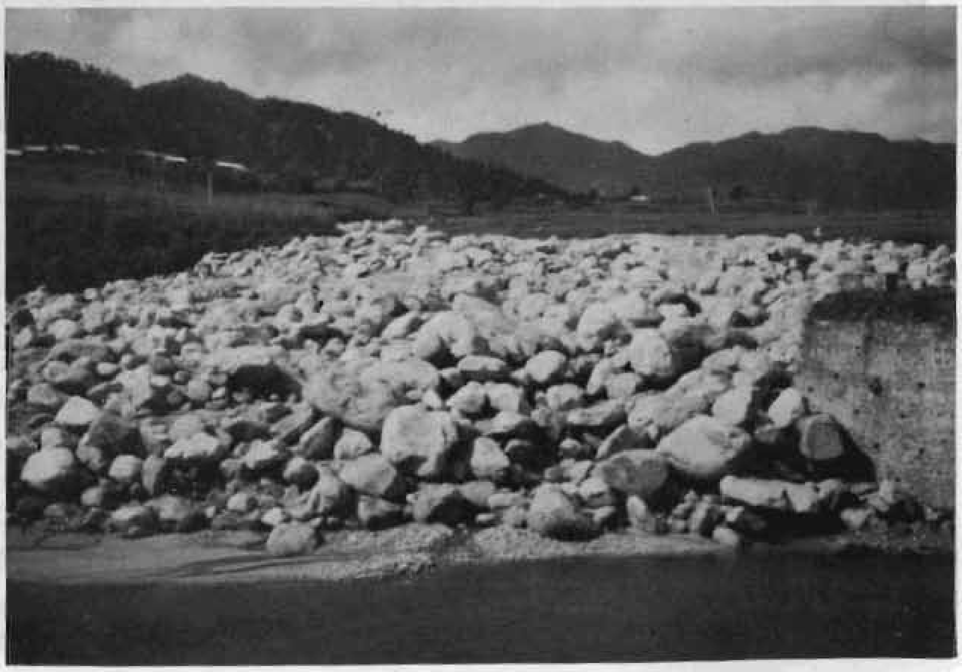
# Plates - PART ONE

Steep gradient of the Kitini *Khola* viewing north. Notice the cascading flow!



The aftermath of the event along the Kitini course. Notice what a close shave it was for the surviving houses!

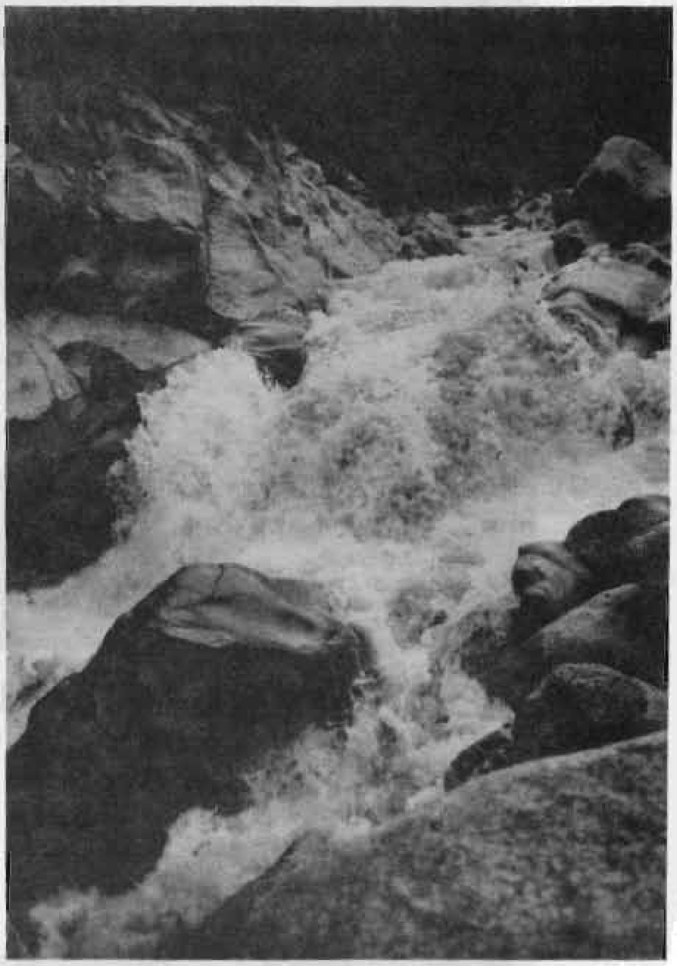
Scouring and deep cutting of flashy channels



Typical fan formed by the cascading rivers. The Kitini catchment received over 300 mm of rain.

High floods touched the bridge level. Notice the weeds entangled on the railings.

The scraped banks of the Palung Khola by the debris flow



Typical torrents in the Mahabharat headwaters ▸

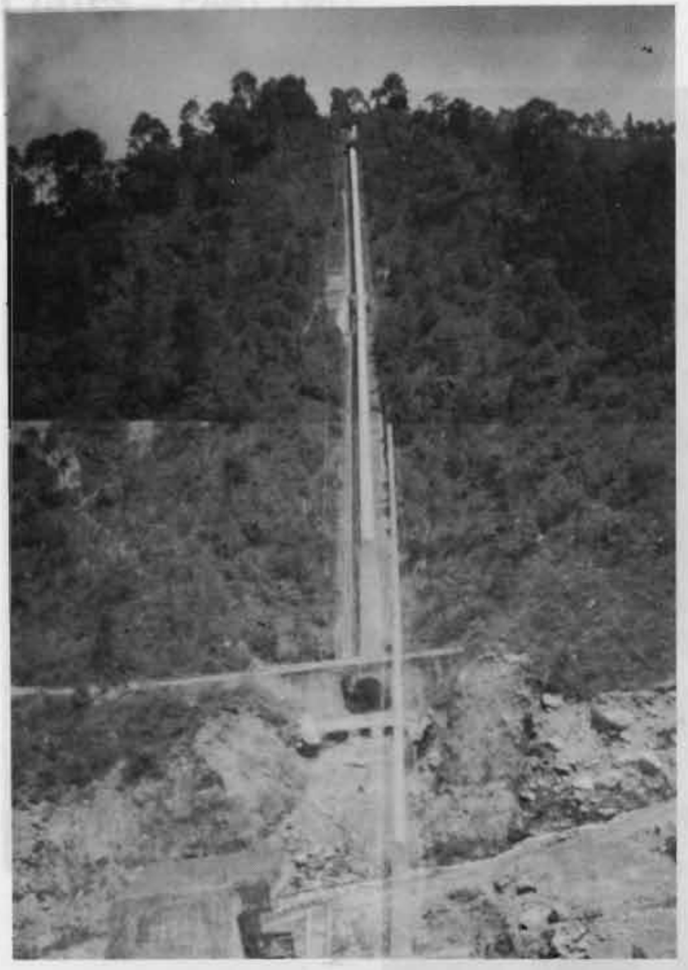
Gauging on the reconnaissance trek ▾

Typical monsoon cloud cover on route (Kitini watershed, August 4, 1993)

Gigantic boulder slumped in the Mandu *Khola*. These boulders will be transported as debris flow in future events.

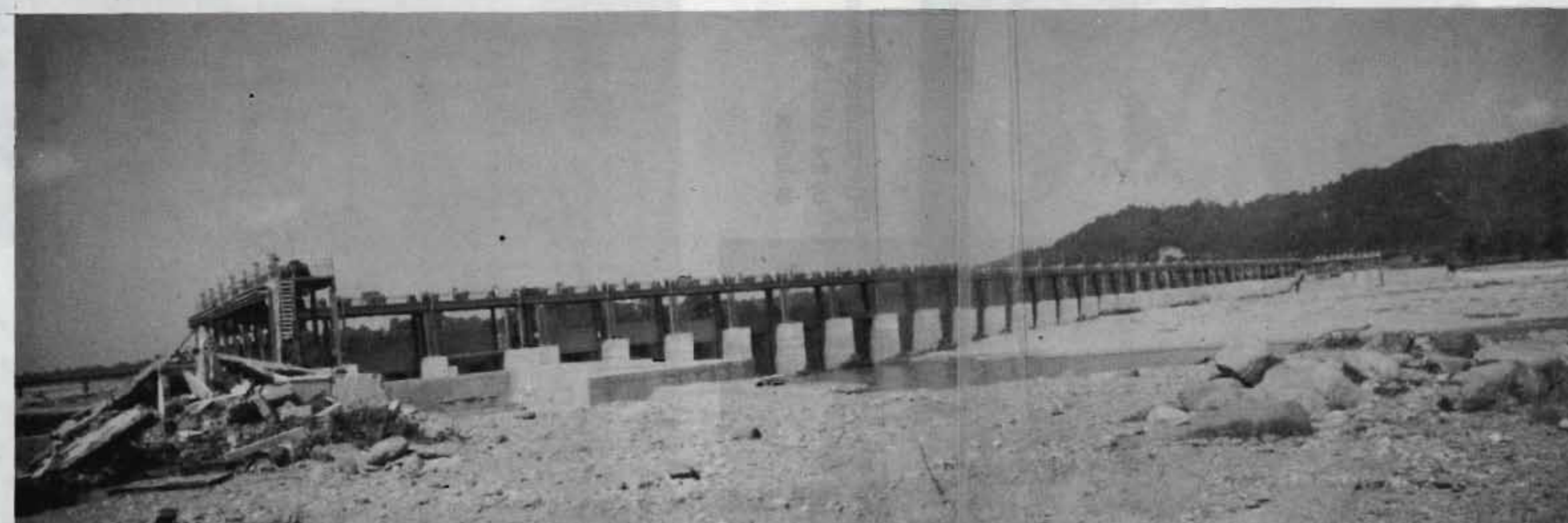
The Kulekhani Reservoir is becoming heavily sedimented.

The Tistung Khola surprisingly was less subjected to flooding in spite of an over 500 mm precipitation record upstream. Perhaps the terraced fields in the wide valley have temporarily detained the downpour.



The smashed penstock
by the debris flow
at Jurikot

Debris entangled above the gates



Downstream view of the crippled Karmaya Barrage - notice the channel bar

# **Plates** - PART TWO

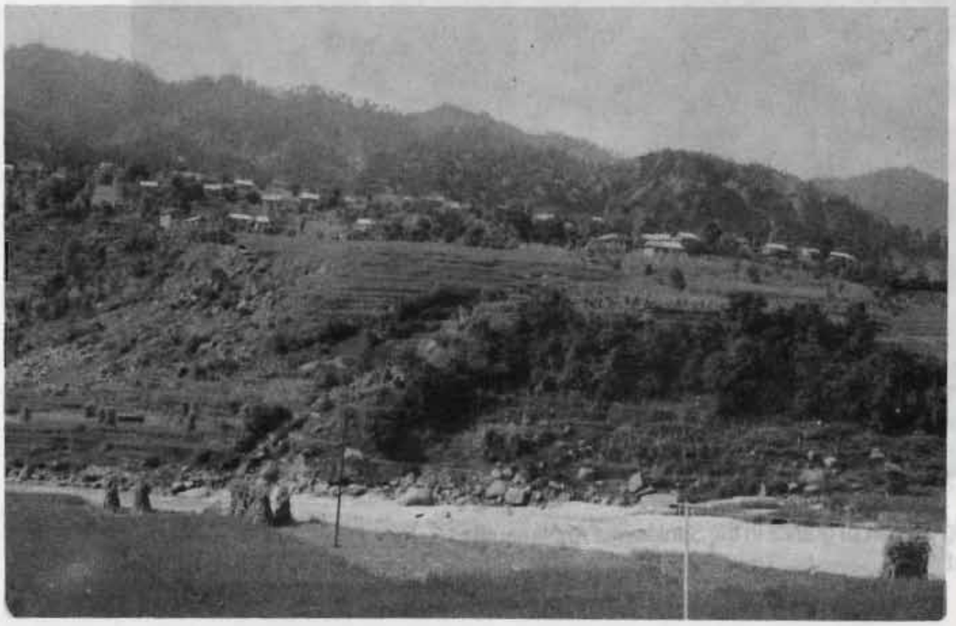


Plate 1: The Middle Hills of Palung and Daman are made up of granite and Kitni Village is on an old alluvial fan. Notice the numerous landslide scars on hillslopes after the floods on July 19 and 20. View towards the west

Plate 2: The contact between Palung granite (white) and the schist and quartzites of the Kulekhani Formation (grey) as observed near the Sankhamul *Khola*, east of Okhargaun. View towards the west

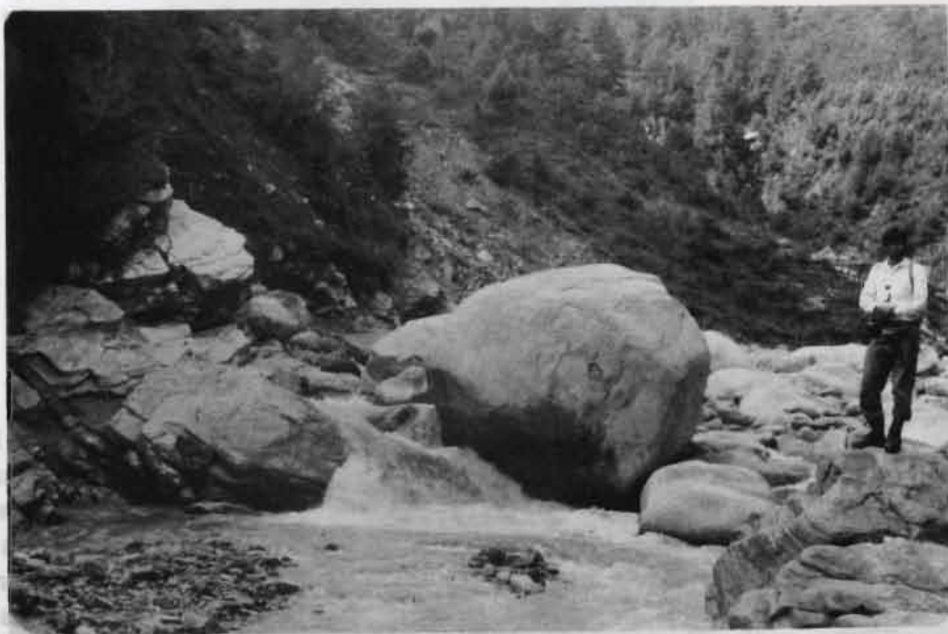


Plate 3: A big boulder of granite in the Sankhamul *Khola* south of Gahate *Danda*. View towards the west

Plate 4: The folded schist and marble of the Markhu Formation on the right bank of the Kulekhani *Khola* south of Khani Khet. View towards the south

Plate 5: The Bagmati River gorge west of Malta, in the granite. View towards the south

Plate 6: The Main Boundary Thrust as observed at Luinche. The fault is passing through the saddle along the gully. Notice also several soil slides and debris fans. View towards the east

Plate 7: Very thick bedded sandstone of the Middle Siwaliks exposed to the south of Rai *Gaun*. The river terrace is seen in the foreground. View towards the north-east

Plate 8: The Flooded Bagmati River at Balkhu on July 19, 1993. The Balkhu *Khola* is to the left. View towards the north

Plate 9: Flooding of the Bagmati River near Chobhar Gorge on August 9, 1993. Notice the overtopping of the right bank near the temple. View towards the south

Plate 10: The Kulekhani Valley and impoundment by the dam downstream. View towards the south-east from Markhu

Plate 11: The debris fan on the Dhital *Khola* between Sulikot and Thulotar. Notice a rockslide upstream on the left bank and the old elevated river terraces of the Kulekhani *Khola* on both banks. View towards the west

Plate 12: The Bagmati River and its floodplain at Rai *Gaun.* At present, the river channel is about 20m below the high flood level of July 21, 1993 (cliff to the left). View towards the north

Plate 13: The mid-channel bar on the Bagmati River between Asrang and Gimdi. Patches of the river terraces are also seen. View towards the north-west

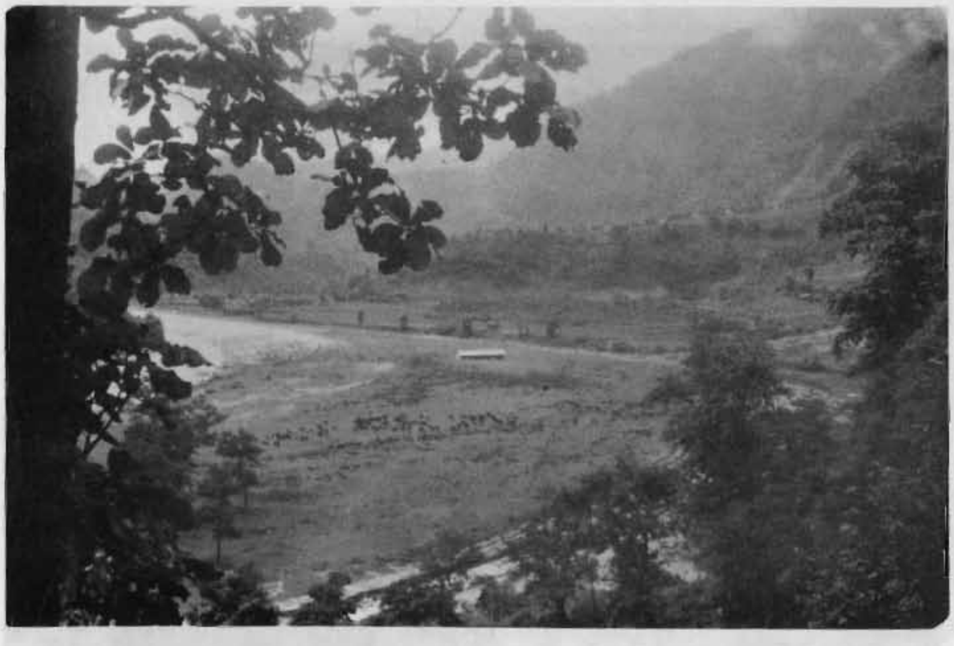


Plate 14: The channel bar on the Bagmati River at Kholme *danda*. Notice a school in the middle of the bar and an inactive channel to the north. View towards the west

Plate 15: The wood debris brought by the Chitlang *Khola* into the Kulekhani water reservoir. Notice also the high flood mark on the right bank. View towards the south-west

Plate 16: Debris slide . View towards the west

◂ Plate 17: A Plane rockslide on the Tribhuvan Highway in the Tistung Formation near Kulgaon. View towards the south-west

Plate 18: Debris flow and rockslide in the very fractured and cleaved slate and quartzite of the Tistung Formation, west of Kulgaun, the Tribhuvan Highway. View towards the east

▾

Plate 19: The site of a washed-out bridge at Bhainse Dobhan. View towards the north

Plate 20: The washed-out bridge at Trikhandi. The steel beams are bent by the debris and boulders passing underneath the bridge. View towards the north-west

Plate 21: The plane rockslide on the Tistung Formation, near Kulgaun, Km 64, on the Tribhuvan Highway. View towards the south-west

Plate 22: The wedge rockslide on the moderately to nighly weathered granite, the Tribhuvan Highway north of Sikharkot. View towards the south

Plate 23: The torrential gully (a tributary to the Kitni *Khola*) on the road north of Sikharkot. View towards the south

Plate 24: The soil slides at the Daman Horticultural Farm. View towards the east

Plate 25: The shallow soil slides and slumps at the Daman Horticultural Farm. View towards the south

Plate 26: The damaged road and retaining wall on the right bank of the Bisinkhel *Khola* View towards the north

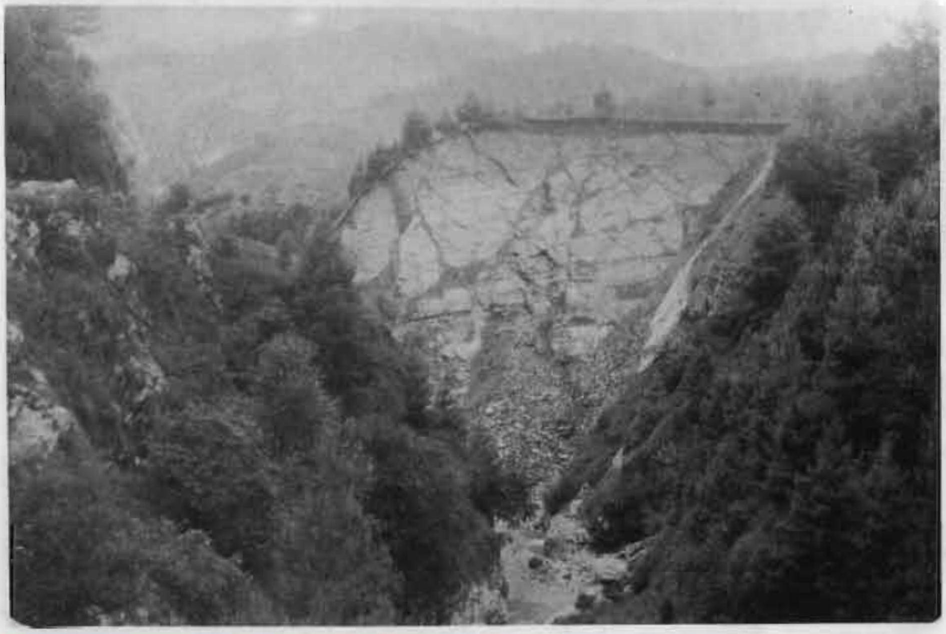


Plate 27: The plane and wedge rockslides on the right bank of the Bisinkhel *Khola* which dammed the stream. View towards the south

Plate 28: The previous (washed out) bridge over the Malekhu *Khola*, as observed on January, 1990. View towards the east. Courtesy T.R. Paudel.

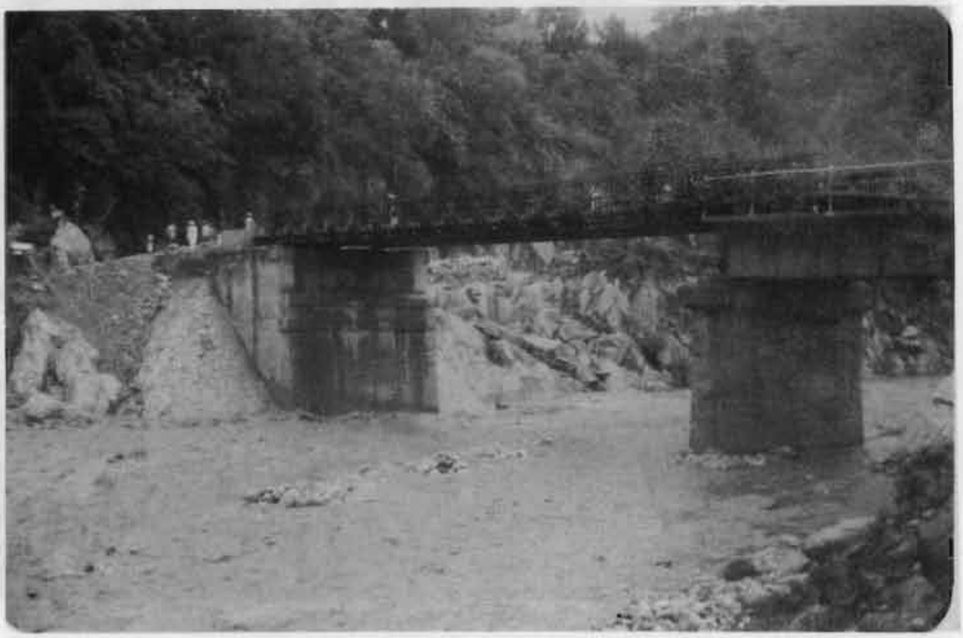


Plate 29: The partially damaged bridge over the Malekhu *Khola* replaced by a Bailey bridge. View towards the east

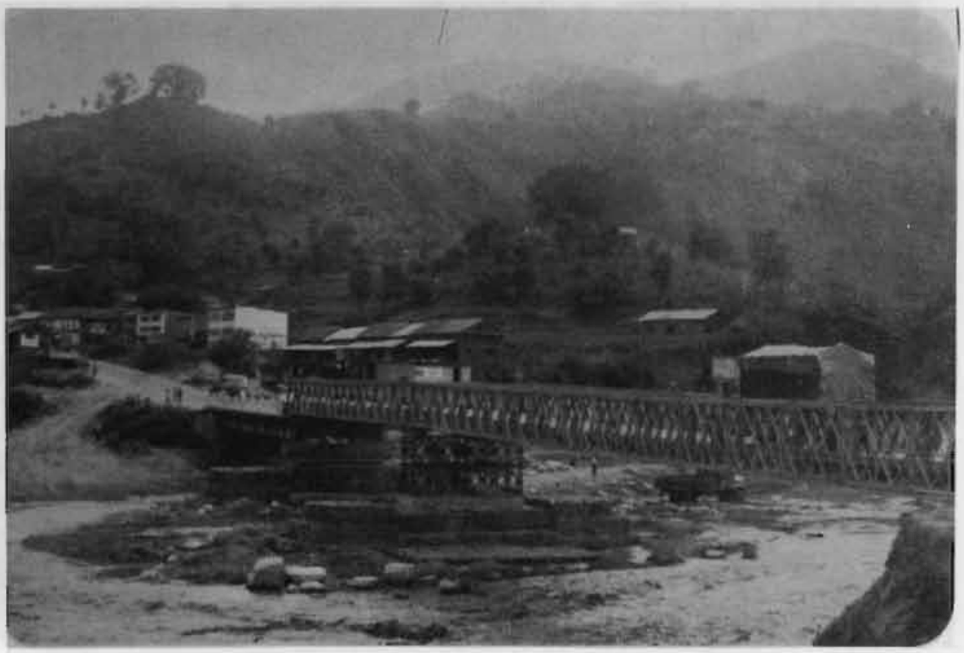


Plate 30: The Bailey bridge over the Agra *Khola* at Mahadev Besi. View towards the south-east

Plate 31: The Prithvi Highway to the east of Jogimara. Notice the thick silt and sand deposits on the road and washed out retaining walls. View towards the south-east

Plate 32: A large debris slide on the right bank of the Mahesh *Khola* at Galchhi. View towards the north

Plate 33: A long stretch of the right bank of the Trishuli River, west of Belkhu, scoured by the flood. View towards the north-east

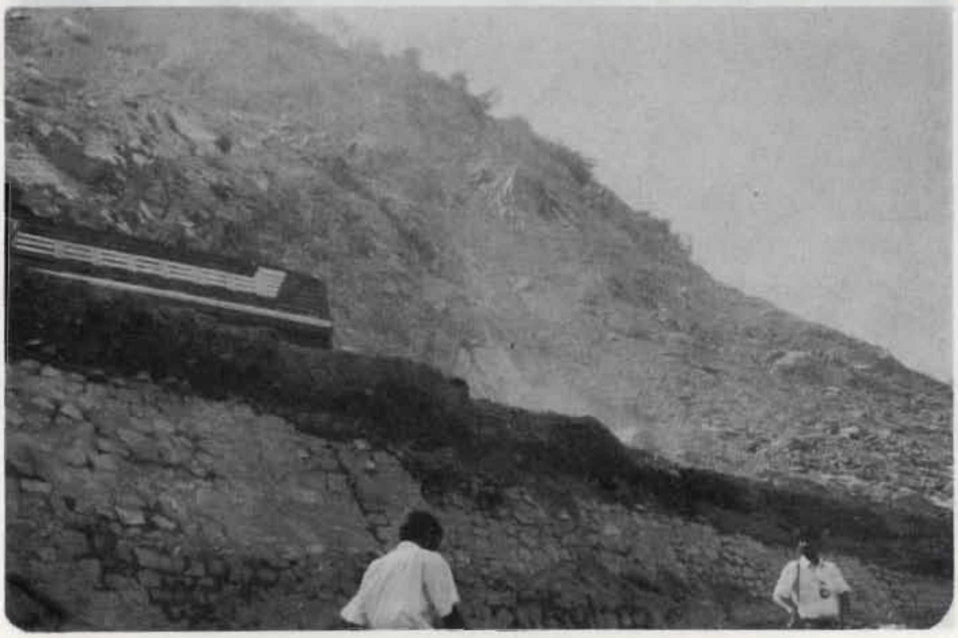


Plate 34: The rockslide at Jogimara. View towards the south-west

Plate 35: The Jogimara rockslide in slates and limestone. A stone quarry is also seen on the right bank. View towards the south-west

Plate 36: About three metres of thick sand and gravel bed deposited on the former cultivated floodplain (marked by a strip of grass) on the Malekhu *Khola*, about 200 m upstream from Malekhu. View towards the south-east

Plate 37: Several rock and soil slides around Chaubas, the Agra *Khola*. View towards the north-west

Plate 38: The Kitni *Khola* alluvial fan at Thana *Bazaar*, the confluence with the Sankhamul *Khola*. All the white boulders are of granite. View towards the north-west

Plate 39: Phedigaun and the debris fans around it. Notice that the middle channel is passing just through the village.View towards the east

Plate 40: A damaged house at Phedigaun. View towards the west

Plate 41: The debris fan at Phedigaun. Notice the green strip of cultivated land to the right. View towards the north-west

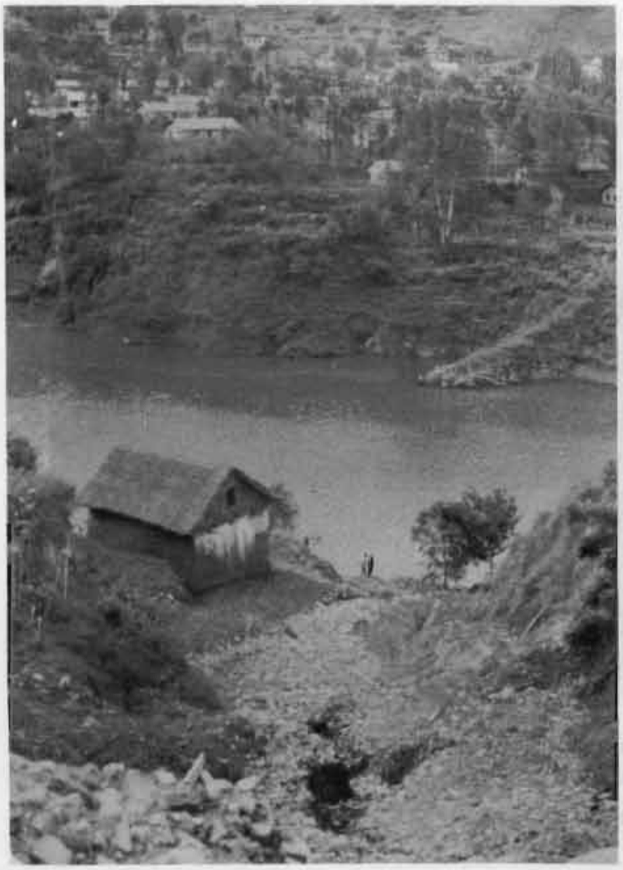
Plate 42: The paddy field in Palung filled up with 0.5 m thick sand. Notice also the damaged houses. View towards the north

Plate 43: The area around the school filled with boulders and wood debris. The present river channel of the Gairi *Khola* is 2.6 m below the inundated cultivated land. View towards the north-west

Plate 44: The left bank of the Gharti *Khola*, about 100m north of the school. Notice the one metre thick gravel bed with cross-bedding and scour marks. View towards the west

Plate 45: The cultivated land filled up with sand at the temple of Indrenithan on the right bank of the Palung (Sankhamul) *Khola*. Notice the flood level mark on the houses about 70 cm above the sandbar. View towards the west

Plate 46: The sand and silt deposits in the temples at Indrenithan, about 70 cm above ground level. View towards the west



◂ Plate 47: Debris flow in the gully at Dalsing *Pakha* destroyed two houses and carried down these two children for 75 m (where the two children are standing). View towards Markhu

Plate 48: Gully erosion and debris flow on the southern slope of the Kulekhani Reservoir near Markhu. View towards the south-west ▸

Plate 49: Large rockslide at the contact between granite (white) and slate (grey) on the right bank of the Ipa *Khola*. There is a wide debris fan below the slide. View towards the west

Plate 50: Sheet flooding and debris flow in Karaonje. Most of the pebbles are derived from the Upper Siwaliks. Notice buried and destroyed houses. View towards the south

Plate 51: Sheet flooding and debris flow in the southern part of Karaonje. Notice that the damaged village is in the middle of the fan. View towards the north

Plate 52: Rai Gaun inundated by flood. The flow direction is marked by the inclined fence to the right. The high flood level was at the ceiling of the ground floor of the hut. View towards the west

Plate 53: Back water flow marked by an even bed of sand in the Sangle *Khola*. Notice the landslide on the Middle Siwaliks and the high flood level marked by the colour difference in grass. View towards the west


Plate 54: Sketch of the Bagmati Barrage command area. The total command area is 122,000 hectares

Plate 55: Downstream view of the Bagmati Barrage and the mid-channel bar. Notice a damaged gate (in the centre) and a 33 m long tree trunk. The Bagmati Bridge is seen in the background. View towards the south

Plate 56: A large tree trunk resting over the dividing wall of the western canal. Notice also another log entrapped in the raised gates. View towards the south

Plate 57: Twisted and torn apart railings of the Barrage road. Notice several logs blocking the road. Most of the wood debris was already removed. View towards the west

- The tangled straw and roots around the gate-raising wires. Notice that straw can be seen up to the ceiling. View towards the north-west

Plate 59: The washed-out control tower on the left bank of the barrage. Notice also that the sediment undersluices and the eastern canal are filled up with gravel. View towards the north

Plate 60: Downstream view from the barrage towards the western bank. Notice the flood water was flowing beyond the houses of the Canteen *Bazaar* (in the background). View towards the south-west

Plate 61: The destroyed penstock pipe is seen above the Jurikhet *Khola*. The damaged pier of the penstock bridge is seen to the left. View towards the north ▸

Plate 62: The outlet portal of the Kulekhani I tailrace tunnel damaged by the debris flow from the Mandu *Khola*. Notice also the damaged intake canal of Kulekhani II. View towards the north ▾

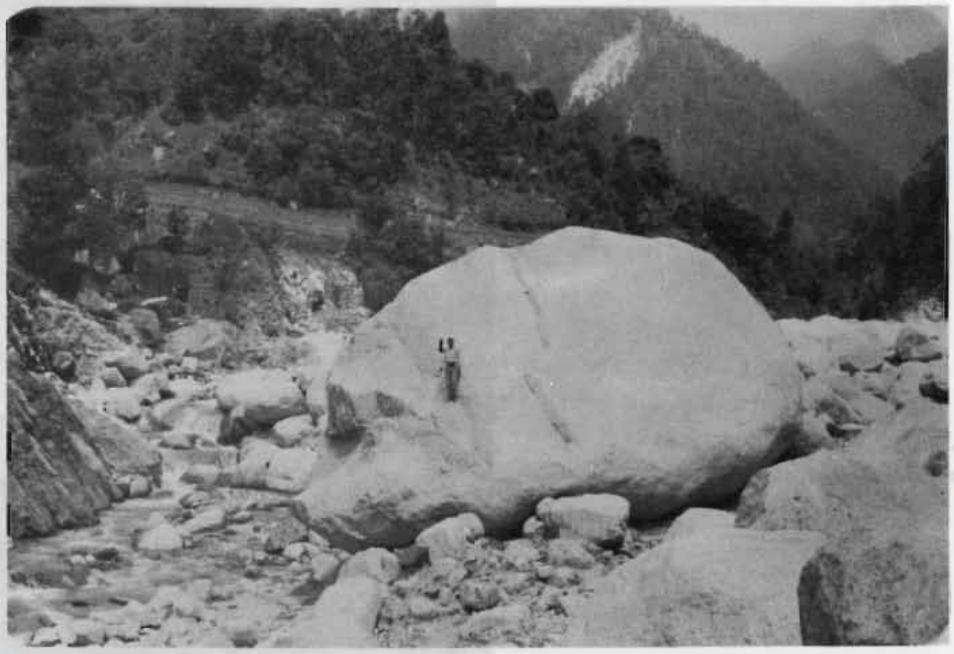


Plate 63: The huge 'Indreni' boulder in the Mandu *Khola*, about 25m upstream from the intake canal of the Kulekhani II. It is about 15m long and 10m high. View towards the north-west

Plate 64: Downstream view of the Mandu *Khola* from Dhorsing. Notice the damaged road on the right bank. The white boulders are of granite. View towards the south

Plate 65: The breached dykes on the right bank of the Manohari Khola. The river shifted to the west and destroyed the cultivated land of the Chitwan Valley

**Participating Countries of the Hindu Kush-Himalayan Region**

- Afghanistan
- Bangladesh
- Bhutan
- China
- India
- Myanmar
- Nepal
- Pakistan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