# 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.

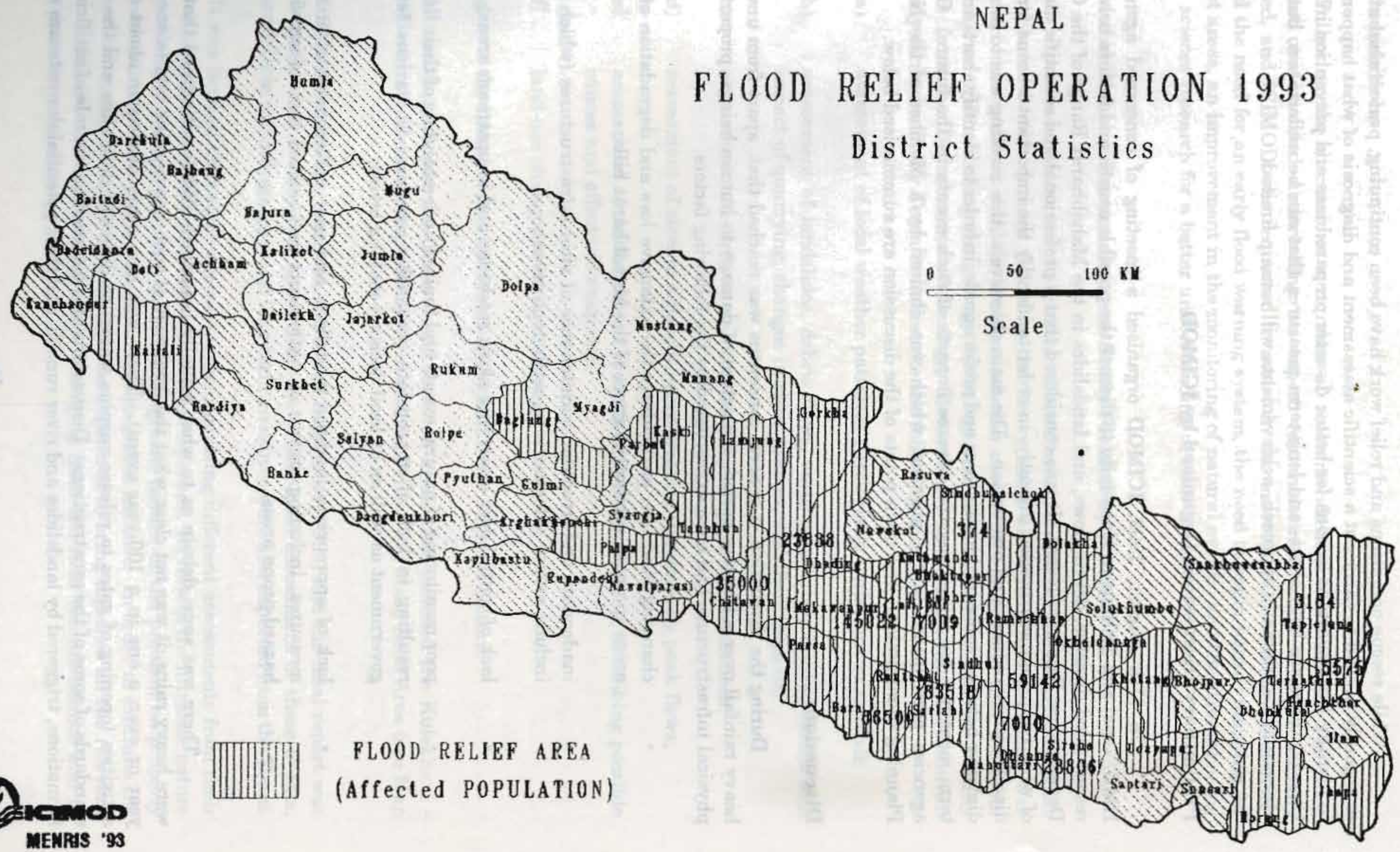
## Table 1.1: Flood Relief Operation 2050

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

Date : 08/21/93 | 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)
Humla
Darchula
Bajhang
Baitadi
Bajura
Mugu
Dadeldhura
Doti
Achham
Kalikot
Jumla
Kanchanpur
Dolpa
Dailekh
Jajarkot
Kailali
Mustang
Rukum
Surkhet
Manang
Bardiya
Myagdi
Baglung
Salyan
Rolpa
Kaski
Parbat
Lamjung
Gorkha
Banke
Pyuthan
Gulmi
Rasuwa
Dangdeukhuri
Arghakhanchi
Syangja
Tanahun
23838
Nuwakot
374
Dolakha
Palpa
Kapilbastu
Rupandehi
Nawalparasi
35000
Chitawan
Dhading
Kathmandu
Bhaktapur
Kabhre
Makawanpur
145022
7009
Ramechhap
Solukhumbu
3184
Taplejung
Parsa
Okhaldhunga
Sindhuli
Rautahat
83518
59142
Khotang
Bhojpur
Terathum
5575
Panchthar
Bara
96500
Sarlahi
7000
Siraha
Dhanusa
Mahottari
23806
Udayapur
Saptari
Sunsari
Ilam
Jhapa
Morang
MENRIS '93

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

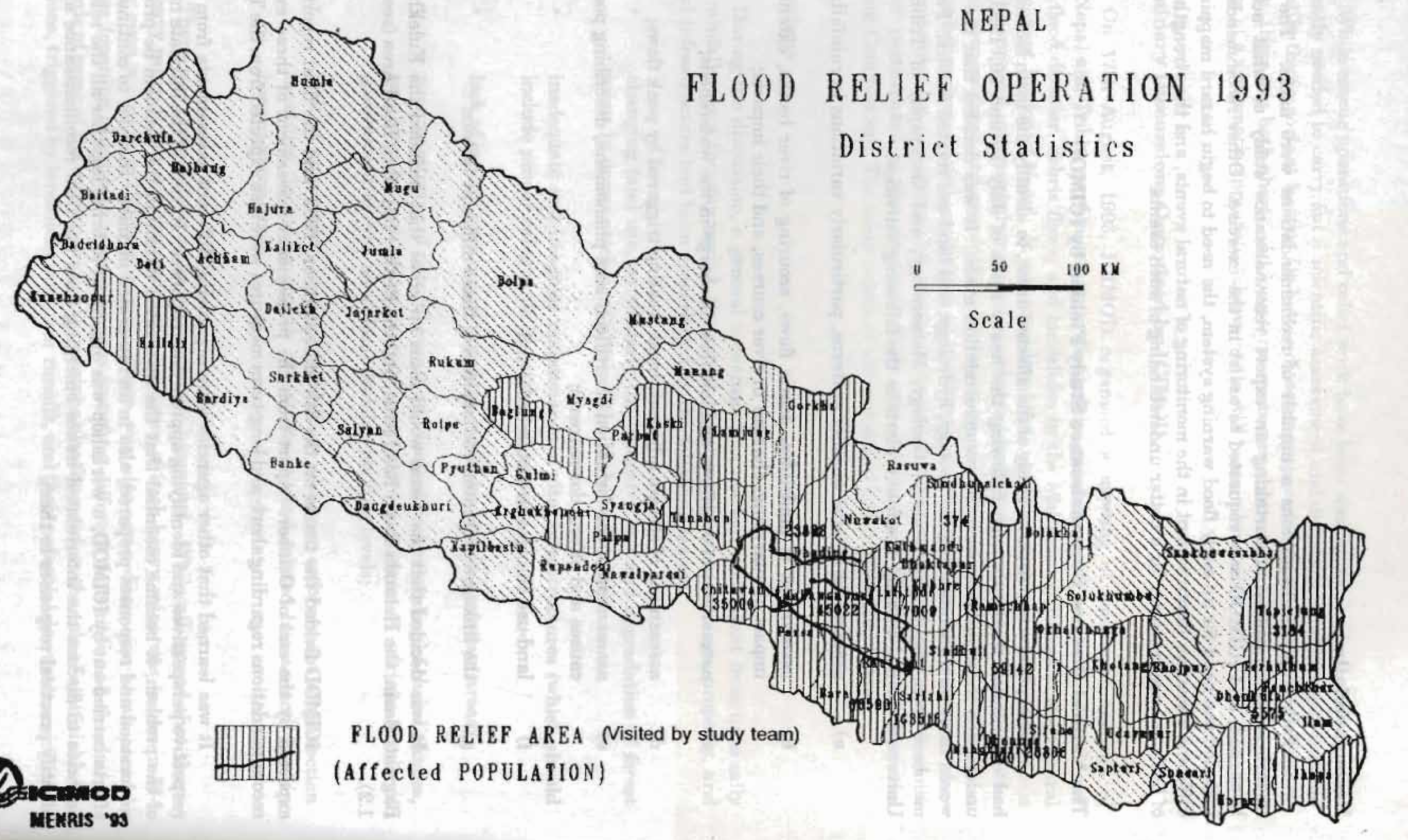
g) the linkages and interrelationships of these different factors.

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
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Dailekh
Jajarkot
Dolpa
Mustang
Rukum
Surkhet
Bardiya
Salyan
Rolpa
Baglung
Myagdi
Manang
Gorkha
Kaski
Lamjung
Banke
Pyuthan
Gulmi
Syangja
Tanahun
Rasuwa
Nuwakot
Dangdeukhuri
Kapilbastu
Rupandehi
Nawalparasi
Palpa
Chitawan
35000
Dhading
Kathmandu
Bhaktapur
Kabhre
Lalitpur
7000
Makwanpur
45022
Parsa
Bara
Sarlahi
Sindhuli
Dolakha
Solukhumbu
Okhaldhunga
Khotang
Bhojpur
Sankhuwasabha
Taplejung
3154
Terhathum
Panchthar
Dhankuta
2575
Ilam
Jhapa
Morang
Sunsari
Saptari
Udayapur
Siraha
Mahottari
ICIMOD
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.

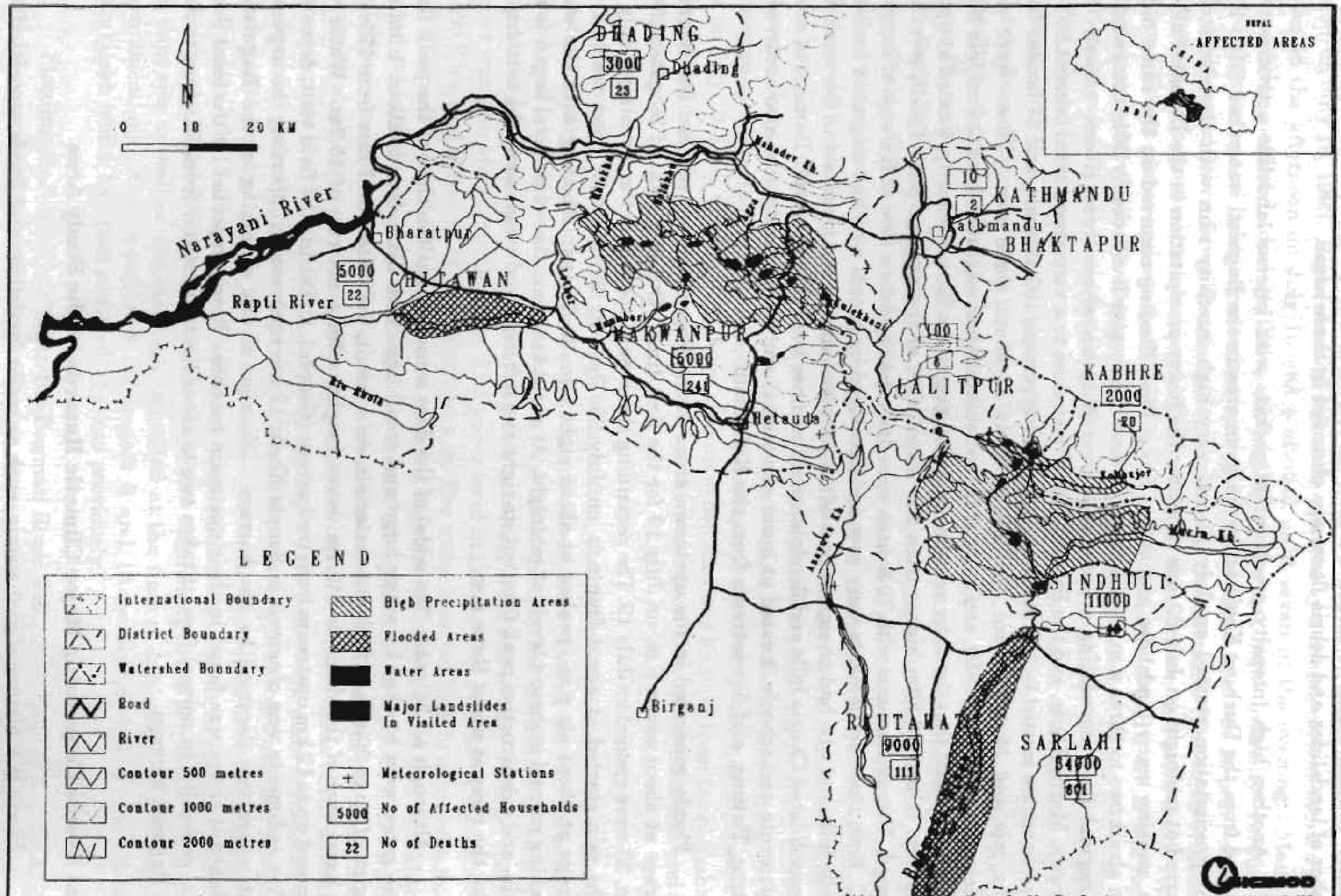
Floods generated in the upstream areas of the Bagmati River reached the Bagmati barrage at about seven p.m. on July 19 for the first time. Out of a total of 36 gates of the dam, 33 were opened on July 19. The remaining three were opened on the morning of July 20. Light rain started at about four p.m. 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**

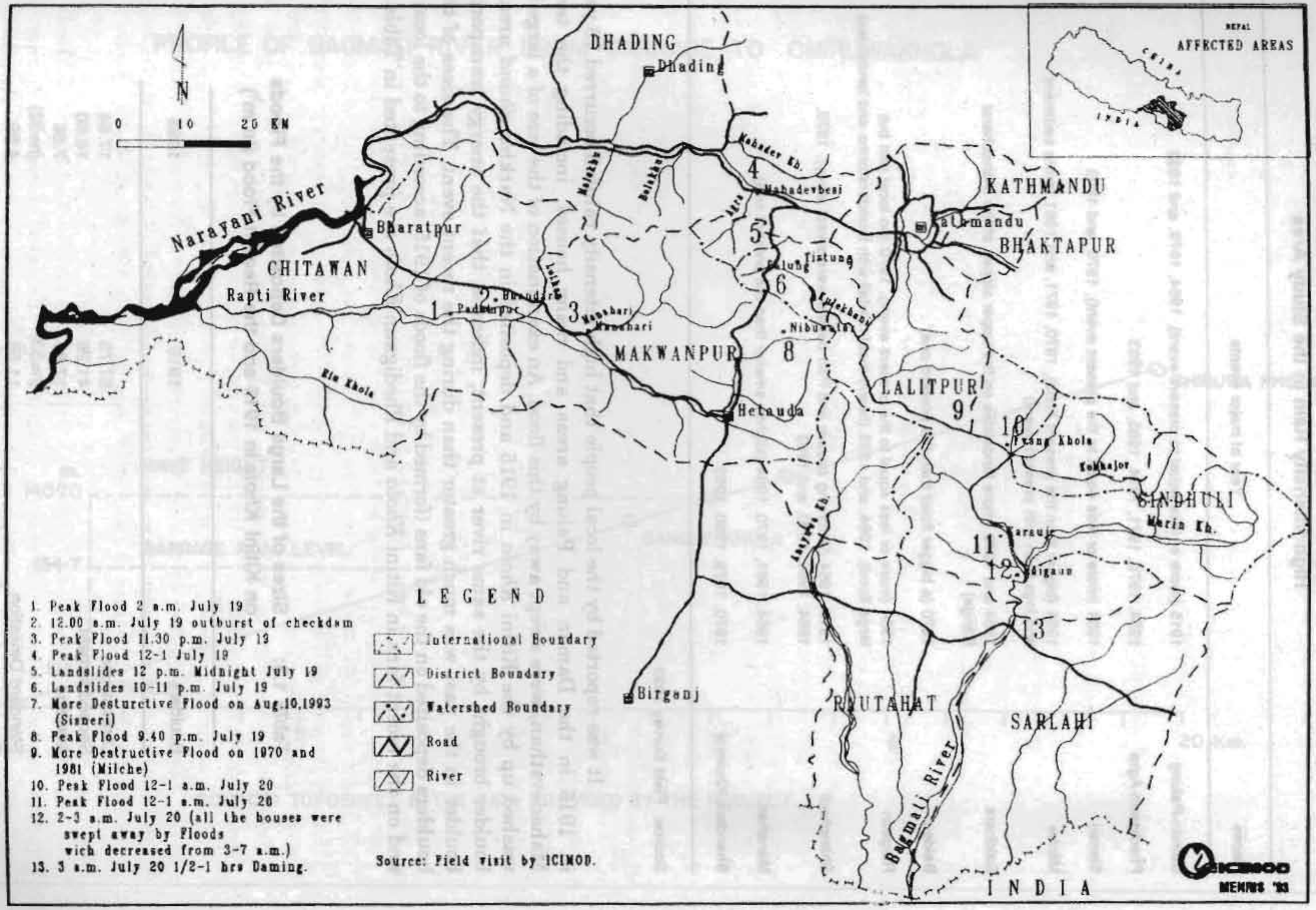


**Table 1.2: Major Landslides and Floods Associated with High Intensity Rain in the Study Area**

| 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

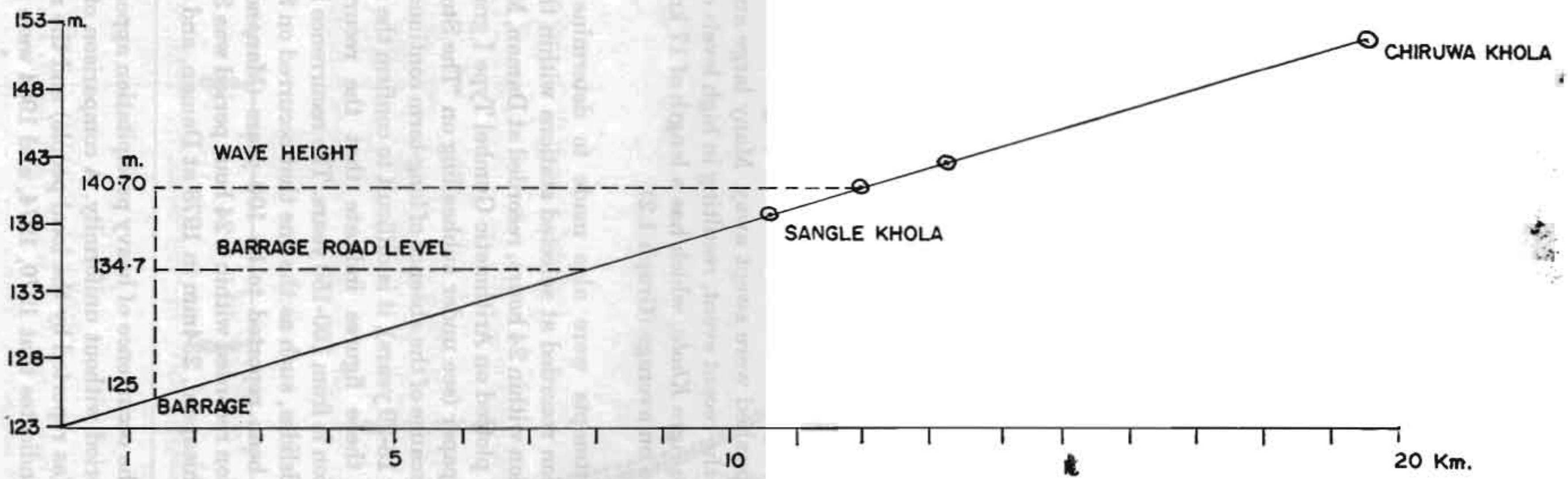
It was reported by the local people that high intensity rainfall occurred 78 years ago in 1915 in the Daman and Palung areas and many houses, including the temple of Mahadevsthan, were swept away by this flood. An examination of the size of a large boulder washed up by the Kitini *Khola* in 1915 and 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

## 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 |

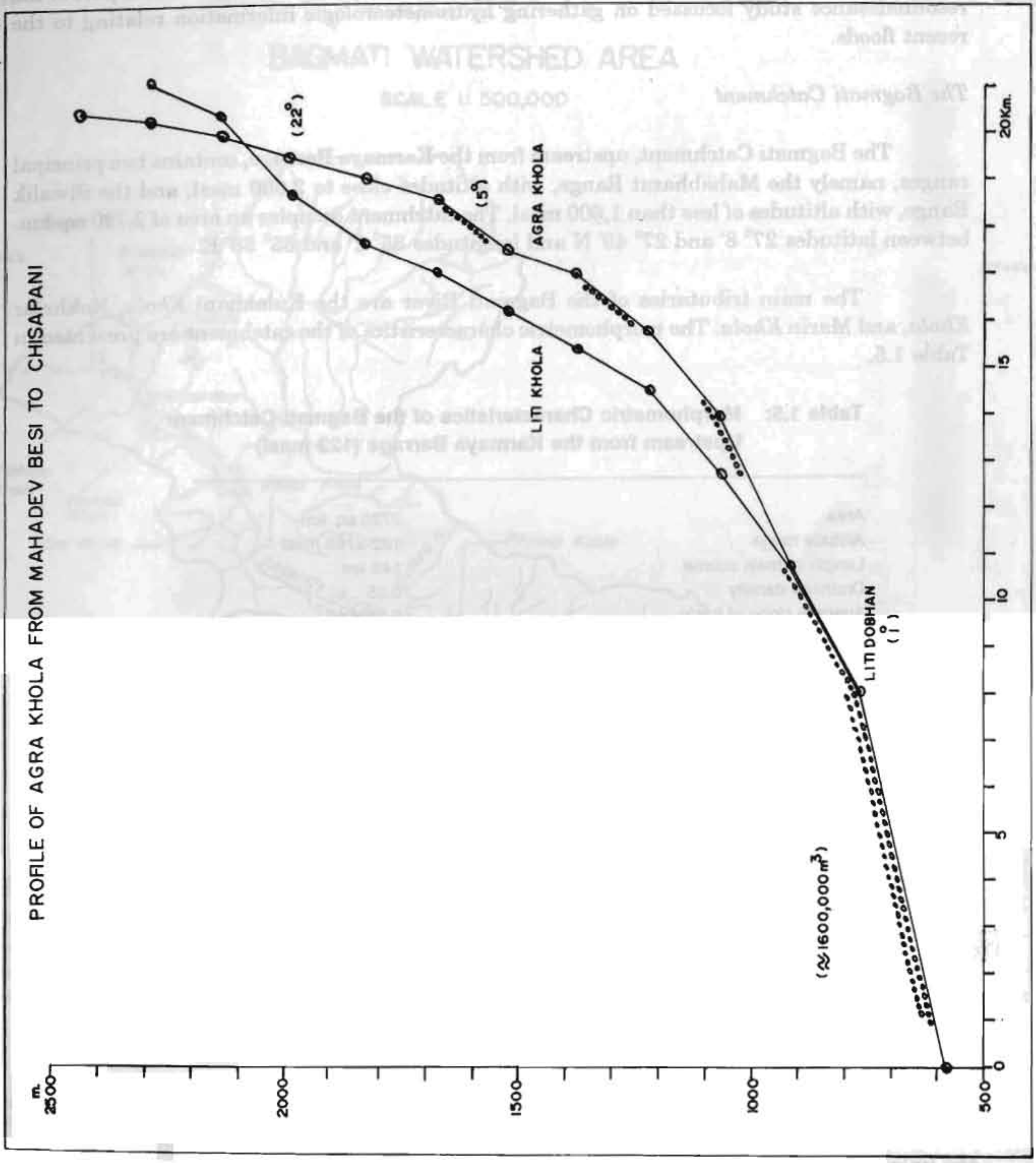
Source: Field Survey 1993

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
m.
2500
2000
1500
1000
500
0
5
10
15
20Km.
(22°)
(5°)
AGRA KHOLA
LITI KHOLA
LITI DOBHAN
(1°)
(≈1600,000m³)

**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.

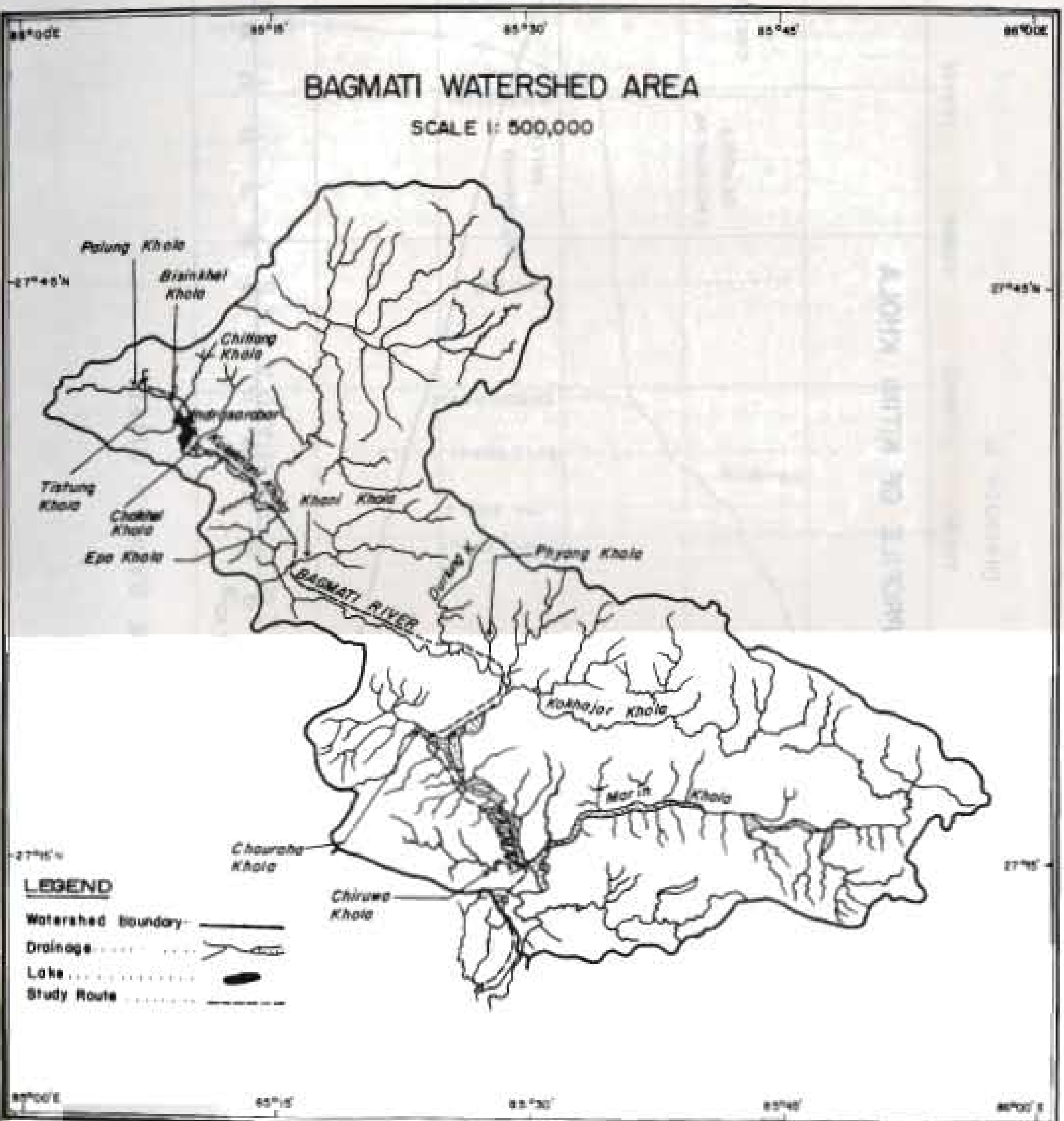



FIG.1.1: THE BAGMATI WATERSHED

FIG.1.2: LONGITUDINAL PROFILE OF KITINI KHOLA

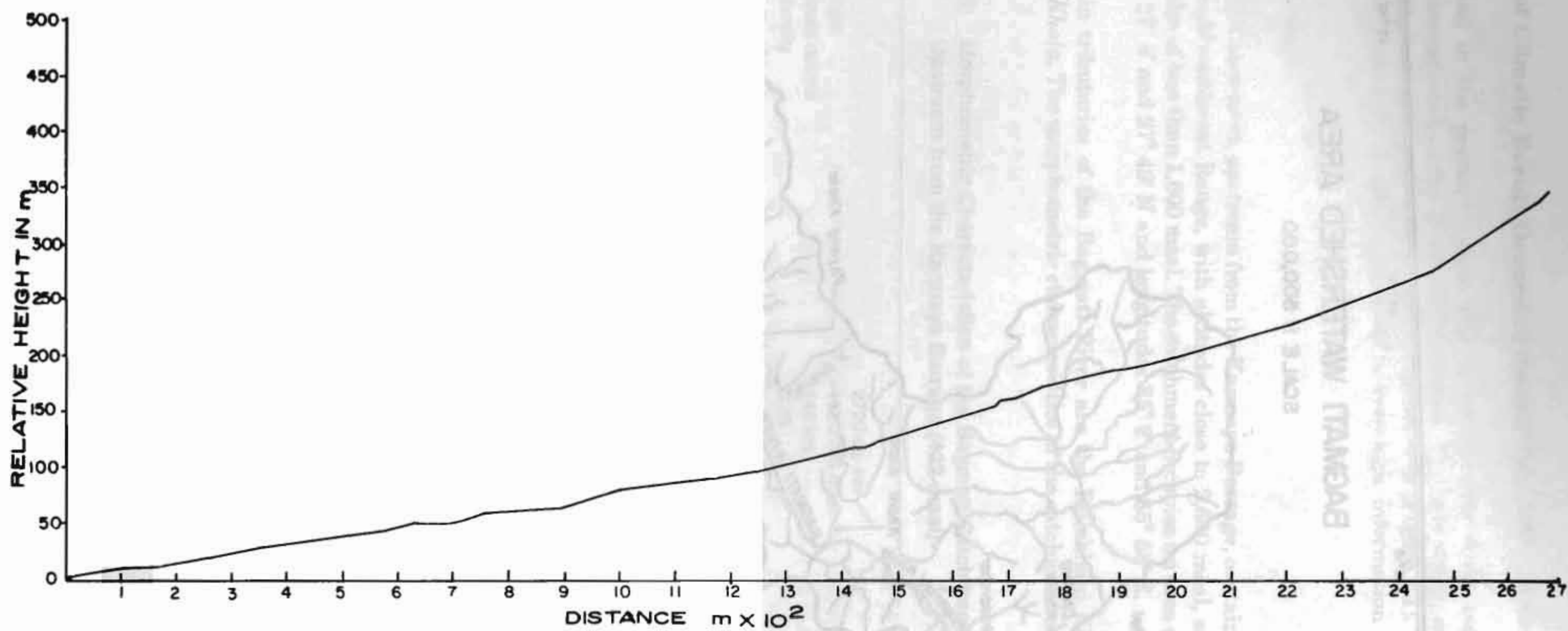


FIG-I.3: LONGITUDINAL PROFILE OF THE BAGMATI RIVER

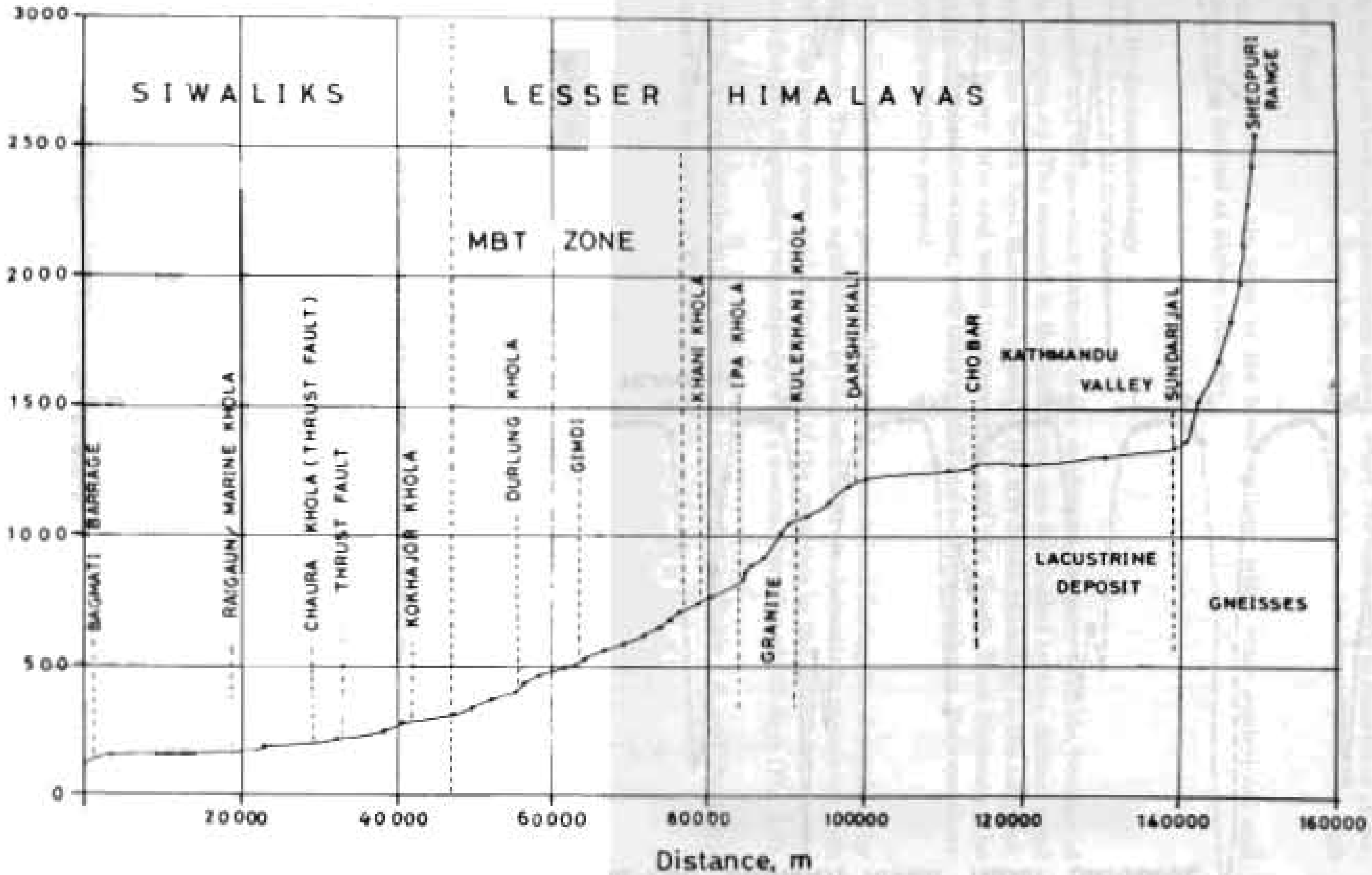
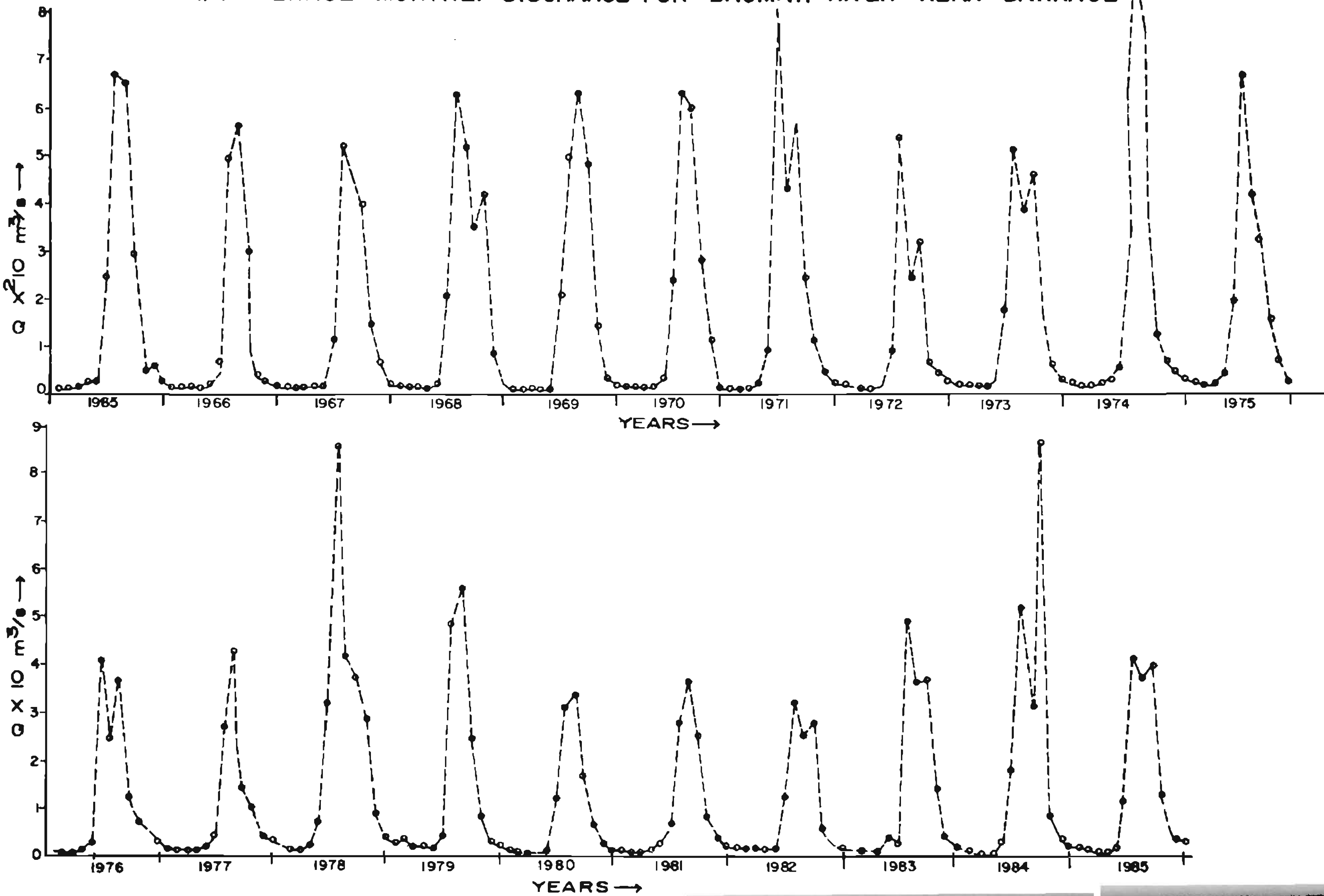


FIG.1.4: AVERAGE MONTHLY DISCHARGE FOR BAGMATI RIVER NEAR BARRAGE



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.

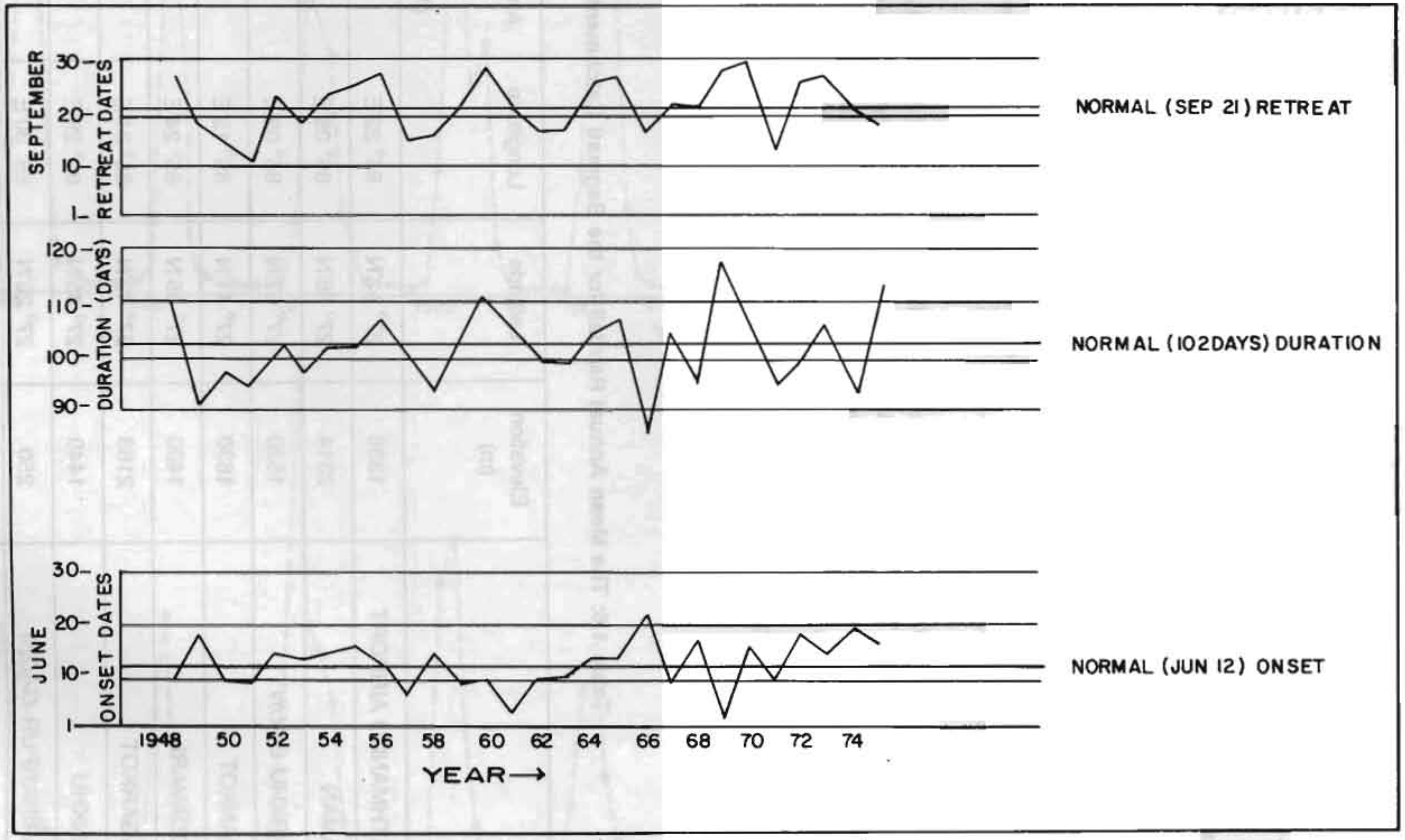
The Bagmati River has a perennial flow which is sustained during the dry season by groundwater sources. Therefore, agriculture in the catchment is substantially associated with the monsoon. The normal onset and retreat dates of the monsoon in the catchment are the 12th June and the 21st September respectively,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

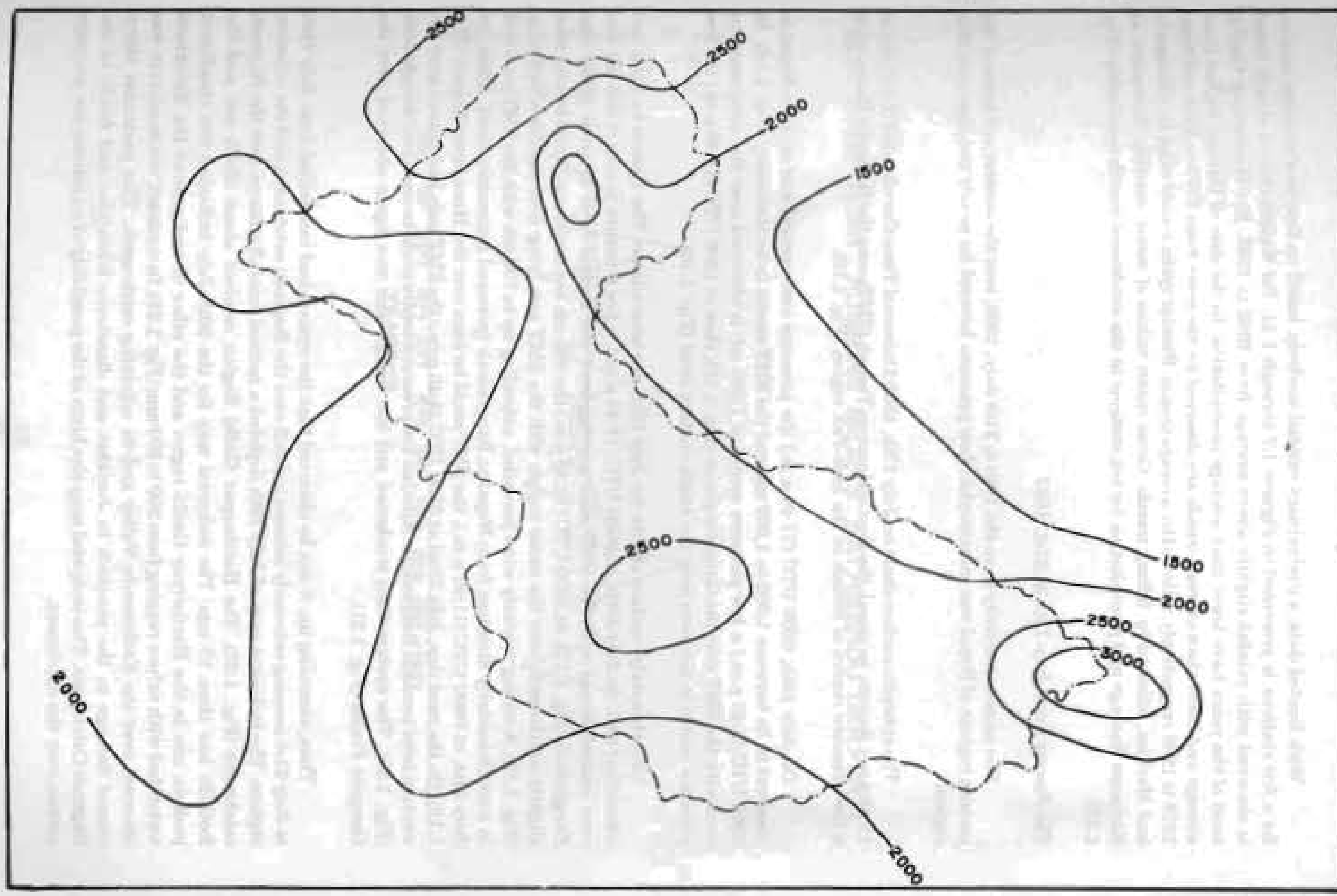
| | Elevation (m) | Latitude | Longitude | Annual average Rainfall (mm) (1987 - 1990) |
|---|---|---|---|---|
| KATHMANDU AIRPORT | 1336 | 27° 42'N | 85° 22'E | 1376 |
| DAMAN | 2314 | 27° 36'N | 85° 05'E | 1748.25 |
| MARKHU *GAUN* | 1530 | 27° 37'N | 85° 09'E | 1362 |
| THANKOT | 1630 | 27° 41'N | 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.I.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)

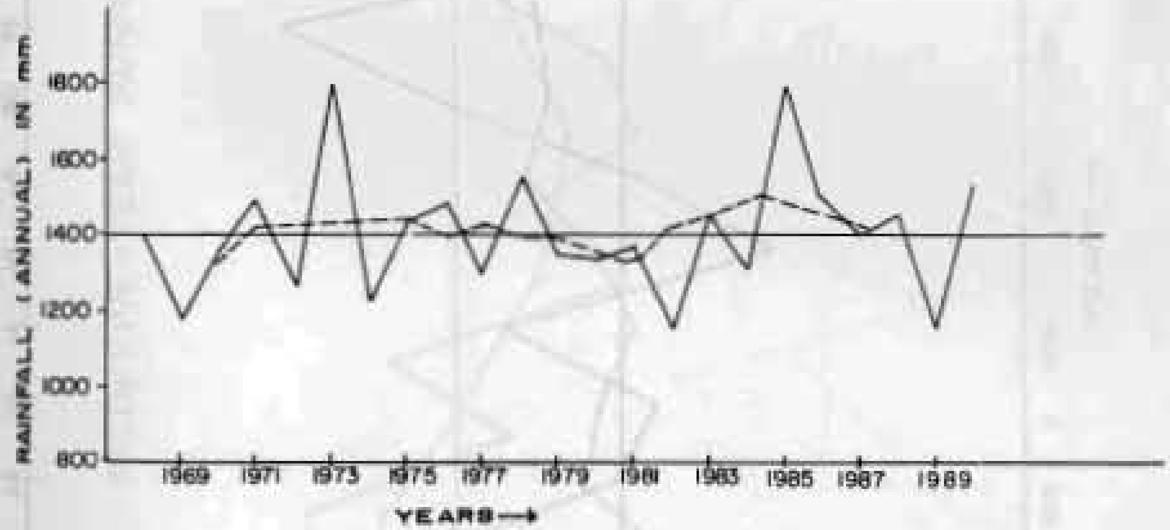


FIG.1.8: FIVE-YEAR RUNNING MEANS (HARIHARPUR GADHI)

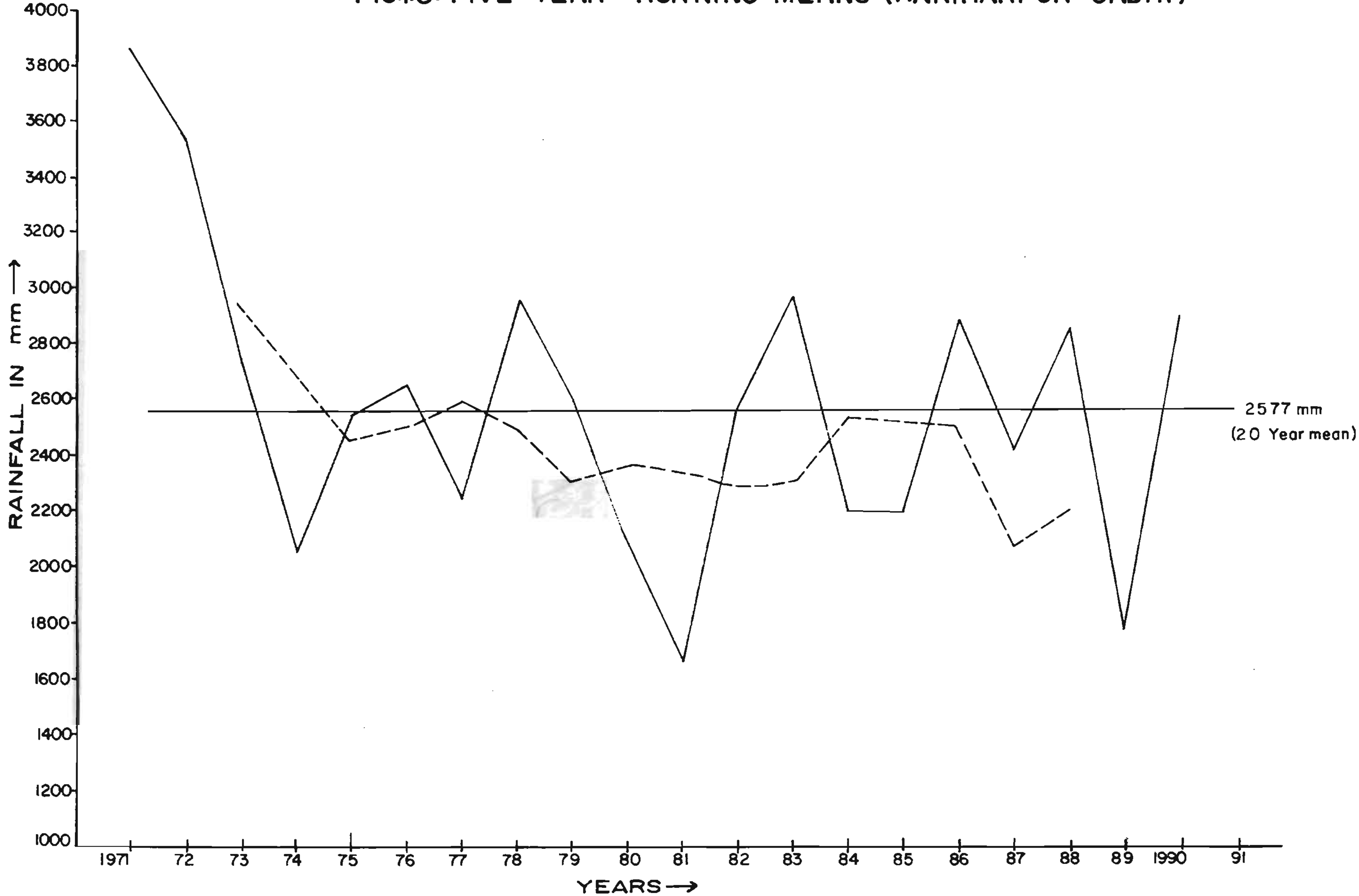
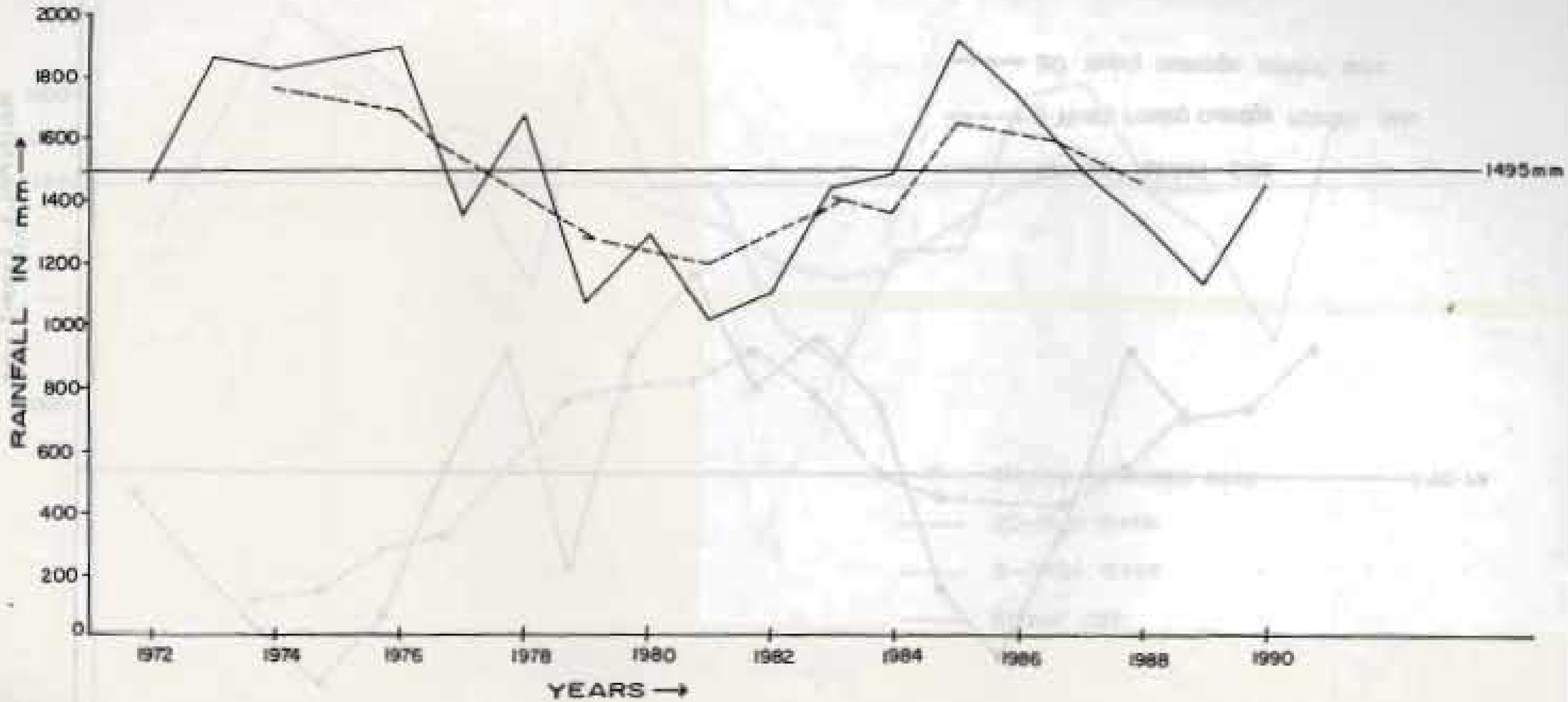


FIG.1.9: FIVE-YEAR RUNNING MEANS (MARKHU)



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

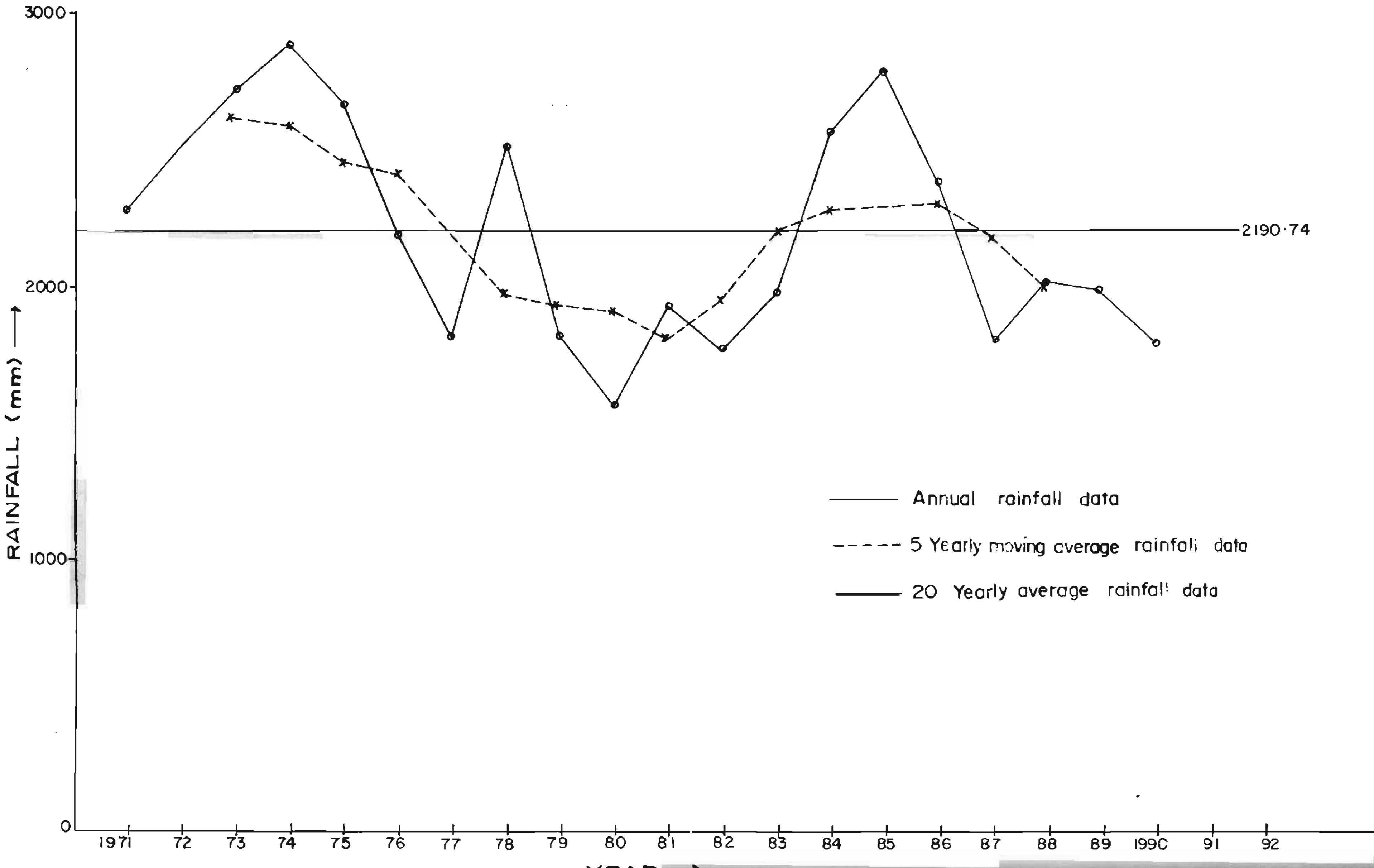


FIG.1.II: FIVE-YEAR RUNNING MEANS (DAMAN)

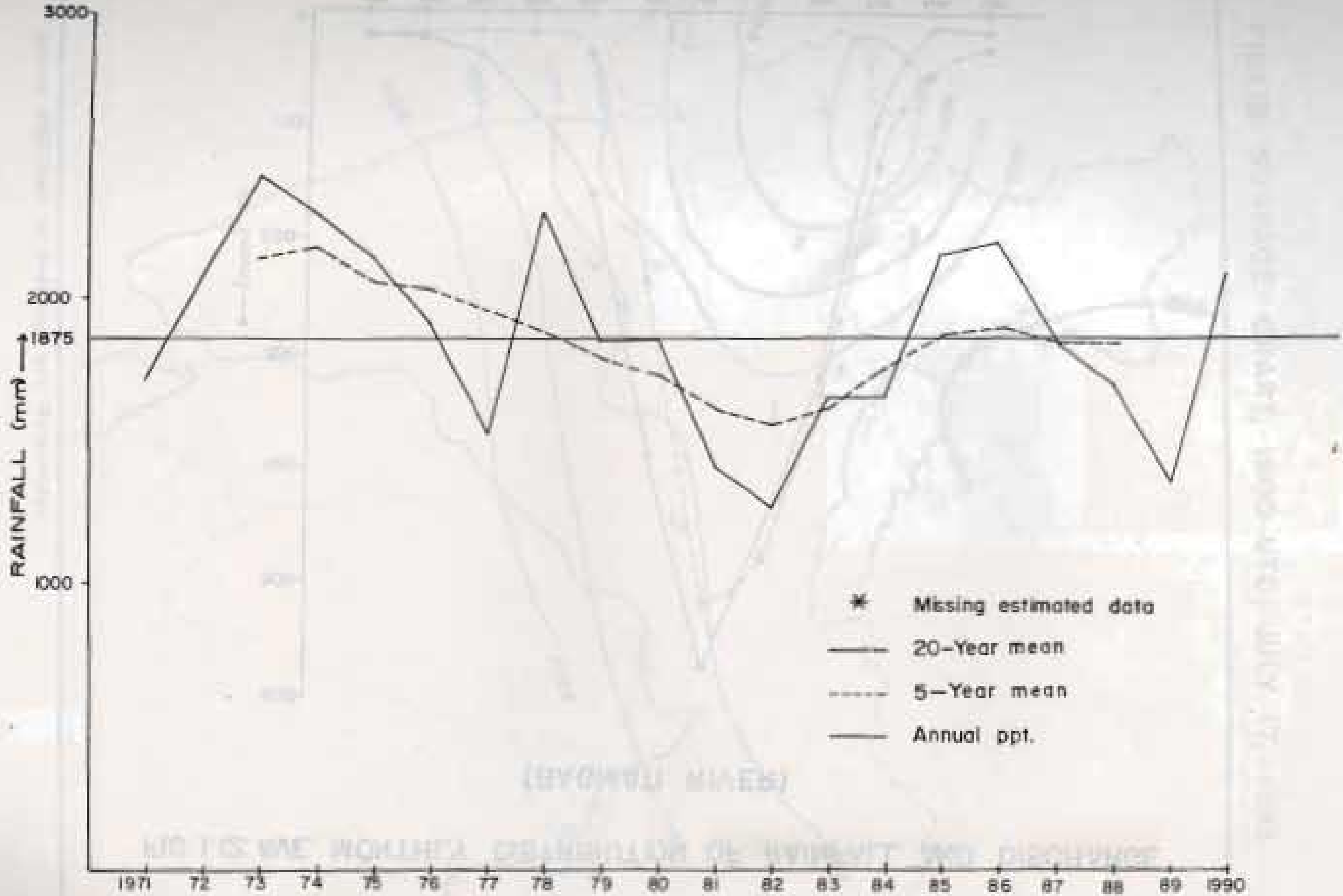


FIG.1.12: AVE. MONTHLY DISTRIBUTION OF RAINFALL AND DISCHARGE

(BAGMATI RIVER)

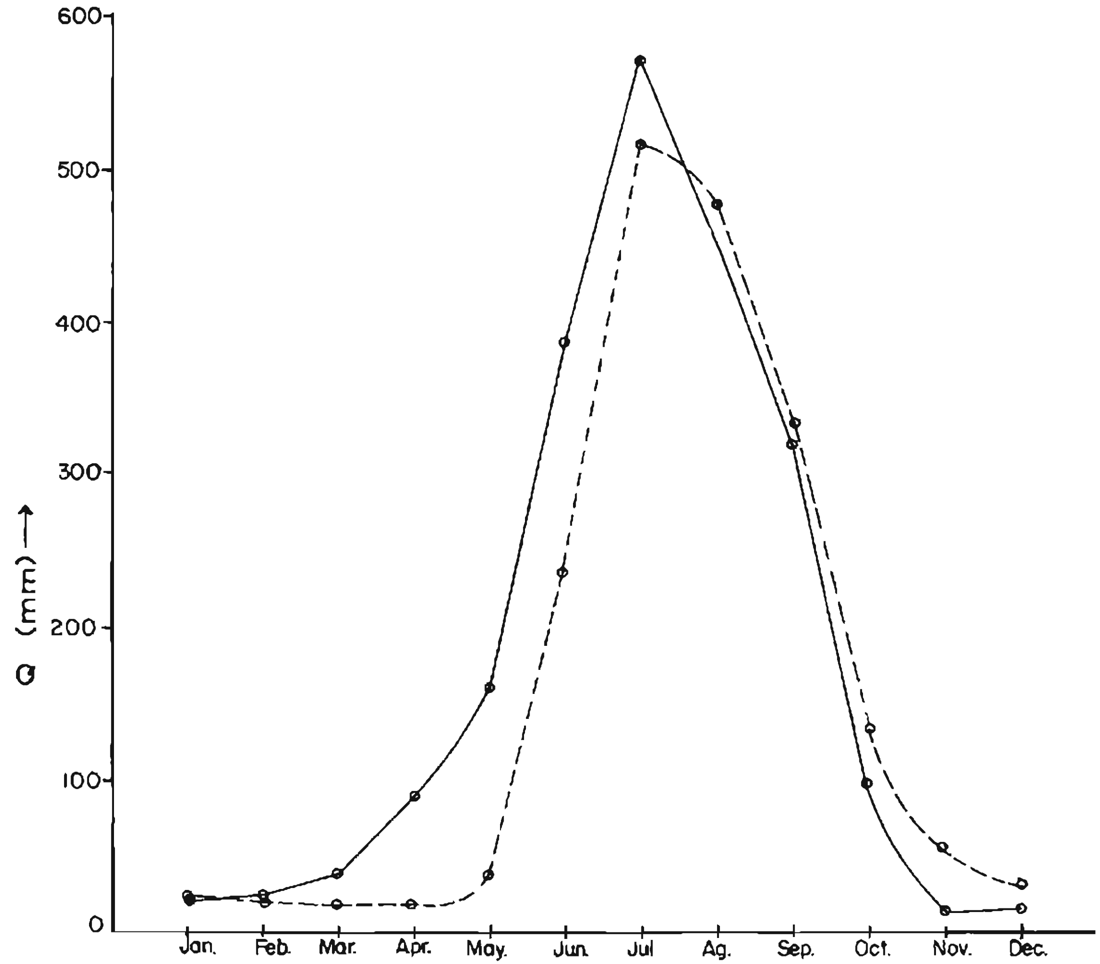
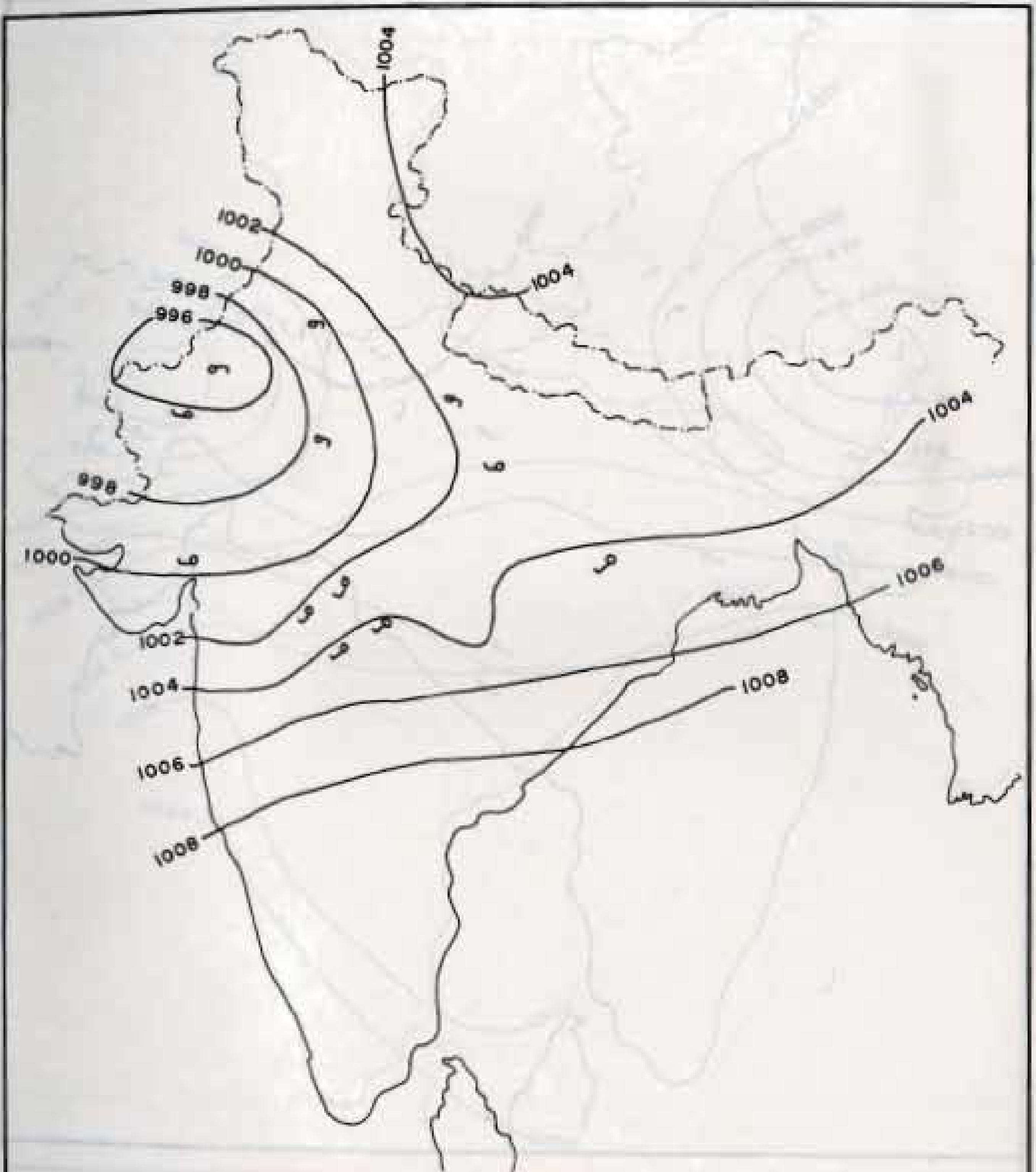


FIG.I.13: SURFACE CHART, 1800 UTC, JULY 17, 1993




Source: HMG/Dept of Hydrology and Meteorology

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

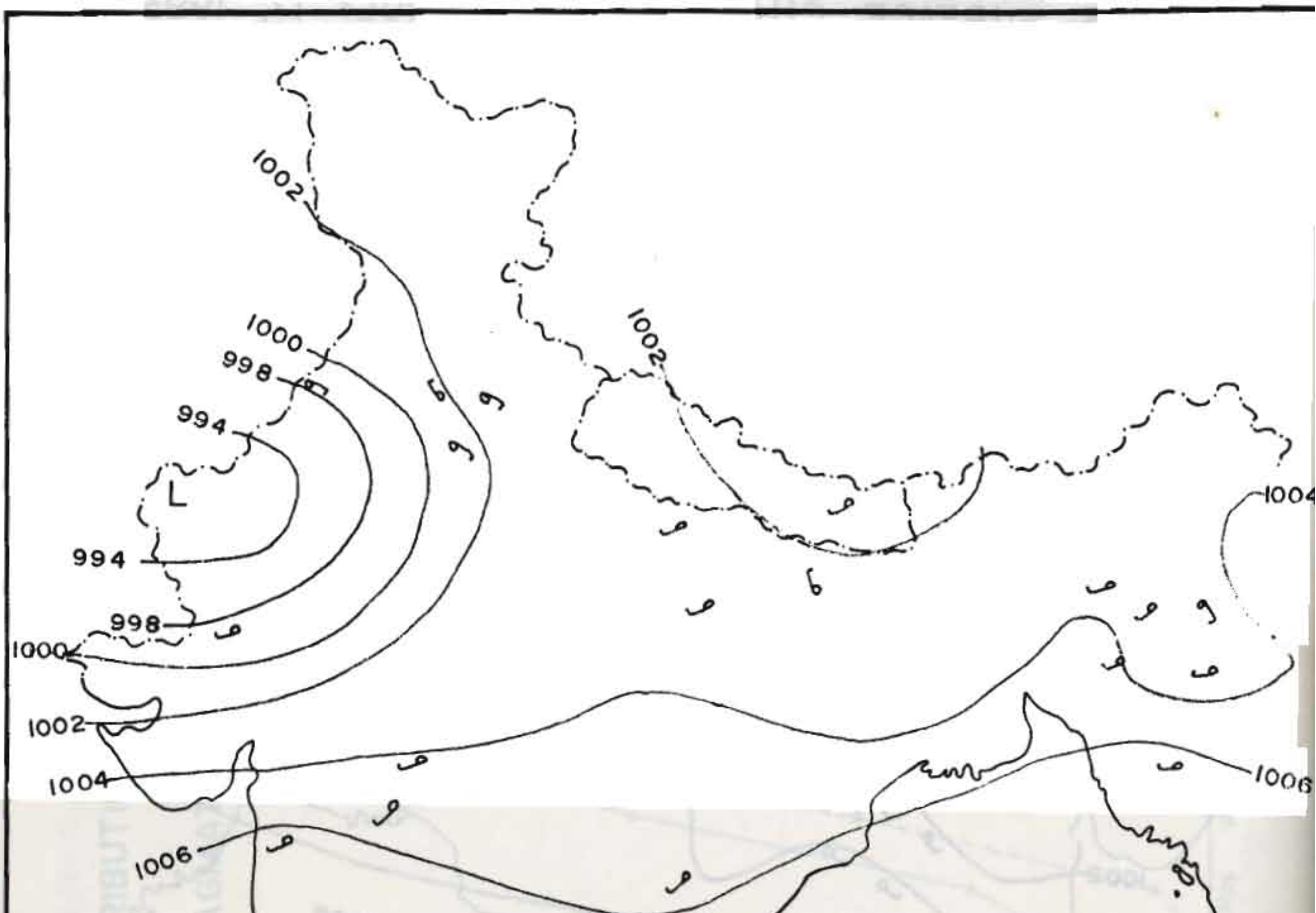


FIG.1.15: SURFACE CHART, 0900 UTC, JULY 18, 1993

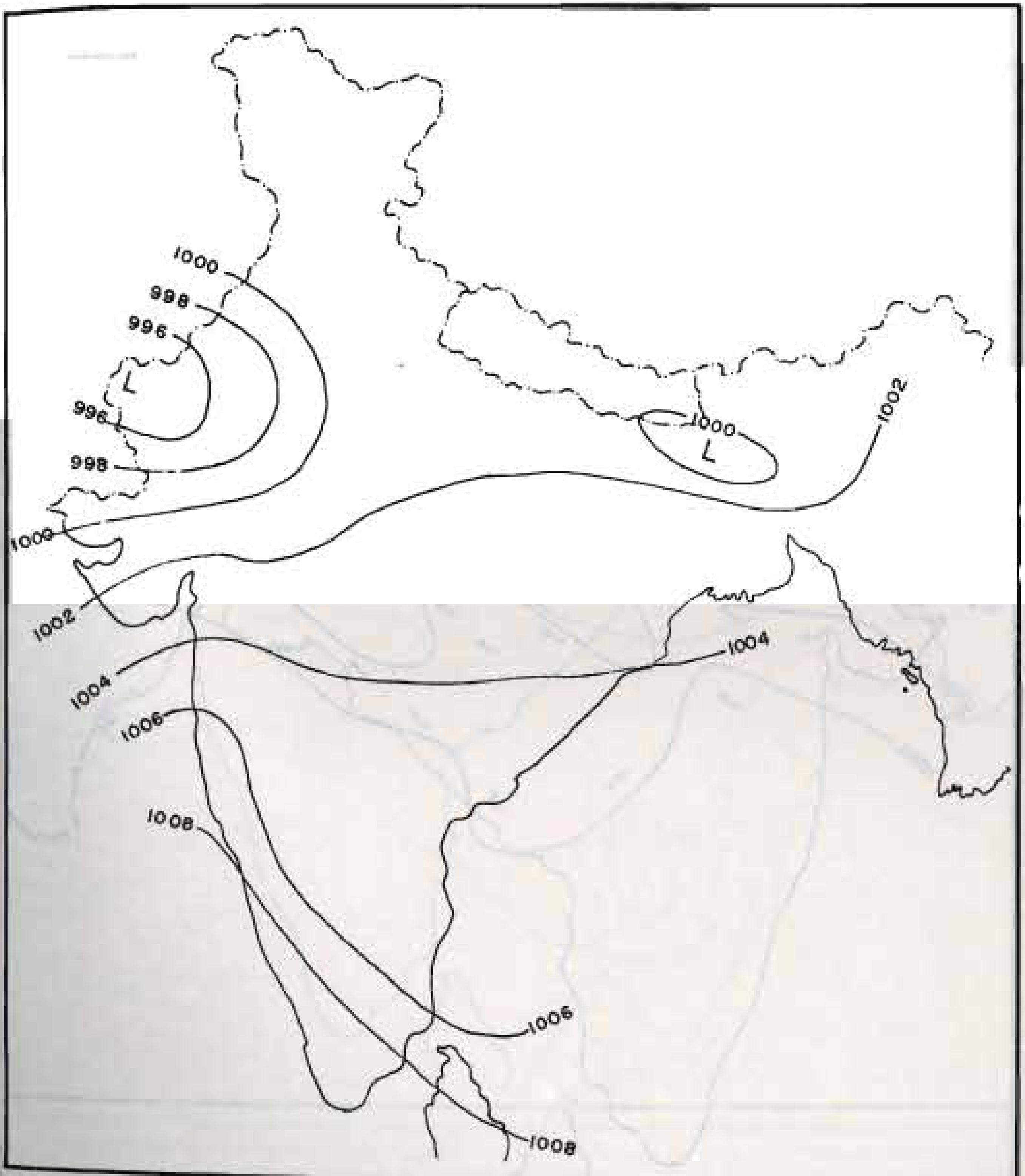


FIG.I. 16: SURFACE CHART, 1800 UTC, JULY 18, 1993

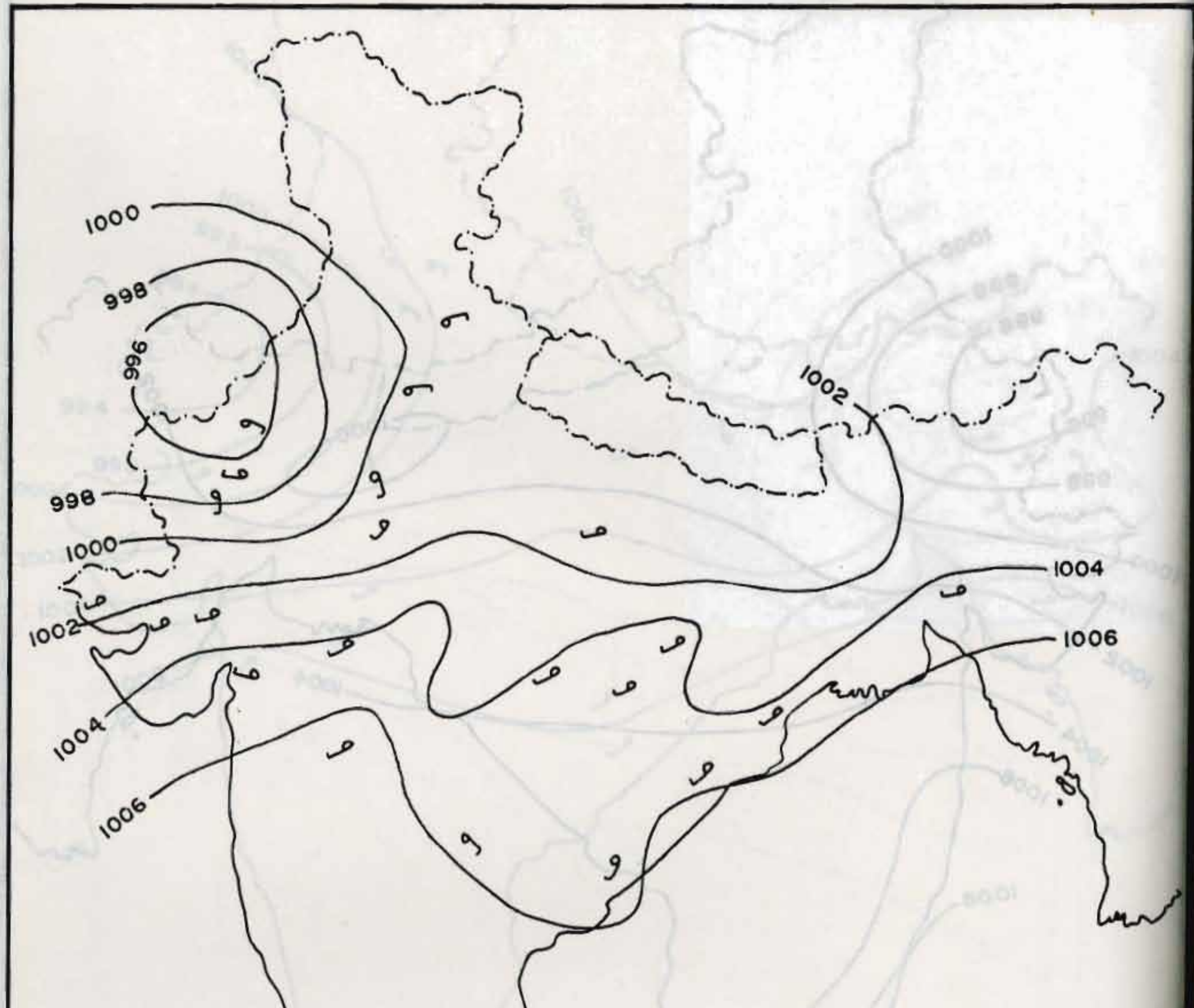


FIG.I.17: SURFACE CHART, 0600 UTC, JULY 20, 1993

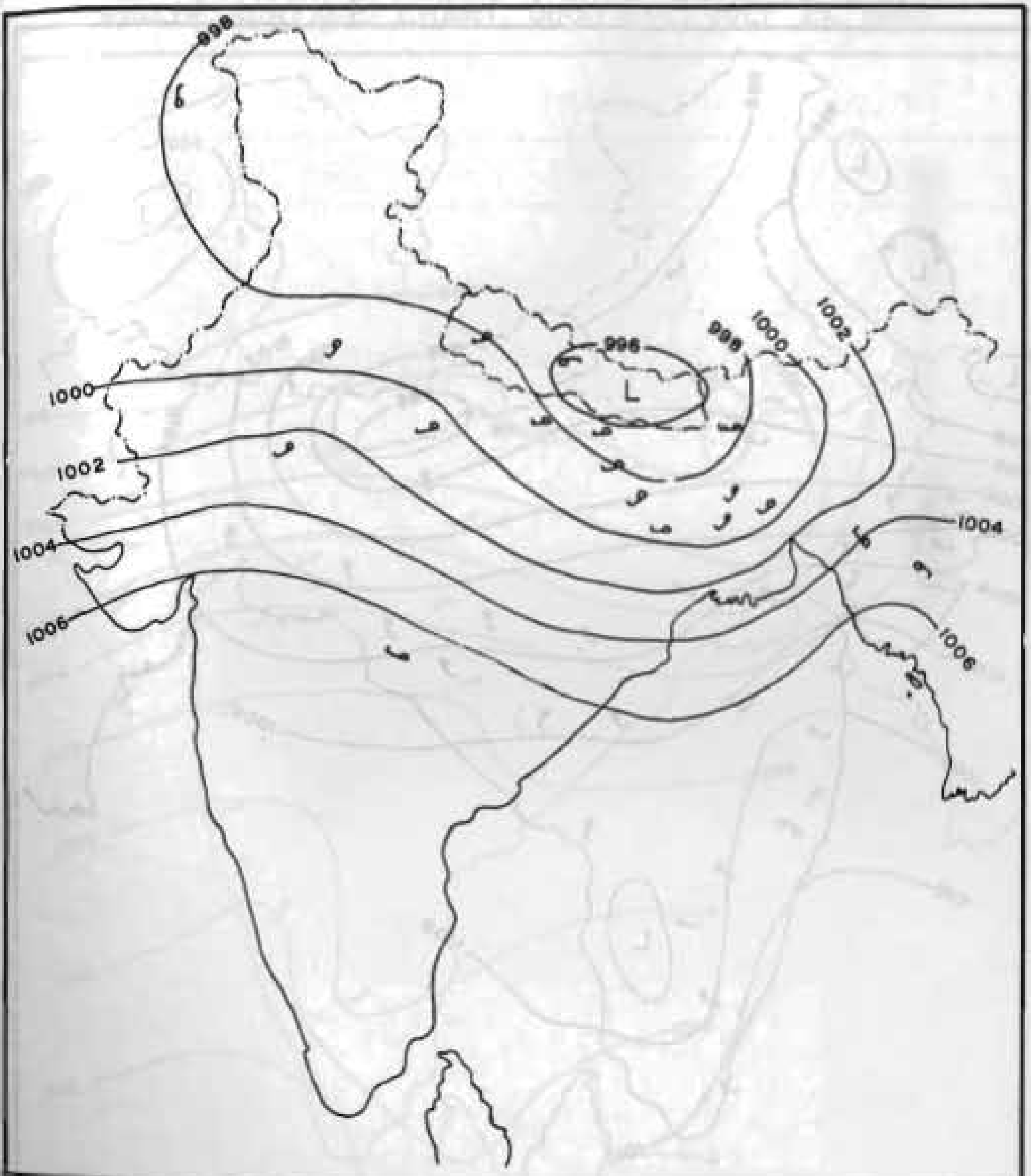


FIG.1.18: SURFACE CHART, 1800 UTC, JULY 20, 1993

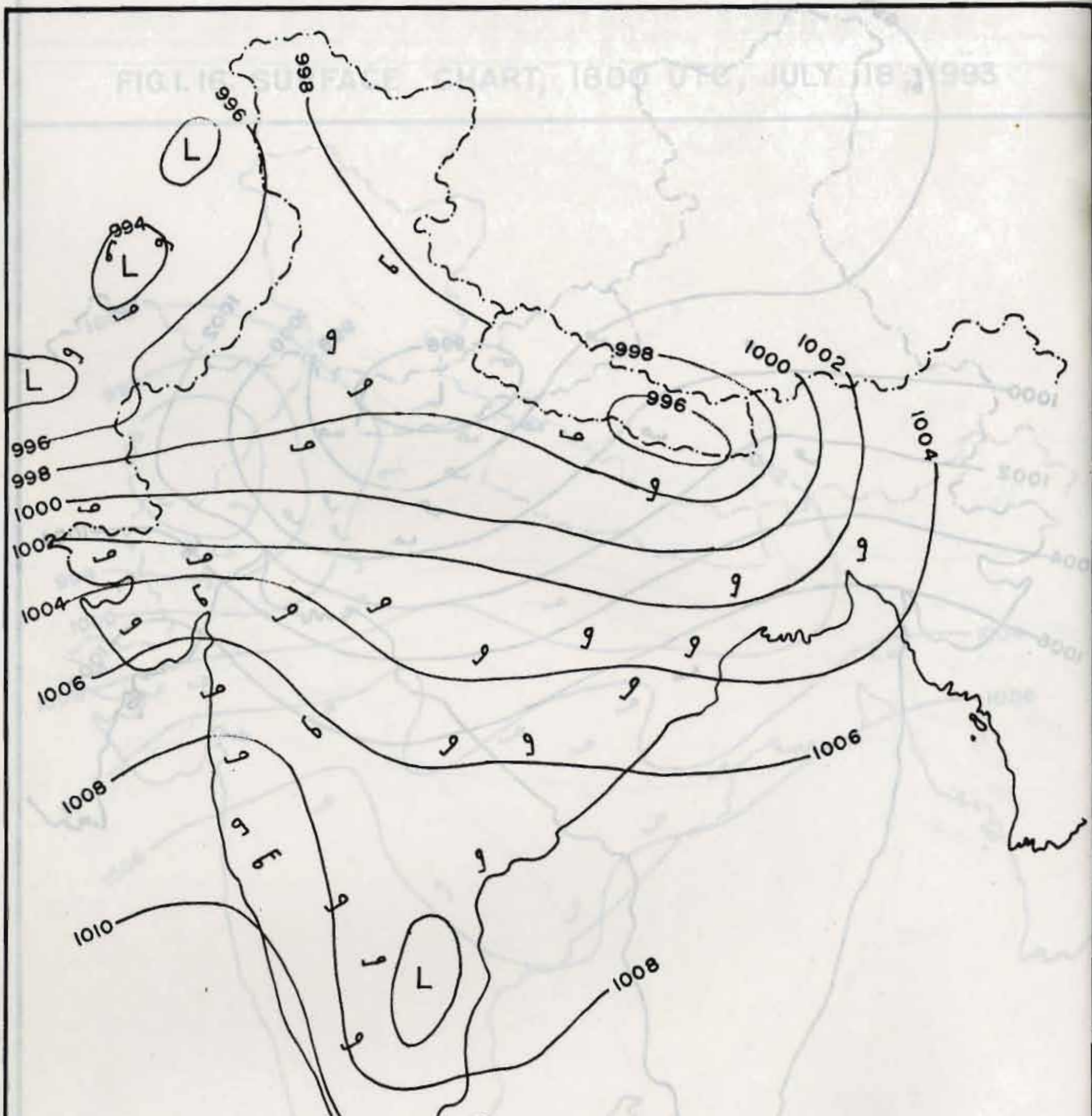


FIG.I.19: SURFACE CHART, 0600 UTC, JULY 21, 1993

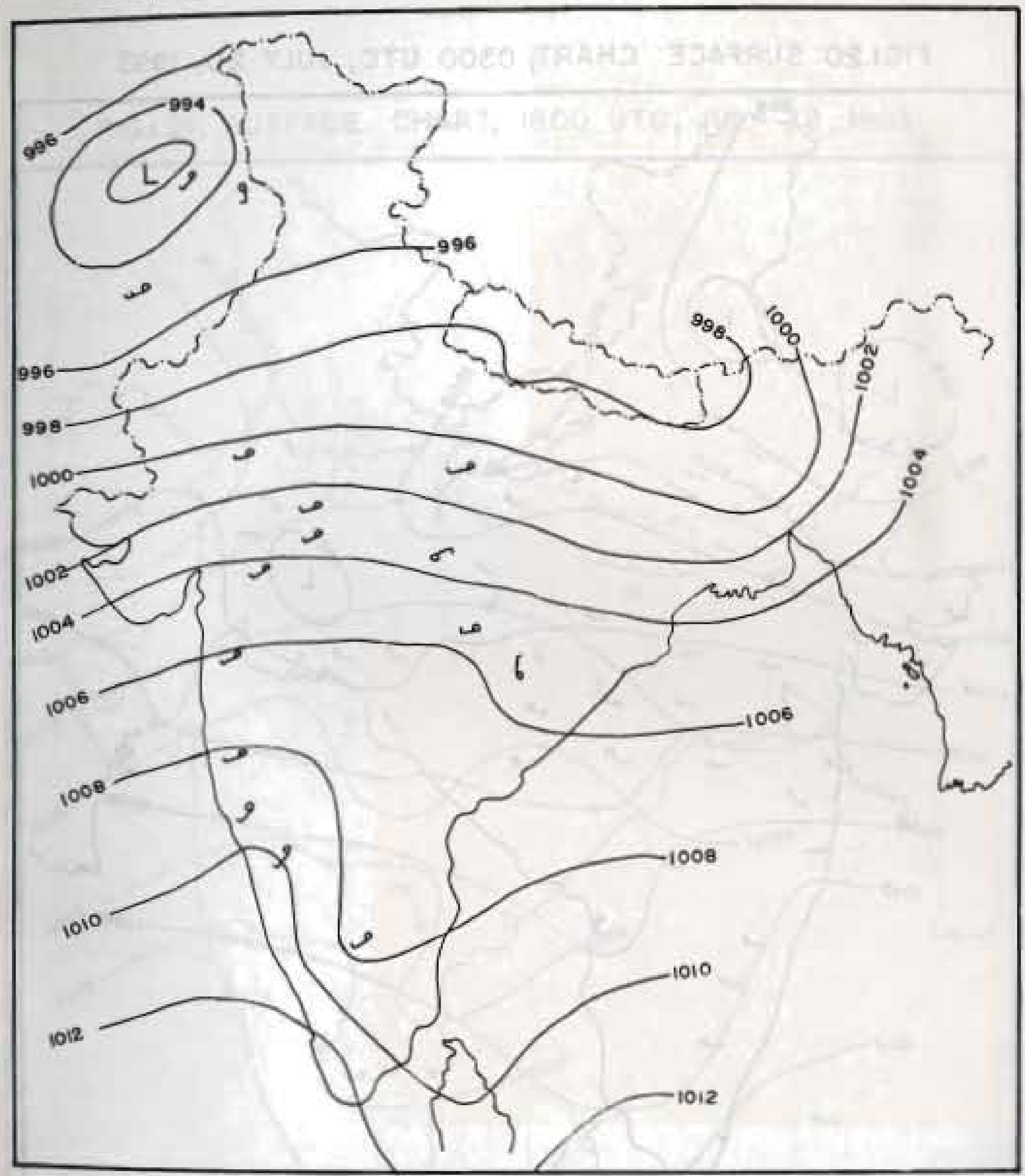


FIG.1.20: SURFACE CHART, 0300 UTC, JULY 20, 1993

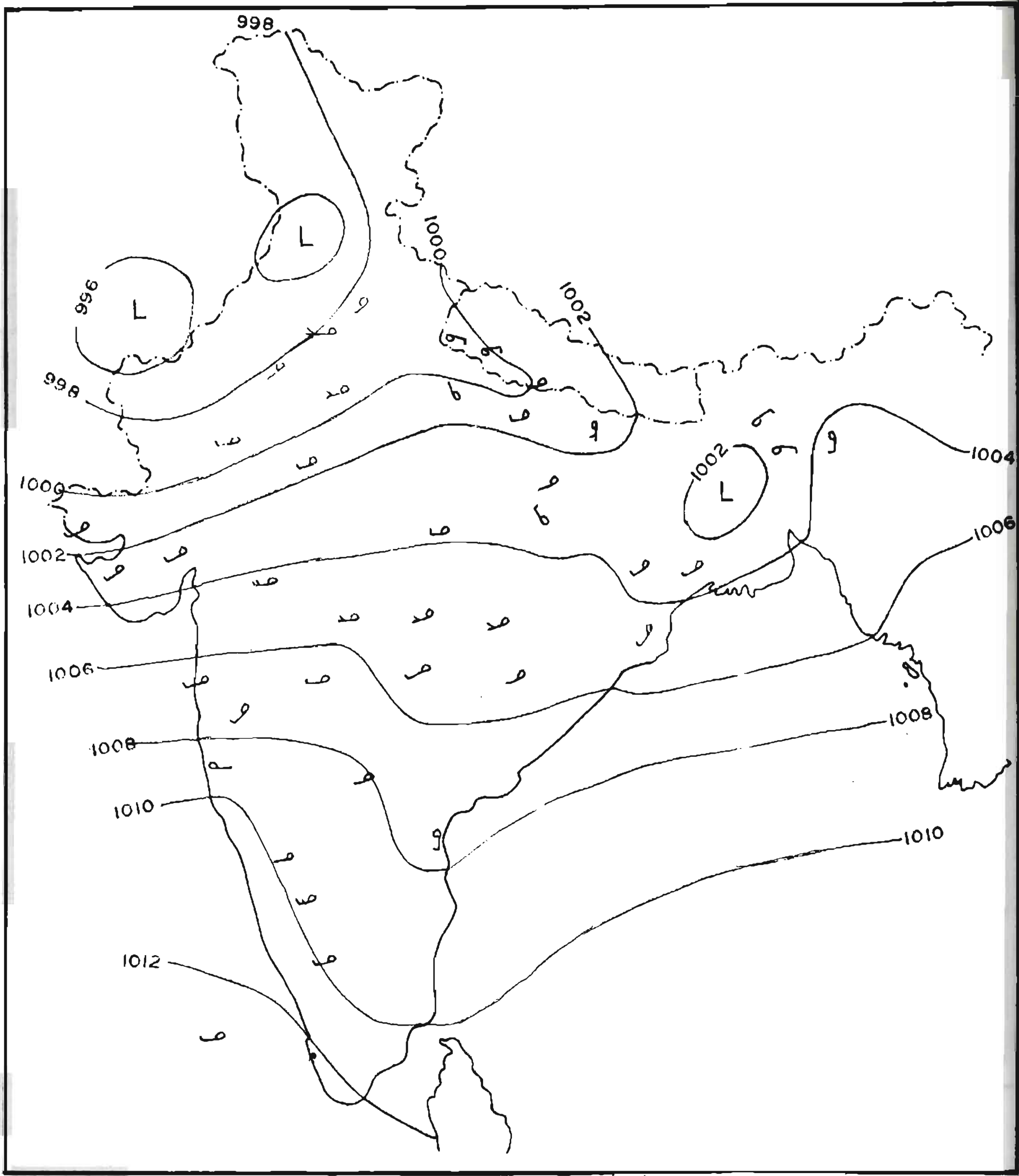


FIG.1-21: SURFACE CHART, 1800 UTC, JULY 22, 1993

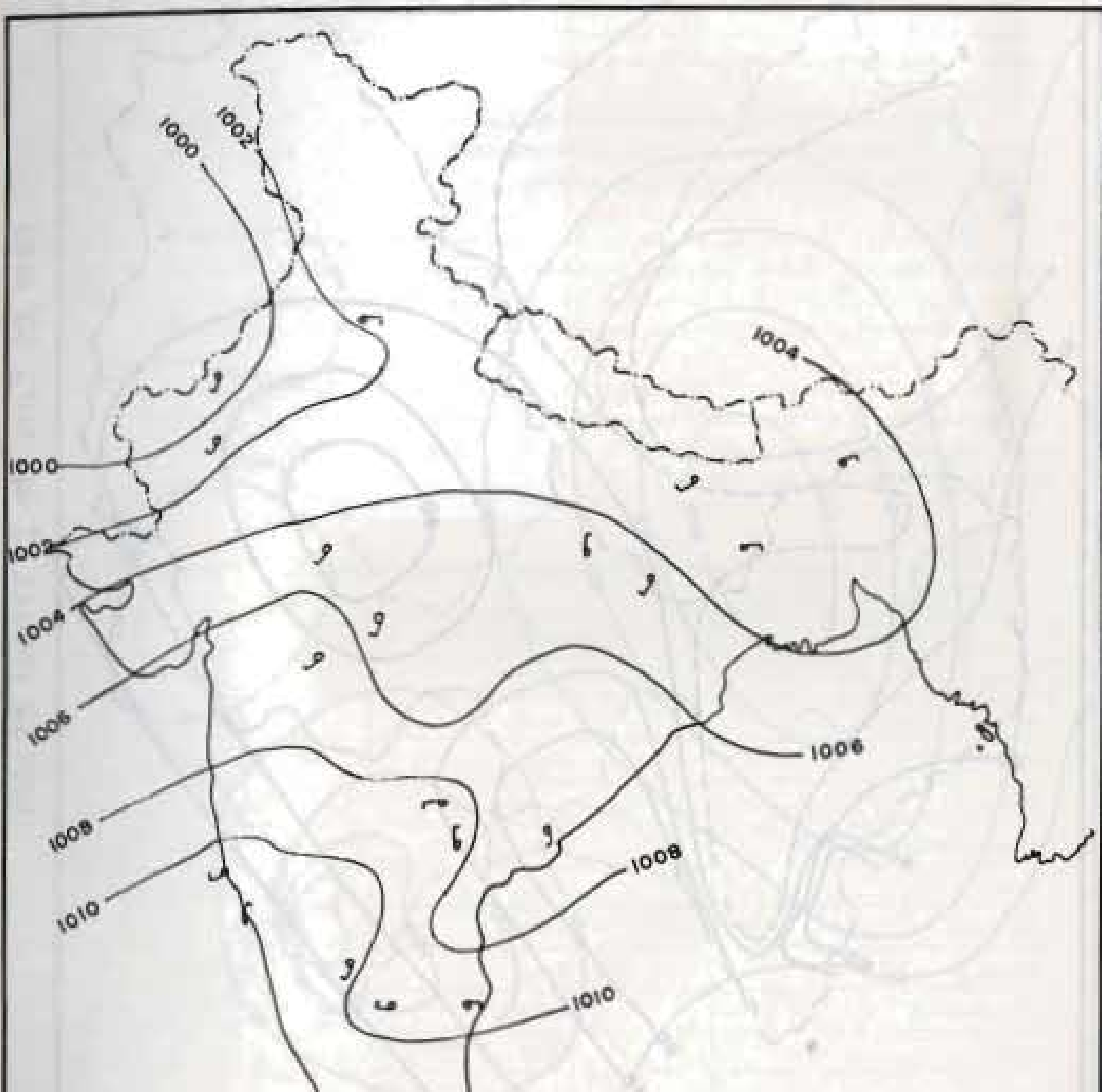


FIG.I.22: ISOHYETS ON JULY 19, 1993

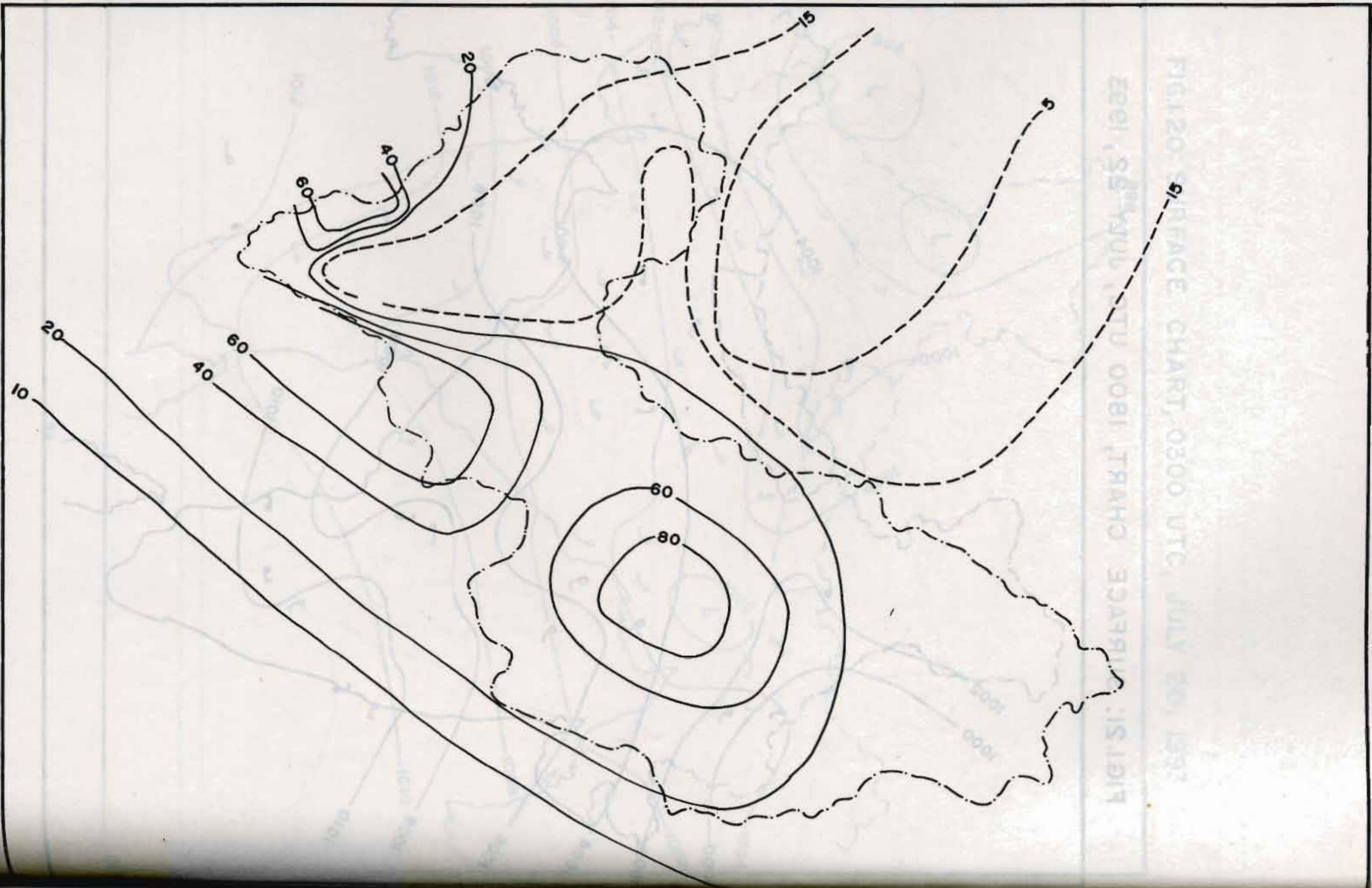
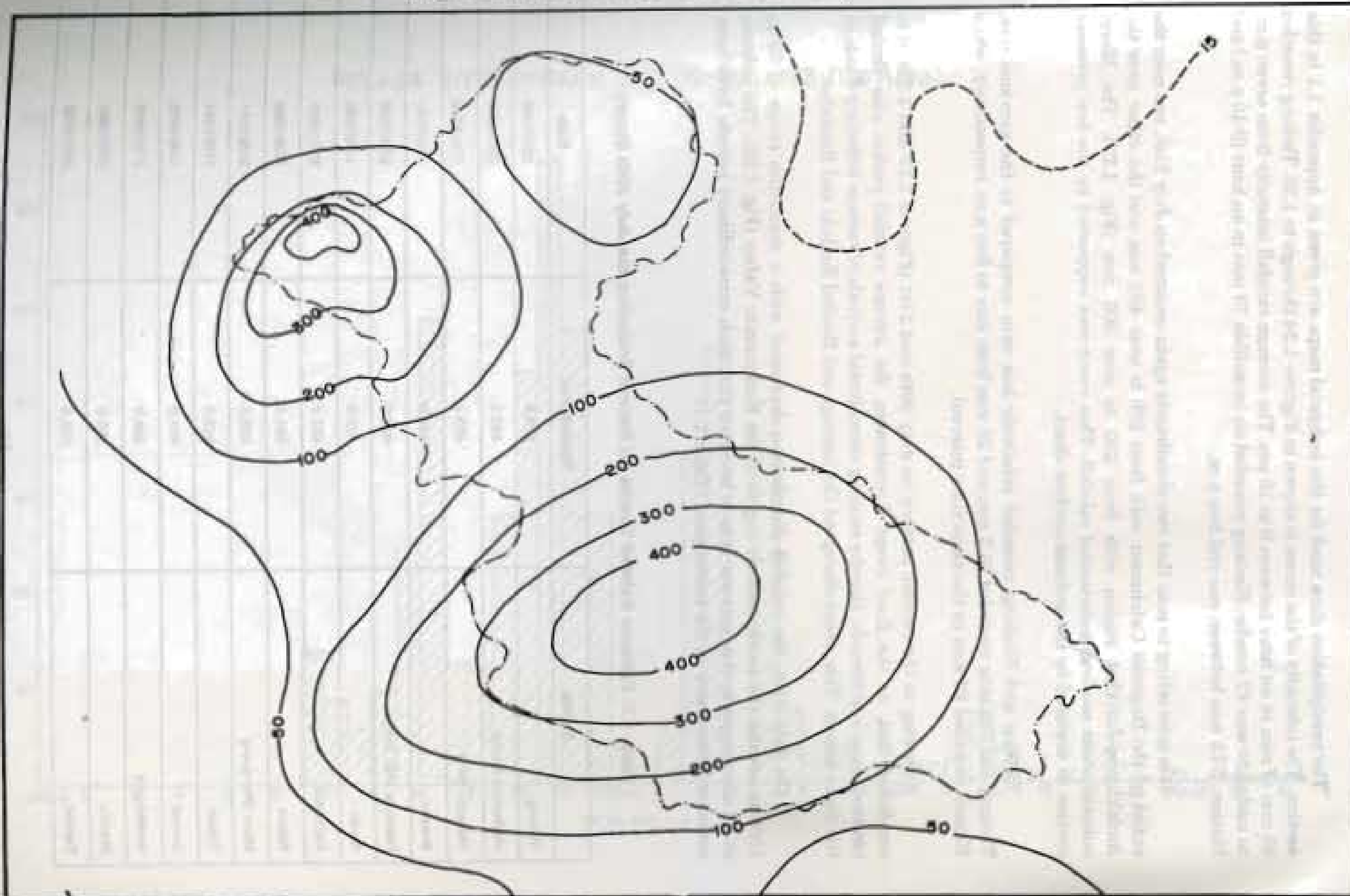


FIG.I.23: ISOHYETS ON JULY 20, 1993



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)

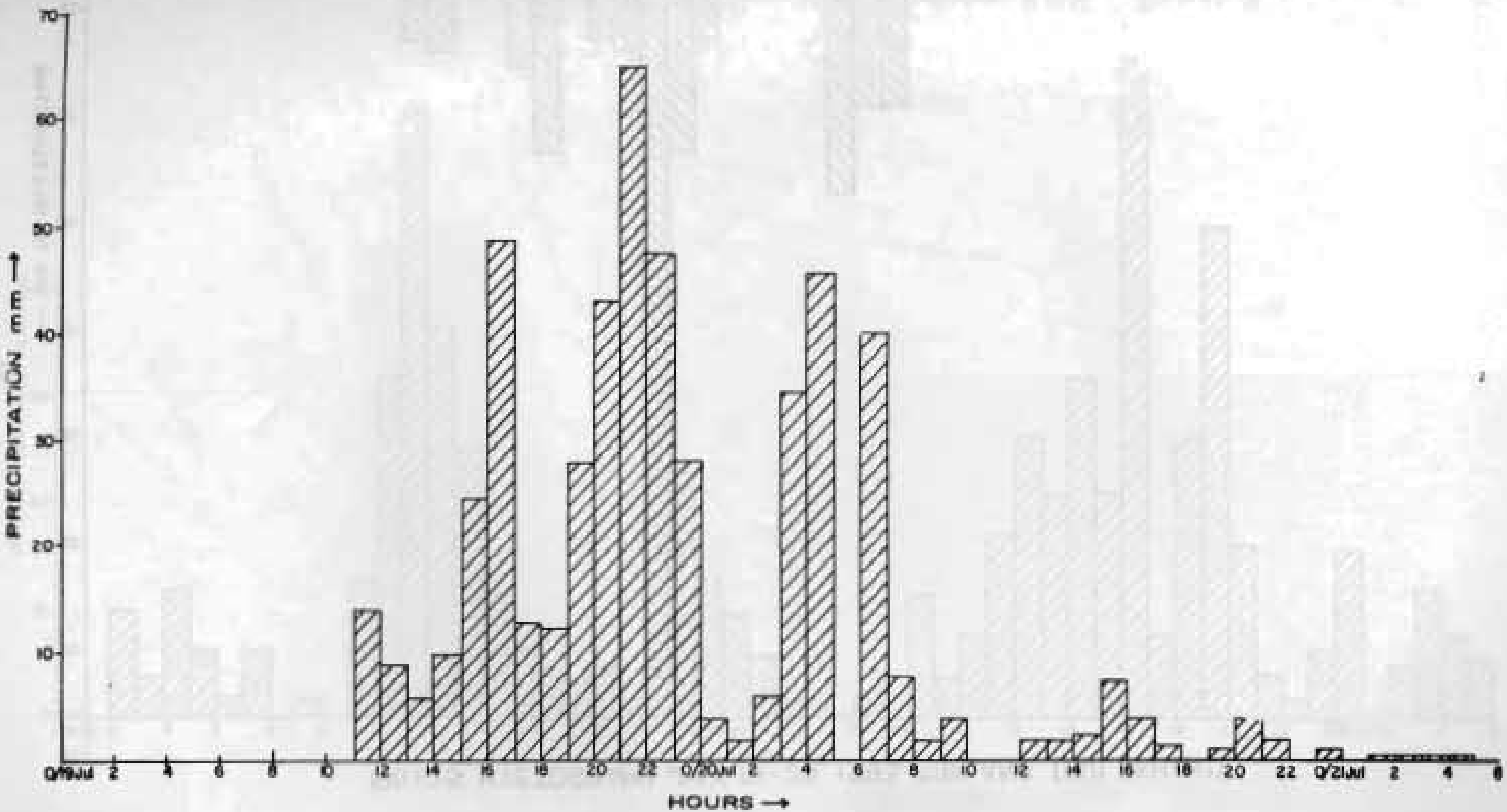


FIG.1.25: HYETOGRAPH JULY 19–20, 1993, SIMLANG (KULEKHANI)

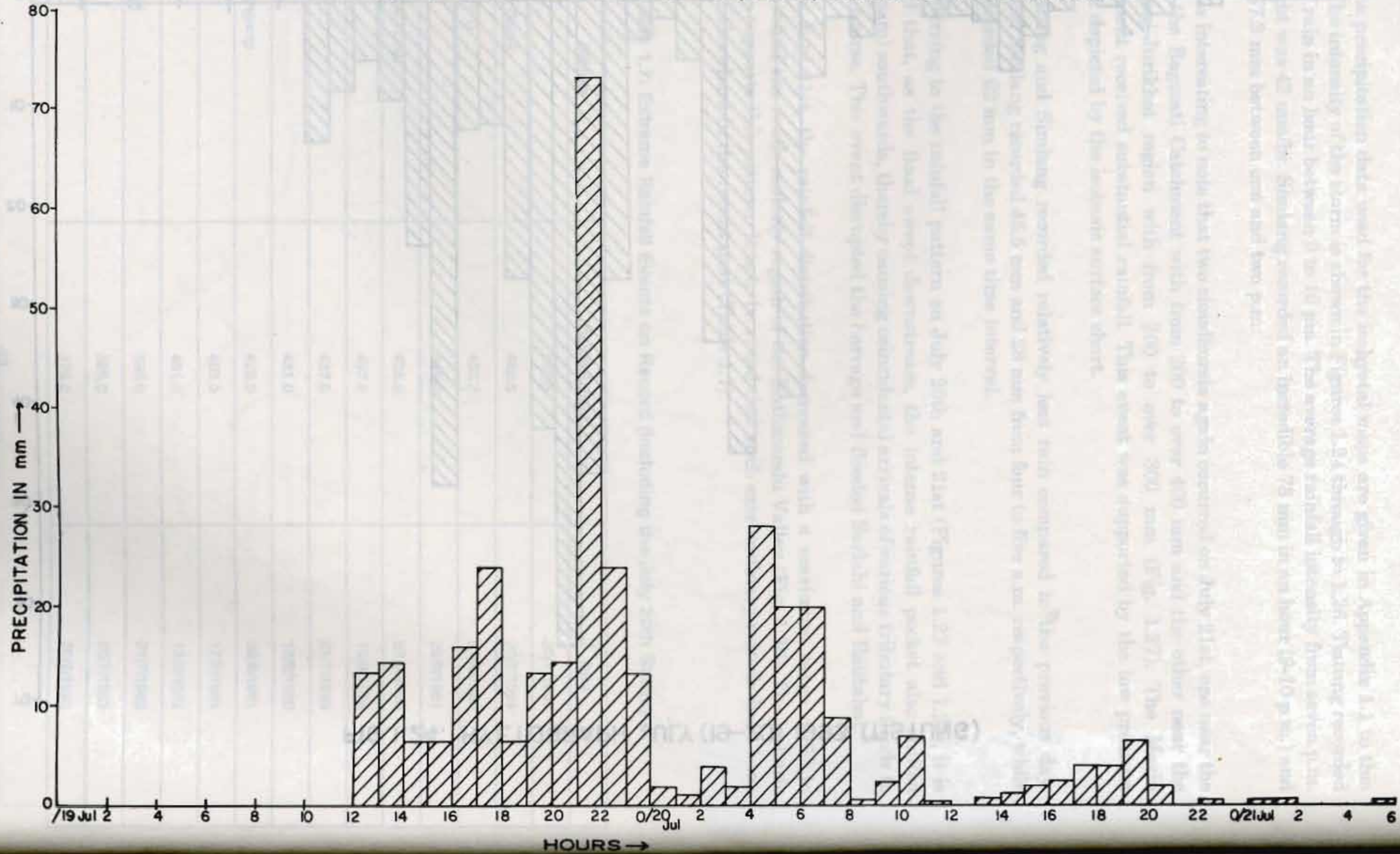


FIG.1.26 HYETOGRAPH, 19–21 JULY 1993, HAZAM

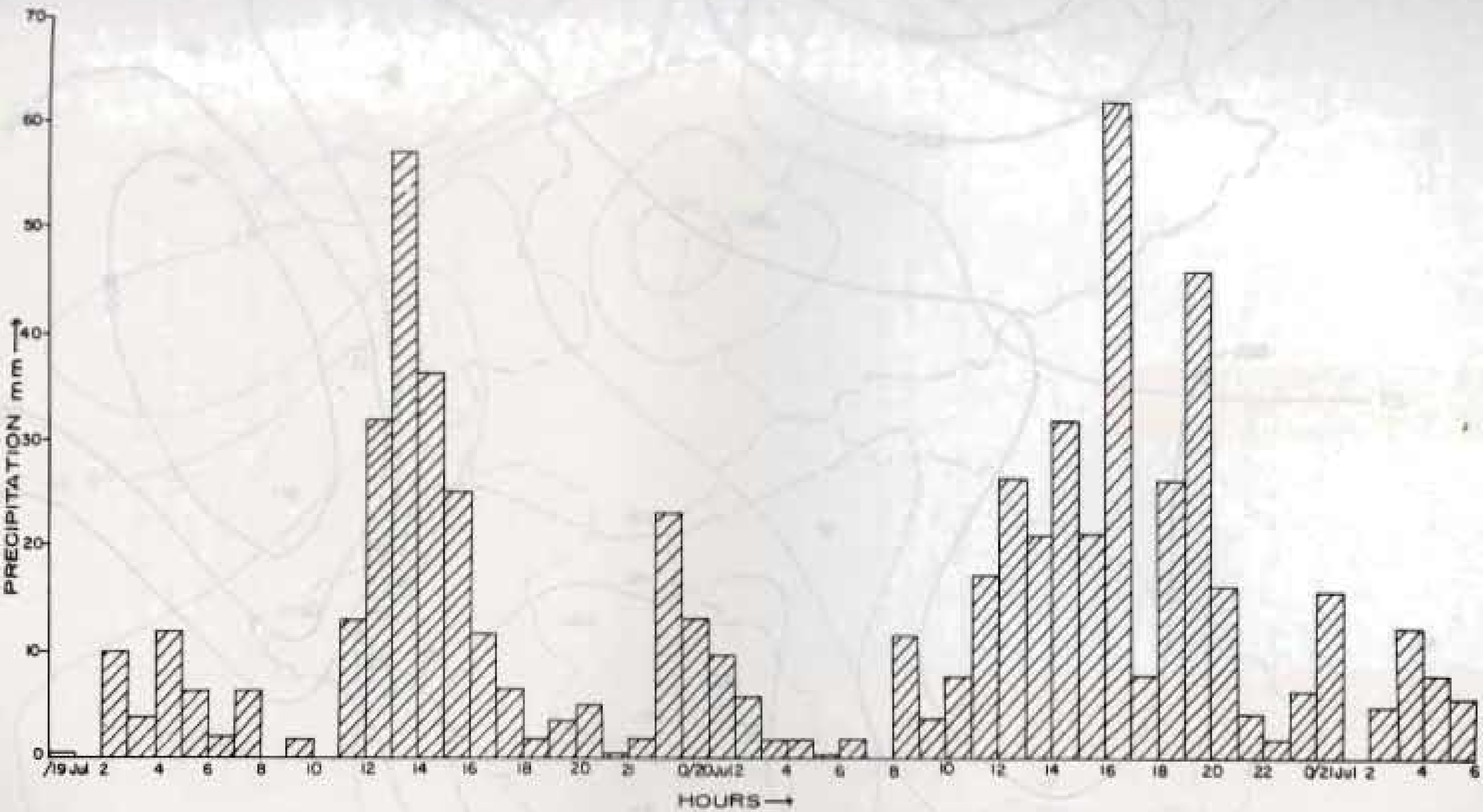


FIG.1.27: ISOHYETS ON JULY 21, 1993

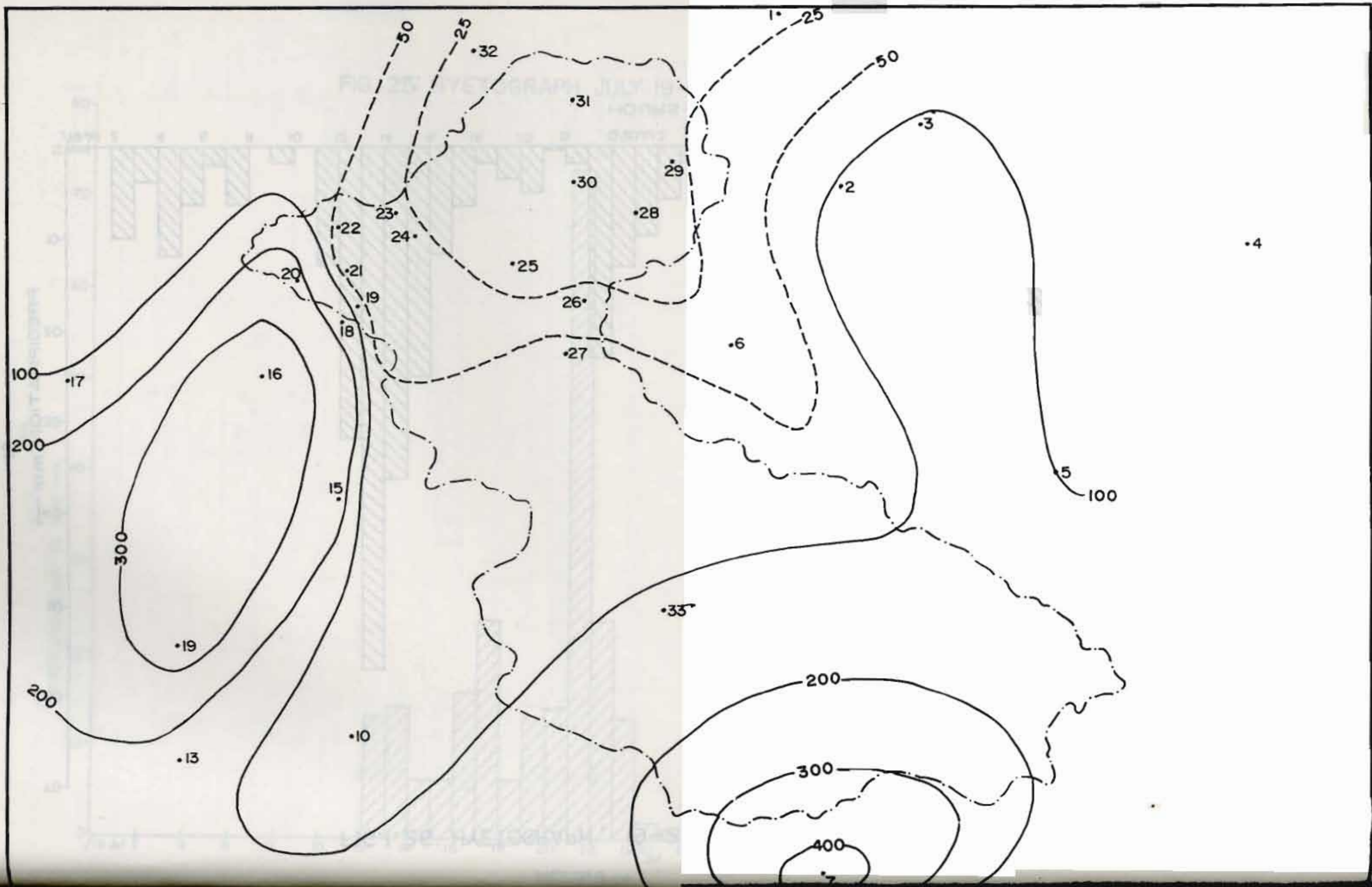
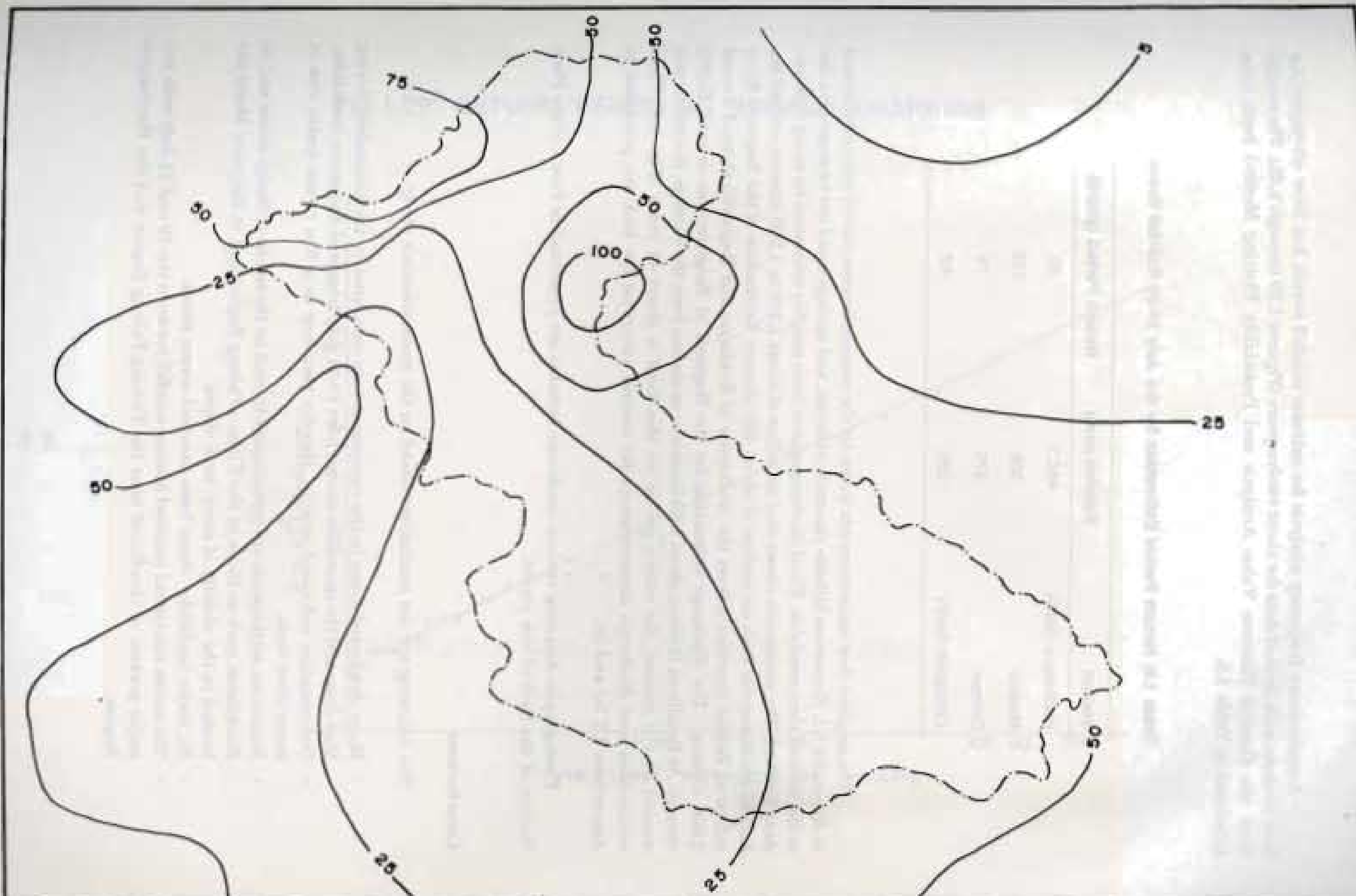


FIG.1.28: ISOHYETS ON JULY 22, 1993



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)

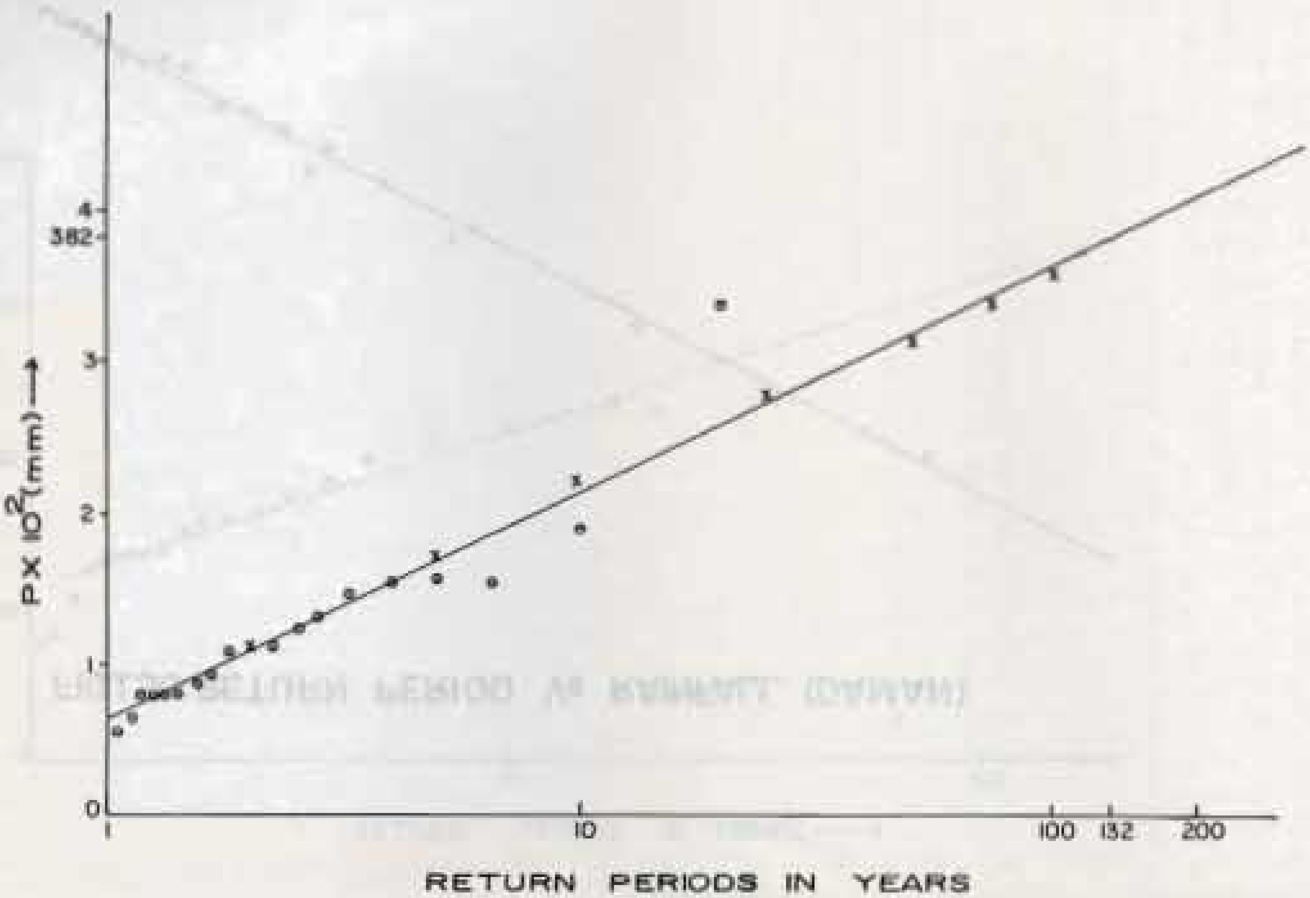


FIG.1.30: RETURN PERIOD Vs RAINFALL (DAMAN)

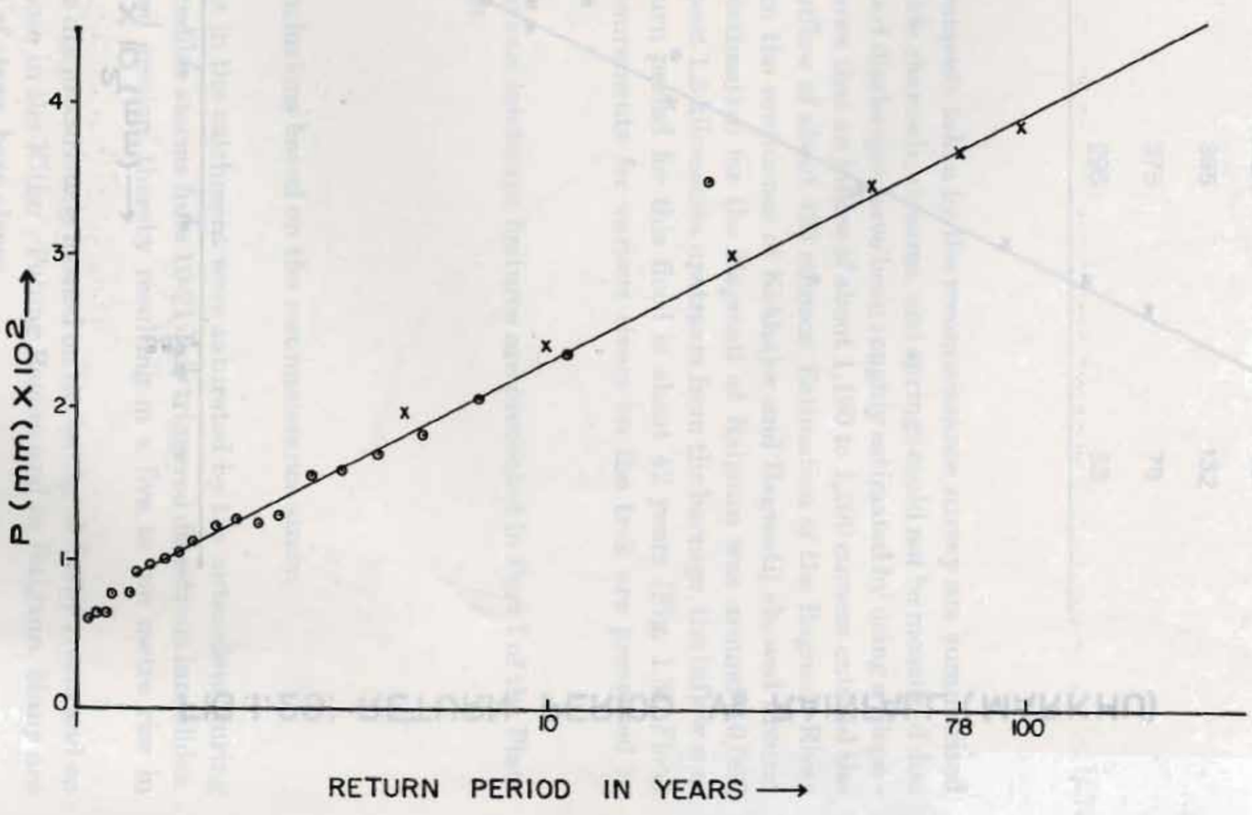


FIG.1.31: RETURN PERIOD Vs RAINFALL (CHISAPANI GADHI)

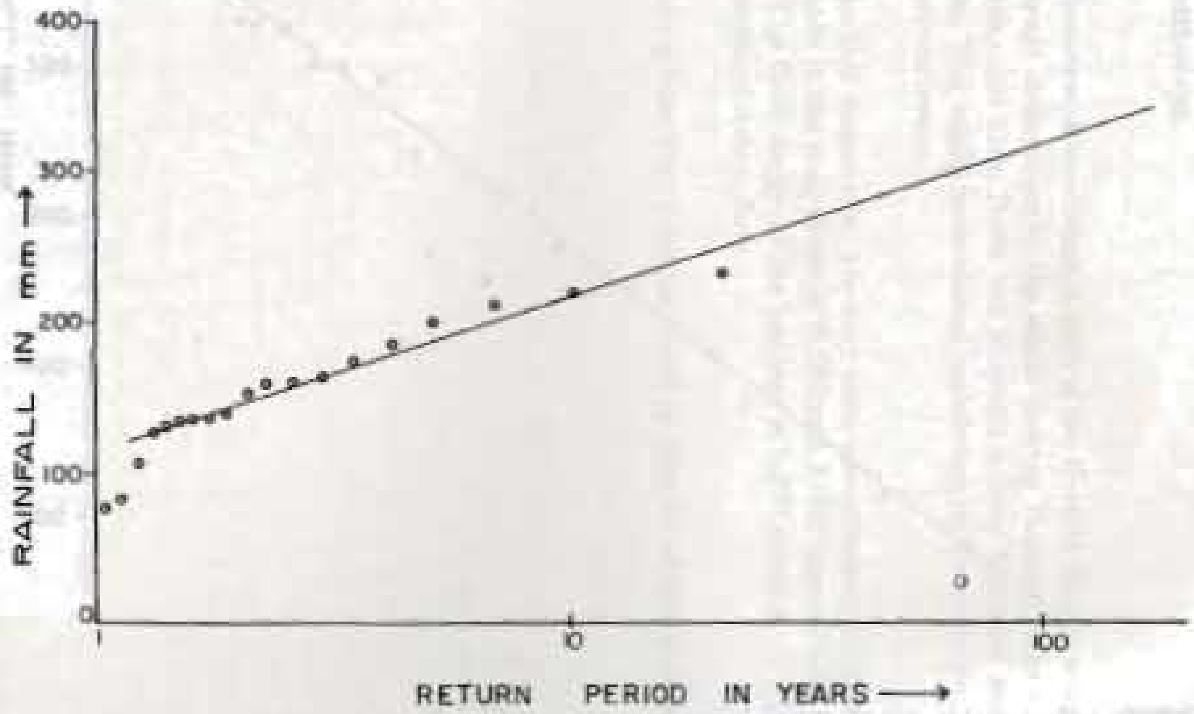
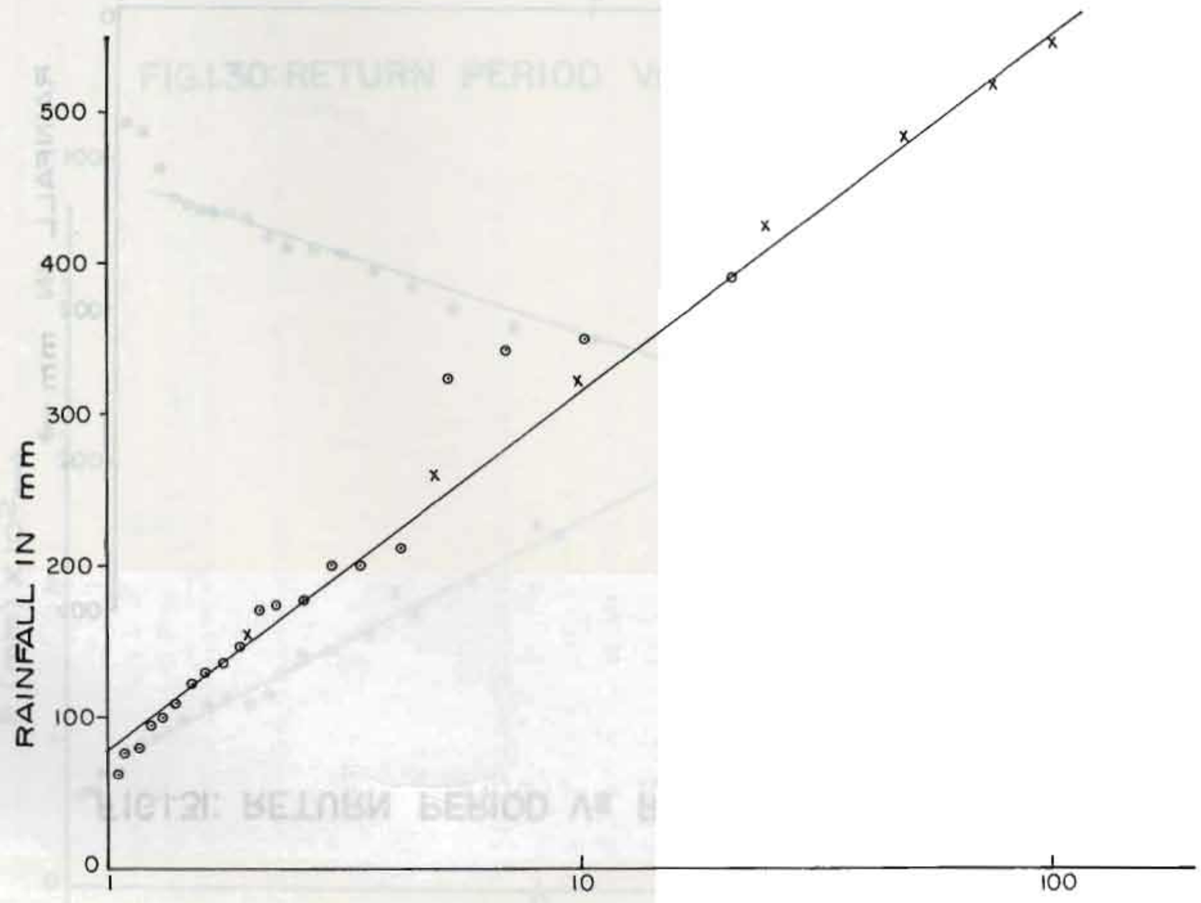


FIG.I.32: RETURN PERIOD Vs RAINFALL (HARIHARPUR GADHI)



- 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 |