JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF WATER RESOURCES
HIS MAJESTY'S GOVERNMENT OF NEPAL

MASTER PLAN STUDY FOR WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS

FINAL REPORT

VOLUME IV

SUPPORTING REPORT

ANNEX I : HYDROLOGICAL ANALYSIS
ANNEX II : [illegible]
ANNEX III : LAND USE, ENVIRONMENT AND WATERSHED

OCTOBER 1993

NIPPON KOEI CO., LTD., TOKYO JAPAN
[illegible] CORPORATION, TOKYO JAPAN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF WATER RESOURCES
HIS MAJESTY'S GOVERNMENT OF NEPAL

MASTER PLAN STUDY FOR WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS

FINAL REPORT

VOLUME IV

SUPPORTING REPORT

APPENDIX I TOPOGRAPHY AND GEOLOGY
APPENDIX II METEOROLOGY AND HYDROLOGY
APPENDIX III LAND USE, ENVIRONMENT AND WATERSHED

OCTOBER 1993

NIPPON KOEI CO., LTD., TOKYO JAPAN
CHUO KAIHATSU CORPORATION, TOKYO JAPAN

This Report consists of

Volume I	Executive Summary	
Volume II	Main Report of Part I (General Study of the Master Plan)	
Volume III	Main Report of Part II (Detailed Analysis of Priority Schemes)	
Volume IV	Supporting Report	
	Appendix I	Topography and Geology
	Appendix II	Meteorology and Hydrology
	Appendix III	Land Use, Environment and Watershed
Volume V	Supporting Report	
	Appendix IV	Hydroelectric Power Generation
	Appendix V	Domestic Water Supply
Volume VI	Supporting Report	
	Appendix VI	Irrigation
	Appendix VII	Flood Mitigation
Volume VII	Data on Geological Investigation and Cost Breakdown of Hydropower Potential Schemes	

The cost estimate was based on the March 1993 price level and expressed in US Dollar according to the exchange rate of US$ 1.00 = Nepal Rupees 46.65 = Japanese Yen 116.30 as of March 31, 1993.

VOLUME IV

SUPPORTING REPORT

APPENDIX I	**TOPOGRAPHY AND GEOLOGY**
APPENDIX II	**METEOROLOGY AND HYDROLOGY**
APPENDIX III	**LAND USE, ENVIRONMENT AND WATERSHED**

LIST OF ABBREVIATIONS

ADB	:	Asian Development Bank
ADBN	:	Agricultural Development Bank of Nepal
AIC	:	Agricultural Inputs Corporation
AMIS	:	Agency Managed Irrigation System
BOD	:	Biochemical Oxygen Demand
C.I.F.	:	Cost, insurance and freight
CBS	:	Central Bureau of Statistics
CDR	:	Central Development Region
CIDA	:	Canadian International Development Agency
COD	:	Chemical Oxygen Demand
DHM	:	Department of Hydrology and Meteorology
DIO	:	District Irrigation Office
DLG	:	Department of Local Government
DNPWC	:	Department of National Parks and Wildlife Conservation
DO	:	Dissolved Oxygen
DOA	:	Department of Agriculture
DOI	:	Department of Irrigation
DPTC	:	Water Induced Disaster Prevention Technical Centre
DSCWM	:	Department of Soil Conservation and Watershed Management
DWSS	:	Department of Water Supply and Sewerage
ED	:	Electricity Department
EDF	:	Electricity de France International
EDR	:	Eastern Development Region
EIA	:	Environmental Impact Assessment
EIRR	:	Economic Internal Rate of Return
EIS	:	Environmental Impact Study
FCN	:	Food Corporation of Nepal
FMIS	:	Farmer Managed Irrigation Systems
F.O.B.	:	Free on board
FWDR	:	Far Western Development Region
G.I.wire	:	Galvanized Iron wire
GLOF	:	Glacier Lake Outburst Flood
GDP	:	Gross Domestic Product
GOJ	:	Government of Japan
HMG/N	:	His Majesty's Government of Nepal
ICIMOD	:	International Centre for Integrated Mountain Development
IDA	:	International Development Aids

IEE	:	Initial Environmental Examination
IRDP	:	Integrated Rural Development Project
IUCNNR	:	International Union for Conservation of Nature and Natural Resources
JICA	:	Japan Internationai Cooperation Agency
KMTNC	:	King Mahendra Trust for Nature Conservation
LRMP	:	Land Resource Mapping Project
MFE	:	Ministry of Forests and Environment
MHDB	:	Marsyandi Hydropower Development Board
MPID2	:	Master Plan for Irrigation Development in Nepal Cycle 2
MWDR	:	Mid Western Development Region
MWR	:	Ministry of Water Resources
NARSC	:	National Agricultural Research Service Centre
NCCNCR	:	National Council for the Conservation of National and Cultural Resources
NEA	:	Nepal Electricity Authority
NEC	:	Nepal Electricity Corporation
NPC	:	National Planning Commission
NPWC	:	National Parks and Wildlife Conservation
NWSC	:	Nepal Water Supply Corporation
RNA	:	Royal Nepal Army
Rs.	:	Nepalese Rupee
SHDB	:	Small Hydro Development Board
SHIP	:	Second Hill Irrigation Projects
S/W	:	Scope of Work
UMN	:	United Mission to Nepal
UN	:	United Nations
UNDP	:	United Nations Development Programme
U.S.A.	:	United States of America
US$	:	Dollars in United States of America
VDC	:	Village Development Committee
WDR	:	Western Development Region
WEC	:	Water and Energy Commission
WECS	:	Water and Energy Commission Secretariat
WSSB	:	Water Supply and Sewerage Board

LIST OF UNIT OF MEASUREMENT

°C	:	degree centigrade or Celsius
cusec	:	cubic foot per second = 0.02832 m^3/s
El.	:	Elevation
GWh	:	Giga Watt hour
ha	:	hectare
km	:	kilometer
km^2	:	square kilometer
kW	:	kilo Watt
kV	:	kilo Volt
m	:	meter
m^3/s	:	cubic meter per second
m^3/sec	:	cubic meter per second
m^3/day	:	cubic meter per day
MW	:	Mega Watt
%	:	percent

APPENDIX I

TOPOGRAPHY AND GEOLOGY

Appendix I
Topography and Geology

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. TOPOGRAPHY AND TOPOGRAPHIC SURVEY

1.1 Topography in the Study Area

The Study Area is identified with the entirety of the Mid Western Development Region and the Far Western Development Region. Its shape is an approximately 280 km x 220 km rectangle with long sides in a west-northwest-east southeast direction along the Himalaya range and southern border line and short sides in a north-northeast - south-southwest direction along the western border line and the boundary between the Mid Western and Western Development Regions, being located between 27°40' and 30°30' north latitude and between 80°05' and 83°40' east longitude. The total land area is 61,917 km^2, consisting of 8,927 km^2 of Terai Ecological Belt, 26,029 km^2 of Hill Ecological Belt and 26,961 km^2 of Mountain Ecological Belt.

The relief of the Study Area (refer to Figure 1.1.1) is characterized by west-northwest - east-southeast running ranges. The Himalaya range of over 5,000 m in altitude lies on the north with high peaks of Api (El. 7,132 m), Saipal (El. 7,031 m), Kanjiroba (El. 6,882 m), Nampa (El. 6,754 m), Changla (El. 6,563 m) and Gorakh Himal (El. 6,088 m). The Mahabharat range is located in the middle mountain region with peaks of 2,000 to 3,000 m in altitude. The Churia or Siwalik range of lower altitude divides Terai and Hill Ecological Belts. There are some ranges, generally trending from north northeast to south southwest between the Himalaya range and the Mahabharat range. The ranges are cut by deep river valleys. The eastern part of Terai Ecological Belt of the Study Area is rather mountainous and the Dundwa range is located along the southern border line. To the north of this mountainous area, there is an open valley, called the inner Terai or Dang Valley, between the Mahabharat range and the Churia range.

The Humla Karnali, the uppermost stretch of the Karnali River originating from Tibet, enters into Nepal near the northwest corner of the Study Area and takes an east-southeasterly course in the valley approximately parallel to the Himalaya range. It joins the Mugu Karnali, which flows from almost the opposite direction. The river, then called the Karnali, runs south-southwest until it reaches the Mahabharat range. The Karnali River takes an east-southeast course along the northern side of the ridge for a distance of 30 km and abruptly cuts through the ridge. Thereby it takes a reverse course to the west-northwest, making a big bend, and thereafter a westerly course along the southern side of the ridge.

The Seti River, originating near the Saipal peak, is a major tributary draining the southwestern part of the Karnali River basin. It takes a south-southeasterly course in its upper reaches and then a southeasterly course along the northern side of the Mahabharat range. The Seti River cuts across the range and joins the above mentioned westerly course of the Karnali. The Karnali River again turns to the east-southeast. Flowing to east-southeast along the northern side of the Churia ridge, the Karnali River joins the Bheri River and cuts the Churia ridge at the proposed dam site of the Karnali Multipurpose Project. Thereafter the Karnali River takes its course to south by branching into several streams in the Terai and finally enters into India.

The Bheri River is a major tributary draining the southeastern part of the Karnali River basin. Its upper reaches are bifurcated into the Thuli Bheri River and Sani Bheri River both originating from the Dhaulagiri mountains and westerly running. The lower stretch of the Bheri River flows southward cutting across the Mahabharat range and takes a west-northwesterly course between the Mahabharat range and the Churia range. In this valley the Bheri River reaches the confluence with the Karnali. The total catchment area of the Karnali River at the proposed dam axis of the Karnali Multipurpose Project is 43,679 km^2, including 3,100 km^2 in Tibet, 40,129 km^2 in the Study Area and 450 km^2 in the WDR.

The Mahakali River originates in the Himalaya range near the point where the international border lines meet among Nepal, China and India. Its south-southwest running course forms the western international border line between Nepal and India. Its major tributaries are the Chamliya River in Nepal, the Guri Ganga River and the Sarju River in India. The catchment area at the Tanakpur barrage under construction in the Churia range is 15,200 km^2 including 3,900 km^2 in Nepal and 11,300 km^2 in India.

The Babai River flows from east-southeast to west-northwest draining the Dang valley and then running in a valley which divides the Churia range into two parallel ridges. It turns to the south and enters India. The Babai River has a catchment area of 3,300 km^2 in the Nepal territory.

The Rapti River flows from the mountainous valley between the Churia range and the Dundwa range to the west-northwest and then to the south to enter India. The Rapti River has a catchment area of 6,500 km^2 including 5,980 km^2 within the Study Area and 520 km^2 in the WDR.

During the course of field investigation in Phase I, a total of 350 sheets of aerial photographs (270 sheets with a scale of 1 : 20,000 and 80 sheets with a scale of 1 : 50,000) was obtained. An index map to show the coverage of the available aerial photographs is given in Figure 1.1.2. Furthermore, topographic maps on a scale of 1 to 50,000 and 1 to 10,000 were also collected in the Study Area to use scheme identification as shown in Figures 1.1.3 and 1.1.4, respectively.

1.2 Topographic Survey for the Hydropower Priority Schemes

Topographic maps were prepared for four priority schemes selected in the hydropower sector, i.e. BR-1, LR-1, SR-3 and CR-2, by applying a technique of photogrammetry, for which aerial photographs used were the existing ones with a scale of 1 to 50,000 and 1 to 20,000 shot in 1977 and 1978. The aerial photographs with a scale of 1 to 20,000 were used for supplementary purposes for a part of BR-1, where the photographs with a scale of 1 to 50,000 are not available. Work quantities and scales of the topographic maps prepared for the selected four hydropower schemes were as follows :

Scheme	Mapping Area, km^2	Scale
BR-1	65	1/20,000
LR-1	175	1/20,000
	30	1/10,000
SR-3	35	1/20,000
CR-2	15	1/20,000

Three schemes, BR-1, SR-3 and CR-2, are a run-of-river type and the topographic maps were prepared for the entire area of the scheme site with a scale of 1 to 20,000. Meanwhile, topographic maps for LR-1, which is a reservoir type, were prepared with a scale of 1 to 20,000 for the reservoir area and 1 to 10,000 for the structure sites including the dam.

Work to prepare topographic maps was commenced with ground control survey in field in October 1992 by the Topographic Survey Team appointed by JICA for this Study immediately after the joint meeting was held between the MWR and the JICA Study Team in September 1992 to discuss the selection of priority schemes. The ground control survey by the Team was finished with successful results in December 1992.

After the completion of ground control survey, the Topographic Survey Team returned to Japan, and began the aerial triangulation and the mapping with plotters. The topographic maps were finally prepared with the finishing work called cartography by the end of March 1993.

2. GENERAL GEOLOGY IN THE STUDY AREA

2.1 General Geology

2.1.1 Geo-structural Setting

The geological units of Nepal Himalaya are divided into three zones (refer to Figure 2.1.1) from the north to south based on the litho-structural and geomorphological condition as follows:

- High Himalaya Group,
- Lesser Himalaya Metasediments, and
- Siwalik Sedimentary Group.

It is noted that Tethys Sedimentary Sequence is included in High Himalaya Group in this report. Adjacent to the south of the Siwalik is the alluvial plain called the Terai, which lies outside the Study Area. Each of the above three units is bounded by thrust faults, and over-thrusting onto the younger sequence is the principal structure. Following are a short description of the each geological unit:

(1) High Himalaya Group

Tethys Sedimentary Sequence

The high peaks of Himalaya Mountains such as Sagarmatha, Lhotse and Makalu are in this sequence. This sedimentary sequence is of fossiliferous shallow sea sedimentary, and extending up to the Tibetan Plateau.

Higher Himalaya Metamorphics

The Higher Himalaya zone is mainly composed of recrystalline metamorphic rocks including the Himalayan gneiss. The grade of metamorphism is of high temperature and high pressure at the bottom horizon, getting lower to the upper horizon.

(2) Lesser Himalaya Metasediments

This zone is distributed between the Siwalik in the south and the Higher Himalaya in the north with an average width of 100 km. Geomorphologically it is characterized by the high mountain chain in the south and lower hills in the middle section, and again higher hills in the north. A wide distribution of low grade metamorphic rocks such as phyllite, quartzite and limestone, and to a lesser degree, mica schist and gneiss, is found in this zone. The geological structure is complicated by folding and faulting, and a number of thrusts are identified in this zone. Their age ranges from Precambrian to Late Paleozoic time.

(3) Siwalik Sedimentary Group

The Siwalik Group is composed of young sedimentary molasse deposits of Tertiary age. They are distributed along the southern margin of the Himalayan Range. South of the Siwalik is the Gangetic plain while in the north is the Midland zone separated by the Main Boundary Thrust (MBT). The Siwalik is divided into four units: Lower, Lower Middle, Upper Middle and Upper which consist of mudstone, sandstone and conglomerate. The width of this zone varies from a few km in Eastern Nepal to about 35 km in Western Nepal. The lower units of the Siwalik tectonically thrust over the younger units.

2.1.2 Stratigraphy

(1) Higher Himalaya Group

Tethys Sedimentary Sequence

The lower parts of this sequence are composed of metamorphosed rocks of various grades and shallow sea sedimentary rocks. The basal part of the Tethys may be of Precambrian age, but abundant fossils of Paleozoic and Mesozoic are reported from the upper part. Since this sequence was deposited on the marginal shelf of the stable continent, the succession of the stratigraphic units could be easily correlated between areas of several hundred km apart. As a whole, the strata of the Lower Paleozoic are mainly composed of calcareous sedimentary rocks, and those of the Mesozoic are mainly composed of sandstone and limestone. The selected four hydropower priority schemes are not related to the Tethys Sedimentary Sequence.

Higher Himalaya Metamorphics

This unit, called the Central Crystallin by some authors, comprises various types of gneiss, migmatite and granite bodies. Thickness is estimated to be more than 10 km in total, but stratigraphy of the recrystalline rocks is not established yet. The selected four hydropower priority schemes are not related to the Higher Himalaya Metamorphics.

(2) Lesser Himalaya Metasediments

This unit, called the Midland Group by other authors, is subjected to the weak metamorphism in certain parts, and mainly consists of various flysh to shallow sea sedimentary rocks. The total thickness of this sedimentary piles may reach 15 km or even more.

The unit is stratigraphically divided into three members; arenaceous formation at the bottom, quartzose formation in the middle and calcareous formation at the top. Details of the stratigraphy are not established yet. Judging from the ripple marks and other sedimentary structures observed in the sandstone, it is indicated that these sedimentary material was supplied from the land to the south into the shallow sea. The paleontological data in this area indicate that the unit is of Early to Late Paleozoic age. Among the selected four hydropower priority schemes, LR-1, SR-3, and CR-2 are located in this sequence. Stratigraphy of each site will be described in subsequent Section 5.1.

(3) Siwalik Sedimentary Group

This unit, called the Sub Himalaya in other terms, mainly consists of siltstone, sandstone and conglomerate of Tertiary age, representing typical molasse facies. The Siwalik Group is generally divided into four formations; Lower Siwalik, Lower Middle Siwalik, Upper Middle Siwalik and Upper Siwalik Formations.

The Lower Siwalik Formation is characterized by alternation of conglomeratic sandstone and siltstone. Purple shale is a peculiar rock face in this formation. The Lower Middle Siwalik Formation is represented by repeating sedimentary cycles, i.e. calcareous arkosic sandstone at the bottom and siltstone at the top. The thickness of the sedimentary cycle varies from 50 to 100 m.

The Upper Middle Siwalik Formation in western Nepal may be easily recognized by the loose and less compacted solidified sequence, comprised of alternation of 1 to 10 m thick bluish gray sandstone and black to gray mudstone.

The Upper Siwalik Formation is composed of poorly sorted, well solidified boulder conglomerate. Graded bedding consisting of 10 m thick conglomerate at the bottom and 2 to 3 m thick sandstone at the top is quite common. Roundness of the boulders and pebbles varies from subangular to well rounded, suggesting that the material is supplied rapidly from the background. Among the selected four hydropower priority schemes, BR-1 is located in this sequence.

2.2 Structural Geology

2.2.1 Active Fault

There are two groups of active faults in Nepal. The group of hill-front faults caused by the collision of the Indian Subcontinent and the Asian Continent tends east-west and dips to the north. The well known Himalaya Front Fault (HFF) and the Main Boundary Fault (MBF) belong to this group.

The Main Central Thrust (MCT), the older E-W trending thrust, has ceased being active about 10 to 20 million years ago, according to Molnar (Ref. I-1). The second group named Karakoram Fault is a NW-SE trending, vertical dipping and right lateral strike slip fault. The significance of this group is not well explained until now, but the hydropower priority schemes selected in this Study are not directly related to this fault group.

In the Study Area, MBF and some other parallel active strike faults exist in the BR-1 area, which is situated in the Siwalik Group. These faults are accompanied by wide sheared and structurally disturbed zones, forming landslide areas. MCT dipping to the north in a low angle exists in the LR-1 area, and a thick augen gneiss layer exists in the basal part of the thrusting slab.

2.2.2 Crustal Movement (Uplifting and Erosion)

Many researchers have contributed many figures on the uplifting rate in the Himalayan area. The largest figure came from Zhang Zusheng, China (Ref. I-2) measured by repeated geodetic surveys, being reported to be 10 mm/y at the southern front of the Tibetan Plateau. In the Greater Himalaya, Gansser (Ref. I-3) estimated a rate of 5 mm/y from topographical observations. In the Lesser Himalaya, zone of the Midland Metasediments, the annual uplifting rate is smaller than that found in the Siwalik Hills (Nakata Ref. I-4). The uplifting rate in the zone of the Mahabharat Mountains is smaller than 1 mm/y in the Kaligandaki River area, and 2 mm/y for the period of sedimentation of the Upper Siwalik Formation (1 million years) (Kisaki Ref. I-5). In the Siwalik Mountains between the Main Boundary Fault (MBF) and the Himalayan Front Fault (HFF), the annual uplifting rate reaches 4 mm/y (Kisaki Ref. I-5).

Compared to the uplifting rate, the data on the erosion rate are quite limited. Gupta (Ref. I-6) gave a figure of 2.6 mm/y for the average erosion rate in the Himalayan area. JICA (Ref. I-7) estimated to be 2 to 3 mm/y for the Nepal Himalayan area. Kasaki (1985) projected a figure of 3 to 4 mm/y for the high mountain areas. These discussions are schematically illustrated in Figure 2.2.1.

3. GEOLOGICAL INVESTIGATION FOR HYDROPOWER POTENTIAL SCHEMES

3.1 Investigation in Phase I Stage

A total of 23 sites for hydroelectric power development was selected in the Karnali River and Mahakali River basins in the past studies. Among these, included are large scale projects such as the Karnali multipurpose project and the Pancheshwar hydropower project.

During Phase I, the Study Team preliminarily surveyed several of the above sites by helicopter. The Team also collected following existing basic data for topography and geology of the Study Area:

- Topomap (1/50,000 scale),
- Geologic map and geologic survey reports, and
- Aerophotos.

Drilling machines of the Ministry of Water Resources were also inspected, since this equipment is planned to use for the drilling works scheduled in the next dry season. Equipment inspection included assessment of spare parts, diamond bits and coring tools required in the event that JICA borrows four units of the aforementioned drilling machinery.

It is known that active faulting, a problem for stability of civil structures, is distributed in the Study Area. This faulting is considered to play a major role in Himalayan orogeny. In Phase I, the Geologist traced by helicopter the M.B.T. (Main Boundary Thrust) among the faults believed to be found in the Study Area. The M.B.T. is one of the clearest lineaments in Western Nepal, and runs east to west over the 100 km distance between Surkhet and Ghorahi. A portion of this correlates with the M.B.F.

3.2 Investigation in Phase II Stage

On the basis of the findings of Phase I, a total of 15 hydropower potential sites were identified by using 1 to 50,000 scale topographic maps (refer to Appendix IV).

In Phase II, the Hydropower Expert and the Geologist of the Team surveyed 12 sites out of the above 15 sites and the previously identified 23 sites in the following order:

First trip (March 22 to 27, 1992)

March 22: KR.1A P/H -> D/S -> TR.1 -> TR.3 -> LR.1 -> BR.1 -> D/S -> P/H

March 24: SR.6 -> BS.1 -> SR.3 -> SR.7 -> West-Seti D/S -> THR.1 -> CR.2 -> CR.1

March 26: KR.4 -> HKR.1 -> HKR.4 -> HKR.3 -> HKR.2 -> TR.4 -> TR.2 -> BR.4 -> BR.5

Second trip (April 3 to 5, 1992)

April 3: BR.6 -> BR.8 -> BR.7 -> BR.3A

April 4: MKR.2 -> MKR.3 -> MKR.1

Basic procedure for the site survey was as follows:

* Maximization of scheme sites to land within the limitations of the helicopter flight schedule

* Preclusion of helicopter landing for 12 sites due to treacherous topography

* Survey items at the sites were as follows:

    - Confirmation of landing location
    - Ground condition
    - Rock type and geological structure
    - Construction materials
        * Concrete aggregates
        * Impervious core materials.

The results of geological field investigation carried out in Phase II are summarized in Table 3.2.1.

During Phase II, the Team tried to obtain the detailed scale geological maps as much as possible (the Department of Mines and Geology has carried out a programme of geological mapping of S = 1 inch / 1 mile). However, there are areas for which such mapping is lacking, and the Team was thus unable to obtain detailed geological maps for all the scheme sites.

A list of the detailed geological maps collected by the Study Team is given in Table 3.2.2. The extent of area covered by the foregoing maps is indicated in Figure 3.2.1. The report number shown in Table 3.2.2 corresponds to the number given in Figure 3.2.1. The Figure indicates road network and airports in the Study Area in addition to the hydropower potential scheme sites.

4. SEISMICITY

4.1 Seismo-tectonics in Nepal

4.1.1 Tectonic Setting

The Himalayan Orogenic Belt is characterized by several litho-tectonic zones parallel to the orogenic belt to some extent. The southernmost unit, named the Siwalik or Sub-Himalaya, consists of the faulted Siwalik molasse sedimentary rocks of Mio-Pliocene age which form the Siwalik Mountains in front of the Ganges Plain (Terai). This zone is bounded on the south by the active fault "HFF", whilst on the north by "MBF", the most active fault in Nepal.

Next to the Sub-Himalaya is the Lesser Himalaya composed of metasedimentary rocks, subdivided into the Midland Sub-group and Mahabharat Sub-group. These metasedimentary rocks are overridden by several thrust slabs which have travelled from the north to the south. This zone is bounded on the north by the "MCT", which caused the several hundred kilometers travel of the thrust slabs.

The next unit adjacent to the north is the Greater or Higher Himalaya. The Greater Himalaya is composed of crystalline rocks. The highest peaks of the Himalayan Mountains are in this zone. Further to the north is the Tethyan Himalaya composed of the thick piles of fossiliferous sedimentary rocks ranging from Cambrian to Cretaceous age. The MCT, a series of thrusts, is regarded as having been active in the early phase, whilst the MBF is assumed to be active in the later phase.

4.1.2 Earthquakes

Great earthquakes causing severe disaster are well known in the zone of the Himalayan Tectonic Province and contiguous alluvial plain to the south. As is well known, earthquakes are consequence of catastrophic failure of rocks under strain, which is generated by the relative movement of the lithospheric plates.

In and around Nepal, seismic activity is not uniformly distributed although the recorded seismicity has been getting abundant after the installation of World Seismo Network during 1960s. Considering all available data, following may be safely introduced:

(a) The Nepal Himalaya Region is subjected to strong north-south compressive stress by the collision of the Indian Plate and European Plate. The conversion rate is estimated at about 4 cm/y.

(b) The occurrence of earthquakes is confined to the crustal depth of about 20 km. No earthquake deeper than 100 km is reported.

(c) Earthquakes mainly occur in the north of the MBF.

4.2 Seismic Coefficient for the Dam schemes

4.2.1 Seismicity

Seismicity data used in this study are based on those retrieved from "Earthquake Data Base System" released by the National Earthquake Information Centre and "Earthquake Catalogs" of the Karnali (Chisapani) Multipurpose Project conducted by Himalayan Power Consultants (Ref. I-8). The collected data lie in an area ranging from 25 to 36 degrees north in latitude, and 75 to 90 degrees east in longitude. The data actually used are the area within a radius of 300 km from each scheme site. The total number of the collected earthquake data is 2,520 occurred in the period of year 1857 to 1993, whilst the number of events used for analysis is 1,087 occurred in the period of year 1905 to 1993.

Figure 4.2.1 shows the epicentres of all earthquake events occurred during the period of year 1905 to 1993, together with the locations of the selected four hydropower priority schemes, the coordinates of which are as follows:

	Latitude	Longitude
BR-1	28.51 deg. N	81.60 deg. E
LR-1	28.78 deg. N	81.68 deg. E
SR-3	29.55 deg. N	81.19 deg. E
CR-2	29.71 deg. N	80.69 deg. E

4.2.2 Attenuation Models

There are some attenuation models previously proposed to calculate peak horizontal accelerations A (gal), using earthquake magnitude M and hypocentral distance D (km). In this report, following three formulas are used for the calculation of peak horizontal accelerations:

(1) Formula proposed by Okamoto

$$P = (D+50) / 100 \times (-4.93 + 0.89 \times M - 0.043 \times M^2)$$
$$A = 1,000 \times 10^P$$

where

D : hypocentral distance in km

M : magnitude

A : peak horizontal acceleration in gal

(2) Formula proposed by the Ministry of Construction, Japan

$$A = 987.4 \times (10^{0.216M}) / (D+30)^{1.218}$$

(3) Formula proposed by Himalayan Power Consultants

A formula to get peak horizontal acceleration was proposed in their report titled Karnali Multipurpose Project as follows:

$$A' = 0.0606 \exp(0.470M) [R + 0.07\exp(0.6M)]^{-0.621}\exp(-0.20S)$$
$$\ln = 0.683$$

where

A' : peak horizontal acceleration in g (gravity acceleration)

R : station-rupture distance in km

S : 1 for soil sites, 0 for rock sites

M : earthquake magnitude.

Values of peak acceleration were calculated for the events of 1,087 by applying the above three formulas. A statistical analysis was applied to the peak acceleration values so obtained for estimating the maximum acceleration in the area as discussed in the following Sub-section. It is noted that the first two formulas out of the above three are generally accepted and the last formula was derived especially for Nepal, but it is not at this moment clear whether or not the formula is authorized in Nepal.

4.2.3 Statistical Analysis of Maximum Acceleration

The peak acceleration values obtained for 1,087 earthquake events were plotted on the respective probability papers prepared for the four hydropower priority schemes as given in Figures 4.2.2 to 4.2.5, through which acceleration of specified return periods can be evaluated for them.

The maximum accelerations were expected at each site by reading an envelope curve of the three regression curves (three formulas discussed in Section 4.2.2) for three different return periods of 50, 75, and 100 years as given in Table 4.2.1. The maximum acceleration to be expected in a probable return period of 100 years are 79 (gal), 80 (gal), 67 (gal), and 240 (gal) for BR-1, LR-1, CR-2, and SR-3 respectively. The maximum acceleration obtained at SR-3 is considerably larger than those of the others (BR-1, LR-1, and CR-2).

The area can be divided into two groups in terms of the density of the hypocentres as shown in Figure 4.2.1; one is the area to include BR-1 and LR-1, and the other is the area to include CR-2 and SR-3. The estimated ground acceleration at CR-2 lying in the latter group, however, is close to those of the former group, in spite of the latter group being situated in the highly concentrated area of hypocentres.

Distances from hypocentres, which have relatively large Magnitude, to the site CR-2 are longer than those to the other sites, and therefore the estimated ground acceleration at CR-2 is relatively small.

4.2.4 Seismic Coefficient Based on the Maximum Acceleration

There is no well established theory on the relation between the maximum acceleration of the earthquake motion and the design value of seismic coefficient. However, there are various conventional methods to convert the maximum acceleration of the earthquake motion into the design seismic coefficient. Three methods among them are described as follows:

Method 1

This is the simplest and most direct method to calculate the seismic coefficient expressed as follows:

$$\alpha = Amax / 980$$

where

α : seismic coefficient

Amax : maximum acceleration of motion (gal).

Method 2

This is an empirical method to calculate the effective design value of seismic coefficient as follows:

$$\alpha_{eff} = R\,\alpha = R \times Amax / 980$$

where

α_{eff} : effective design value of seismic coefficient

R : reduction factor, the value of which is empirically estimated in a range of 0.5 to 0.65.

Method 3

This is the most reasonable method to evaluate the equivalent design value of seismic coefficients by executing the analysis of dynamic models.

In this study, Method 2 was applied to estimate the design value of seismic coefficients from maximum accelerations. R is decided based on the distance from the epicentre to the site. In this report, R = 0.6 was temporarily applied to each site.

As a result, the design value of 0.05, 0.05, 0.05, and 0.15 is applied as the seismic coefficient of BR-1, LR-1, CR-2, and SR-3 respectively (Table 4.2.2).

4.2.5 Seismic Coefficient Based on the Seismic Risk Maps

(1) Evaluation based on Aseismatic Design Code for Nepal

The Aseismatic Design Code for Nepal has been prepared by Satyanarain R.(Ref. I-9). Figure 4.2.6 shows the seismic risk map for Nepal. In that paper, Nepal is divided into three seismic risk zones, and the soil foundation is classified into three kinds of soils based on the allowable bearing capacity in order to determine the seismic coefficient.

All the sites except for BR-1 are situated in the second seismic risk zone of Nepal (zone-2), whilst BR-1 is situated in the zone-1. The soil foundation at BR-1, LR-1, SR-3, and CR-2 belongs to the Average-soil (sandstone, mudstone), Soft-soil (phyllite), Soft-soil (phyllite), and Hard-soil (limestone) respectively.

The Basic Horizontal Seismic Coefficient is considered to be 0.05, 0.08, 0.08, and 0.05. In regard to the dams, the importance factors shall be taken as 1.5, 1.5, 1.5 and 1.5. Consequently, the design value for the horizontal seismic coefficients of BR-1, LR-1, CR-2, and SR-3 can be evaluated to be 0.075, 0.12, 0.12 and 0.075, respectively, based on the Aseismatic Design Code for Nepal.

(2) Evaluation based on Indian Standard

Figure 4.2.7 shows the seismic risk map for India which shows "Indian Criteria for Earthquake Resistant Design of Structures" (Ref. I-10). In that paper, India is divided into five seismic risk zones. T. Ohmachi reported on the correlation between "Code for Nepal" and "Indian Standard". According to Ohmachi's report, the third seismic risk zone of Nepal (zone-3) is equivalent to the fifth seismic zone of India (zone-V).Accordingly, BR-1, LR-1, CR-2, and SR-3 sites can be thought to be located in the forth, forth, fifth, fifth seismic zone of India, respectively. The basic horizontal seismic coefficient shall therefore be taken as 0.05, 0.05, 0.08, and 0.08 for those schemes (Table 4.2.3).

The design value for the horizontal seismic coefficient in the Indian Standard is defined by the following equation:

$$\alpha h = \beta I \times O$$

where

αh : Design value for the horizontal seismic coefficient
β : Soil foundation factor
I : Importance factor
αO : Basic horizontal seismic coefficient.

The design value for the horizontal seismic coefficients of BR-1, LR-1, CR-2, and SR-3 in conformity with the Indian Standard is evaluated to be 0.10, 0.10, 0.16 and 0.16 respectively.

4.2.6 Seismic Coefficient at Each Site

Table 4.2.4 summarizes the values of the design seismic coefficients calculated by ways mentioned above. Taking the largest one among them, the design seismic coefficients for BR-1, LR-1, CR-2, and SR-3 are determined to be 0.10, 0.12, 0.16, and 0.16 respectively.

5. GEOLOGICAL SURVEY FOR THE PRIORITY SCHEMES

5.1 Geological and Construction Material Survey for the Hydropower Priority Schemes

5.1.1 Introduction

During the field investigation of Phase III, geological and geophysical surveys were carried out at the selected four hydropower priority scheme sites by the geologists and geophysicists of the Study Team and the counterpart staff. Core boring including core logging and Lugeon tests was also conducted at each site together with construction material survey by entrusting the work to the local contractor. This Section deals with the geological condition at the proposed site of four hydropower priority schemes.

5.1.2 Geological Survey for BR-1 (Bheri River)

(1) Topography

The Bheri Khola runs roughly east to west through the Study area. River width is 60 to 100 m with small scale terraces of 15 m to 20 m high on both banks.

Slope wash and talus deposits are distributed in the area between the steep mountain slope and terrace. This gently sloped area is on occasion utilized for cultivation. The mountains running east-west to the south of the Bheri River are part of the Siwalik range. Maximum elevation in this mountainous area reaches 5,500 ft, which corresponds to a relative height of 4,000 ft compared with the river bed elevation of the Bheri River.

(2) Geology

Siwalik super formation is distributed throughout the entire Study area (refer to Figure 5.1.1). This formation belongs to the Middle Miocene to Lower Pleistocene, originally comprising sediments deposited in lowland and shallow sea bed area existed between the Indian subcontinent and the Asian continent prior to the collision of the two. Siwalik super formation is divided into four subformations; Lower Siwalik, Lower Middle Siwalik, Upper Middle Siwalik and Upper Siwalik in an ascending order.

Siwalik formations in the Study area are briefed as follows:

Lower Siwalik formation

Distribution : This formation has been thrust up over the Upper Siwalik formation by the Bheri thrust. It is broadly distributed in the Study area from the vicinity of the confluence of the Kalpani and Bheri Kholas to the confluence of the Chinchiu and Bheri Kholas.

Facies : The rock facies of the formation is composed of frequent alternation of 10 to 30 m thick massive compact quartzose sandstone and intercalated purple shale and/or gray mudstone of 1 to 3 m thick.

Stratigraphic relation : The extreme lower portion of this formation is cut by the Bheri thrust. Relationship to underlying formation is unclear.

Lower Middle Siwalik formation

Distribution : This formation is distributed on the northern slope of the Siwalik range to the south of the Bheri Khola. Representative outcrops are seen along the Bhareng Khola (Bharyang Khola) flowing northeast from the mountain village of Bhareng.

Facies : This is a formation formed through repetition of the sedimentary cycle from massive coarse grain sediment at the lower portion to laminated fine sediment at the upper portion. The thickness of one cycle ranges from 50 m to over 100 m with 10 cycles or more being recognized. Sandstone at the lower portion of each cycle is calcareous and generally arkosic. The formation is thus hard and compact as a whole; however, the top facies mudstone is weakened from weathering and erosion, and sheet erosion is commonly observed along the formation face.

Stratigraphic relation : Direct observation was not possible. However, research to date suggests that the formation conformably overlies the Lower Siwalik formation.

Upper Middle Siwalik formation

Distribution : This formation is distributed in the Study area from the confluence of the Kalpani and Bheri Kholas to the downstream reaches. Distribution is particularly evident on the left bank of the Bheri Khola.

Facies : The formation consists of alternating layers of (i) poorly consolidated, bluish gray sandstone of medium granularity and 1 to 10 m thick, and (ii) easily weathered, black to gray mudstone. Relatively thick sandstone layers are predominant in the lower portion of the formation with mudstone becoming predominant towards the upper portion. Approximately 25 beds of sandstone were observed in total.

Stratigraphic relation : Both rock facies are transitional and conformable.

Upper Siwalik formation

Distribution : This formation is distributed in the Study area upstream of the confluence of the Kalpani and Bheri Kholas. Outcroppings occur for a 50 m stretch along the left bank of the Bheri Khola.

Facies : The formation is highly solidified boulder conglomerate which is poorly sorted. In one portion, a repeated combination of gravel stone layer (10 m thick) and sandstone layer (2 to 3 m thick) was observed, indicating that this type of sedimentary cycle is the constituent unit of the formation. Boulders are subangular to well rounded, and it is assumed that these have accumulated in large quantity over a relatively short period of time from the nearby mountain area.

Stratigraphic relation : Direct observation was not possible during the study. However, judging from the distribution of the formation, it is believed to conformably overlie the underlying formation.

Geological structure

The entire Siwalik formation in the Study area strikes N50°W - N60°W, and dips around 50° to the northeast. However, since a thrust fault is present roughly parallel to the bedding plane and the same layers repeatedly occur, the geological structure of the area is concluded to be more complex than meets-the-eye.

Dam site geology

Geology around the selected dam site is Upper Middle Siwalik formation. In the vicinity of the confluence of the Bheri and Kalpani Kholas, this formation consists of alternation of sandstone and mudstone with the dominant layer of the latter. However, at the dam site, sandstone is dominant.

Poor geological structure such as fault or sheared zone is not seen in or around the site. However, sandstone shows low consolidation, and mudstone is susceptible to fragmentation when exposed to air.

Tunnel and underground geology

The anticipated geologic profile along the proposed alignment of the tunnel is indicated in Figure 5.1.2.

For a distance of about 100 m from the Bheri River, geology is Upper Middle Siwalik formation with poor foundation characteristics. From that point on, formation is Lower Middle Siwalik with well solidified calcareous sandstone anticipated to have stable foundation characteristics.

At the surface, Lower Middle Siwalik formation forms steep yet stable rock cliffs in excess of 100 m, and is considered to be the optimum of all the Siwalik formations for construction of a large underground cavern, despite the presence of some intercalated mudstone bands.

Geology at the tunnel exit is reported to be Lower Siwalik formation, however, this was not confirmed under the Study. Since this formation is mainly conglomerate and sandstone which is well consolidated, no geological problems will be anticipated in tailrace tunnel excavation.

5.1.3 Geological Survey for LR-1 (Lohore Khola)

(1) Topography

The Lohore Khola joins with a tributary at a point just south of Dailekh town in the centre of Dailekh district, from which point on it forms a broad river plain flowing virtually on a straight course southward. The proposed dam site under the project is located along this straight portion.

At the site, topography on the right bank has a generally steep slope and cliff. In contrast, the left bank is of gentler topography, covered with thick talus deposits. A clearly evident terrace is only seen on the left bank at about 250 m above the present river bed.

(2) Geology

Strata distributed in the subject area comprise midland phyllite and thrust slab associated with the Main Central Thrust. The thrust slab is composed of augen gneiss, amphibolite, quartzite and so on (refer to Figure 5.1.3).

The appearance of rock facies of the formation, in ascending order, in the Study area is described below:

Phyllite : Phyllite is dark gray to black , fine grained sediment rock with extremely well developed cleavage. It is weakly metamorphosed, implying that source rock may have been thin alternation of fine sandstone and slate. This phyllite is broadly distributed on both banks of the Lohore Khola.

Quartzite : Quartzite is milky coloured, massive, cryptocrystalline rock. At times, stratification of around 10 cm is seen.

Amphibolite : Amphibolite is black coloured, massive microcrystalline rock. Bed thickness is around 5 m.

Impure limestone : This is gray to greenish gray coloured, weakly banded (stratified) calcareous slate and impure limestone. Bed thickness is in a range of 5 to 20 m.

Schist : This is gray coloured, biotite quartz schist with extremely well developed schistosity. Microfolding is frequently observed. Bed thickness is several tens of meters.

Augen gneiss : This is white spotted massive gray rock, containing elongated or oval shaped feldspar parallel to gneissosity. Bed thickness is observed to be 100 to 150 m.

Geological structure

A marked anticlinal structure with north-south strike is seen in the phyllite at and around the dam site (refer to Figure 5.1.4). Lohore Khola flows roughly straight southward along this anticlinal axis. Since deep penetrating fissures are often formed parallel to the axial plane in the vicinity of an anticlinal axis, it is assumed that the Lohore Khola river channel is most likely controlled by such fissuring.

A synclinal axis is observed approximately 1,500 m to the west of the aforementioned anticlinal axis with a second anticlinal axis again located another 500 m to the west of the synclinal axis. This type of north-south folding axis system is the result of east-west compression, indicating a tendency for old geological structure.

Dam site geology

Two alternative dam sites have been selected, located approximately 2,000 m apart. Both sites are located on phyllite formation with commonly occurring small cracking such as cleavage and phyllitic texture.

During the Study, both of test drilling and seismic exploration were carried out at the upstream site, whilst seismic exploration alone was carried out at the downstream site.

Upstream site

River width at the site is about 20 m. The right bank topography is steep with outcroppings of dark gray phyllite. Phyllite gently dips toward the hill side. The left bank is covered with thick mud flow deposits and slope wash including huge blocks of augen gneiss. No outcropping of the bedrock was observed.

An elevated river terrace is present on the left bank hill side at about 250 m above the present river bed. Nevertheless, the mud flow deposits are considered to be of younger age than this terrace. Marked gully intrusion is seen in the mud flow deposits, and active landslide zones are recognized.

Downstream site

Topography on the right bank is steep with many outcroppings of phyllite observed. The top layer of soil and slope wash is thin. Although topography is steep, the left bank is cut by three small creeks. The site is located at the west wing of an anticlinal axis, and as such the right bank rock condition is estimated to be good. However, it is possible that a north-west system of hidden fissures exists.

(3) Seismic Exploration

Seismic exploration was performed by selecting two lines at each of the alternative sites (four lines in total). At the upstream site, a low velocity layer was seen in the base rock below the river bed and the road running on the left bank. This may be due to fissuring associated with the aforementioned anticlinal axis.

A thick layer on the left bank with seismic wave velocity of 1.2 to 1.4 km/sec was observed, considered representative of the mud flow deposits and agreeing well with the findings of geological survey.

The velocity exhibited by base rock at the downstream site is 4.0 to 4.3 km/sec. A low velocity layer was identified in the vicinity of the road on the left bank, and this is thought to be due to fissuring, which was not seen in or around the river bed.

(4) Geological Hazards Associated with Dam Ponding

The LR-1 hydropower scheme is a dam type, creating a large reservoir. Following two items were studied in this regard.

Landslide

Thick mud flow deposits are present on the left bank for a distance of 500 m upstream from the upstream alternative site. Marked and recent gully intrusion is seen at these mud flow deposits, around which landslides have occurred. Around half of the cultivated field area shows signs of slope collapse. Other than the foregoing, there are no locations that appear to pose the threat of landsliding.

Mass wasting

The Lohore Khola forms a broad river plain just south of Dailekh town. This implies a large amount of sediment comes from the upstream area.

Using 1/50,000 topographic maps, a relief map was prepared (side of one grid cell equal to 1.8 km) as given in Figure 5.1.5. The map clearly shows the steepness of topography upstream of the boundary line formed by the Main Central Thrust. Accordingly, zones of rock outcropping and slope failure are concentrated in this steep terrain area.

In other words, the basin upstream of the upper MCT boundary is composed of gneiss, which is rather resistive against weathering, forming steep mountain slope. The geotectonic movement caused by subduction of the Indian plate under the Himalayan mountains makes the slope fragile for failure and contributes to mass wasting, which is beyond the capability of control by man.

The area in the MCT zone is composed of phyllite and augen gneiss, and the basin downstream of the lower MCT boundary is composed of phyllite, which is prone to weathering, forming gentle hill slope with rather thick top soils suitable for cultivation.

It can be said that top soil erosion mainly results from the area extending downstream of the upper MCT boundary due to the deterioration of watershed, i.e. deforestation.

5.1.4 Geological Survey for SR-3 (Seti River)

(1) Topography

The project area is located immediately downstream of the confluence of the Seti River and Bauli Gad flowing in the vicinity of Chainpur, Bajhang District. The river at this point has a width of 80 to 100 m. River terraces are well developed in the area. Low terrace, middle terrace, and high terrace are located on the left bank, and respective heights above the river are 15 m, 25 m, and 150 m.

On the right bank, low terrace and middle terrace are found with heights of 15 m and 25 m above the river , forming broad flat areas. A hospital and an airfield lie on the middle terrace. Geologically, river terraces are developed in the area of phyllite distribution, and steep valleys are formed in the areas of quartzite and limestone distribution.

(2) Geology

The geology of the entire area belongs to midland metasediment consisting of dark gray phyllite, limestone/dolomite, quartzite, and greenish phyllite in an ascending order (refer to Figure 5.1.6). The greenish phyllite indicates a clear bedding plane, preserving the sedimentary structure of the source rock. It is well consolidated.

The calcareous formation consisting of limestone/dolomite is generally massive, forming steep topography and continuous large scale outcropping. The limestone/dolomite is gray, recrystalline, and shows no evidence of fossil content.

Quartzite is white and hard, forming outcrops which can be traced over a wide area. As a result, this formation can be applied as a key bed in analysis of geological structure. Detailed examination of the uppermost dark gray phyllite formation shows frequent alternation of beds of thin and flaky phyllite and massive compact sandstone. Topographically, the massive compact sandstone beds form small jutting ridges, whilst the latter, due to its ease of exfoliation, forms thick slope wash deposits at slope bases which are used for cultivation.

Geological structure

The dark gray phyllite, distributed over a wide area from Chainpur to the confluence with the Kachali Khola 5 km downstream on the right bank, and the underlying quartzite together form a broad syncline with northeast-southeast axis. The limestone/dolomite shows folding with the identical axis. The relationship of the foregoing to the phyllite quartzite group could not be directly observed under the Study; however, it is thought that the boundary between the two may be a fault.

Geology at the site

At the proposed site for the weir, the river is wide together with terraces on both banks. As a result, bedrock outcrops are few.

Geology at the site consists of dark gray, fissile phyllite with partial intercalation of massive, compact bed of sandy phyllite. Strike is roughly perpendicular to the river axis, and dip is toward the downstream direction with an range of 40 to 50°.

Geology in the tunnel

The upstream two-thirds of the almost 10 km long tunnel route consists of dark gray phyllite forming a broadly open syncline. The remaining downstream portion of the route consists of 200 m thick quartzite with limestone/dolomite farther downstream forming a folding calcareous sequence over a 3 km area. Greenish phyllite is anticipated to be present in the area of the proposed power station site (refer to Figure 5.1.7).

(3) Seismic Exploration

Seismic prospecting was carried out for four lines;one is the line traversing the river, and the other three are the lines along the top of terrace. Wave velocity for base rock is in a range of 4.3 to 4.5 km/sec. However, a thick bed likely to correspond to the weathered zone exhibits a wave velocity of 2.3 to 2.5 km/sec.

A 50 m wide low velocity zone is identified under the river plain, and a 1.2 to 1.4 km/sec sand and gravel layer extends to deep ground under the middle terrace on the right bank. Underlying base rock is likewise located in deep ground. This is interpreted as the indication of the ancient river channel.

5.1.5 Geological Survey for CR-2 (Chamliya River)

(1) Topography

The Chamliya River flows largely from northeast to southwest. As in the case of other areas, topography where the river cuts through the phyllite formation is relatively gentle with a well developed terrace. In contrast, where the river cuts through the quartzite or limestone formation, topography is steep with deep gorges.

The project area for CR-2 consists of a broad terrace zone to the downstream reach and dissected limestone zone to the upstream reach.

(2) Geology

The geology of the area falls within the Midland Metasediments and consists of sedimentary sequence with large content of calcareous facies such as limestone/dolomite and so on (refer to Figures 5.1.8 and 5.1.9).

A description of facies in an ascending order for the study area is as follows:

Phyllite	:	Gray to dark gray coloured fissile metasediment with minor intercalation of meta-sandstone and greenish gray chloritic phyllite
Banded limestone	:	Alternation of thin slate layer and 10 cm thick band of gray limestone
Massive limestone	:	Recrystallized, gray coloured, saccharoidal limestone

Calcareous phyllite	:	Dark gray coloured phyllite, finely intercalated with gray coloured thin band of calcareous slate and/or bluish gray limestone layer
Conglomerate/sandstone	:	Fine to medium grained greenish gray compact sandstone and pebble conglomerate. Pebbles are mainly quartzite. This layer is distributed on a small scale atop the synclinal axis. It is assumed to unconformably overlay the lower calcareous phyllite on both sides of the axis in light of the fact that the thicknesses of the two are extremely different.

Geological structure

A NE-SW fault system is anticipated to follow the left bank of the Chamliya River. However, this system is located away from the structure sites under the project and is therefore not considered a problem.

Folding structure in the area is comprised of a WNW-ESE synclinal axis with sandstone conglomerate at the vicinity of the confluence of the Bheli Gad and the Chamliya River with an anticlinal axis located 500 m to the north. Another anticlinal axis is located 3,500 m to the south (downstream side), and the Chamliya River channel changes to follow this axis.

These folding axes are all cut by the aforementioned fault. An anticlinal axis following the Gandi Gad was observed to the south of this fault, or in other words on the left bank of the Chamliya River.

Dam site geology

There are two candidate sites for the dam structure. The downstream site is located on phyllite formation, whilst the upstream site is located on massive limestone. Under the Study, test drilling and seismic exploration were performed at the downstream site, and seismic exploration at the upstream site.

Downstream site

River plain at this site is 100 m wide; nevertheless, topography on both banks is extremely steep.

Geology consists of fissile phyllite with strike roughly perpendicular to the river axis, thereby resulting in the above described steep topography. Dip is a steep 50° or more toward the upstream side.

Upstream site

Topography on the right bank at this site is extremely steep with a slope of 60 to 70°. Terrace with 20 m width and located 30 m above the river bed is found on the left bank. Geology of both banks is massive gray limestone. Terrace consists of less sorted river sediment containing huge blocks of limestone. Limestone caves are not known in this area. This is considered due to the fact that uplifting speed in the lesser Himalayan zone to which the area belongs was too rapid to allow for the formation of such caves.

(3) Seismic Exploration

Seismic wave velocity of the base rock at the downstream site is 4.8 to 5.0 km/sec. Although the weathered portion is somewhat thick, leading to the conclusion that the bedrock phyllite was possibly originally fissile, no marked low velocity layer was identified.

The right bank topography at the upstream site was too steep to set measuring lines. However, no problems with regards to geological structure are anticipated since massive limestone outcrops are seen at the site.

Terrace is located on the left bank with unexpectedly thick weathered portion. However, no marked discontinuities such as fault, etc. were found.

5.2 Hydrogeological Survey in Surkhet Valley

Hydrogeological investigation was carried out to search for groundwater in the Surkhet Valley by electric survey. The condition of site where the investigation was carried out is summarized as follows:

Location : Birendranagar and its suburbs, Surkhet district

Accessibility : Motorable road is connecting the area to Nepalganj, whilst access by air is available from Kathmandu and Nepalganj.

Electric surveys were carried out at three sites as depicted in Figure 5.2.1, whilst the survey results are given in a form of resistivity profile as shown in Figure 5.2.2. Following deal with the results of electric survey:

(1) Geomorphology

The intermountain basin called "dun (doon)" is known to occur between the Siwalik mountain range and the Mahabharat mountain range. Surkhet Valley is one of the largest duns in Nepal with a flat land of more than 60 km^2 in the altitude ranging from 2,100 ft. to 2,300 ft. above mean sea level. Four major streams running down to south in the valley meet at the southern end of the flat land to form the Nikas Khola, a tributary of the Bheri River.

At the foot-hill of the Siwaliks extended in the northern part of Surkhet Valley, those four streams are forming the fans composed of loose and highly permeable boulder bed, resulting in scarcity of the surface water in the reaches during the dry season. In the southern half of the flat land, sub-surface soil is impervious massive dark-gray silty mud, causing the ill-drained paddy field.

(2) Hydrogeology

Surface flow of the four rivers running across the valley is quite limited in the dry season, and most of the surface water in the upper reaches is used for drinking and /or for the small scale irrigation.

The middle reaches of the rivers were completely found dry during the field survey conducted in January 1993. At the central part of the valley, between the middle reaches and the lower reaches of the rivers, a number of springs are known to occur, and most of these springs are located at the "terminal fan". A brief description is given for main springs.

The largest yield is measured at the famous Bulbule spring where groundwater of 20 l/sec is pouring out. Next to the Bulbule spring is Mulpani spring located in Uttraganga, which is pouring out about 10 l/sec. All of the other springs yield less than 2 l/sec. The fact that the lower reaches of the streams are draining much water than the upper reaches suggests that the maximum quantity of water could be obtained at Nikas Khola, the only stream flowing out from the valley.

(3) Electric Survey

To study the status of groundwater in the dried-up middle reaches of the stream , three lines of electric survey were conducted by Dipole-Dipole configuration along the Itram Khola (refer to Figure 5.2.1). As is clearly shown in the resistivity profile of Line-1 (refer to Figure 5.2.2), the iso-resistivity line is getting deeper towards the downstream reaches, whilst at the Line-2, which is located close to the terminal fan, the iso-resistiviey line is getting shallower towards the downstream reaches. Since the iso-resistivity line is parallel to the groundwater table, the survey result could explain the mechanism of springs at the terminal fan.

The Line-3 was arranged perpendicular to the stream. The iso-resistivity line is shallow at the dried-up river bed, suggesting that the groundwater is being recharged with the underflow water of the river bed. Another low-resistivity was detected at the depth of 15 m of the Station No. 5 which might be the buried ancient river channel.

(4) Conclusive Remarks

According to the results of electrical prospecting, variation in resistivity values is small to a depth of 20 m below ground surface. Although a stable water bearing layer is anticipated to be present, pump up per existing well is under 10l/sec, which is not suitable for agricultural purposes. Furthermore, resistivity values show almost no change to 20 to 50 m depth below the surface.

List of References

Ref. I-1 Molnar, P., (1986). The Geologic History and Structure of the Himalaya. Am. Scientist, V. 74, pp 144 - 154.

Ref. I-2 Zhang Zusheng. (1987). The Map Compilation of the Recent Vertical Deformation Rate in China. (paper presented 19th IUGC, Aug. 1987, Vancouver, quoted from the "Uplifting Himalaya: 1988 Kisaki ed. Tukiji Pub. Tokyo).

Ref. I-3 Ganser, A., (1982). The Morphogenic Phase of Mountain Building. in "Mountain Building Process" Hsu ed. Academic Press.

Ref. I-4 Nakata. T., (1985). Geomorphic History and Crustal Movement of the Foot-Hill of Himalaya. Sci. Rept. Tohoku Univ., Ser. 7, 22.

Ref. I-5 Kisaki, K., (1985). Uplifting Himalaya. in the "Uplifting Himalaya". Kisaki ed., Tukiji Pub. Tokyo.

Ref. I-6 Gupta, G. P., (1977). Appraisal of the Sedimentation Problem in the Country and Measures to Control. Proceedings of Symposium on Silting of Reservoirs, Central Board Irrigation and Power, Pub. No. 126, New Delhi.

Ref. I-7 JICA, (1983). Feasibility Report on Sapt Gandaki Hydro-Electric Power Development Project. V. 1. Main Report.

Ref. I-8 Himalayan Power Consultants. (1989). Seismology. Karnali (Chisapani) Multipurpose Project.

Ref. I-9 R. Satyanarain. (1988). Aseismatic Design Code for Nepal. Bull. Int. Inst. Seismol. Earthquake Eng., vol. 22, P113 - 124.

Ref. I-10 Criteria for Earthquake Resistant Design of Structures. (Third Revision). Indian Standard.

TABLES

Table 3.2.1 RESULTS OF GEOLOGICAL FIELD INVESTIGATION CARRIED OUT IN PHASE II (1/5)

Scheme	Description of Location and Geology	Geological Conditions
TR-3	Helicopter landing is impossible. Rocktype is schist and phyllite (Nawakot group). The site is located 30 km north of existing and planned road between Surkhet and Dailekh. Construction materials: Concrete aggregates are available from gravel bed of terrace deposits.	Fair
TR-4	Helicopter landing is possible. The site is located 10 km upstream of Jumla, and about 150 km north of Dailekh-Surkhet road now under construction. Rock type is well foliated schist. Geological structure shows N 75 E / 30 N. Construction materials: concrete aggregates are available from gravel bed of terrace deposits. The site is located in the uppermost among those in the Tila River basin.	Fair
MKR-2	Helicopter landing is possible. The site is located 3 km east and upstream from Gamgadhi, the district headquarters of Mugu. Rock type consists of gneiss with quartz vein (Himal group). Concrete aggregates are available from terrace deposits.	Good
MKR-3	Helicopter landing is impossible. The site is located about 35 km east of Gamgadhi. Two-day walk is necessary along foot path from Gamgadhi to the site. Rock type is gneissose granite according to the geologic map. Construction materials cannot be expected from the gravel bed. A quarry site is thus necessary. The site is located in the uppermost of the Mugu Karnali River basin.	Good
HKR-2	Helicopter landing is impossible. Motorable access road does not exist. A foot track exists from Simikot airport for about 25 km in the northwest direction. Rock type consists of Himalayan gneiss according to the geological map. Construction materials: concrete aggregate is not available. A quarry site is thus necessary. Remarks: Darma fault, which is an active fault trending in NW-SE direction, is running near the site.	Good
HKR-3	Helicopter landing is possible. Together with the HKR-2 site, access by motorable road is very hard. The site is located about 5 km south from the Simikot airport by foot track. Rock type is Himalayan gneiss intercalated with schistose gneiss. Geological structure shows N 60 W / 60 N. Construction materials: Concrete aggregate is available from terrace deposits. Remarks: Darma fault line appears to pass at the east side of the site.	Good
HKR-4	Helicopter landing is possible. The site is located about 3 km southwest from the Simikot airport. Access by motor vehicle is not possible. Rock type is Himalayan gneiss with granite. Geologic structure shows N 80 E / 20 - 25 W. Concrete aggregate is available from gravel bed of terrace deposits. Remarks: The site is located in the uppermost of the Humla Karnali River basin.	Good

Table 3.2.1 **RESULTS OF GEOLOGICAL FIELD INVESTIGATION CARRIED OUT IN PHASE II (2/5)**

Scheme	Description of Location and Geology	Geological Conditions
BR-7	Helicopter landing is possible. Access by motor vehicle is not possible. The site is located about 30 km northwest of the Dolpa airport. Rock type is schist. Geological structure shows N 35 E / 45 E. Construction materials: concrete aggregates are available from river terrace deposits located in the upstream area. Remarks: The site is located in a meandering valley, showing a favourable topography for hydropower generation.	Fair
BR-8	Helicopter landing is possible. Only a foot track from the Dolpa airport is available to reach the site. The site is located about 30 km southeast of the Dolpa airport. Rock type is gneiss intercalated with mica-schist, having N 40 W / 55 N geological structure. Construction materials: Concrete aggregate is available from river terrace deposits. Remarks: The site is located in the uppermost among those in the Thuli Bheri River basin.	Fair to Good
BS-1	Helicopter landing is possible. A foot track exists between the intake site and the Safebagar airport, and distance is about 20 km. Construction materials: Concrete aggregates are available from river terrace deposits, and impervious core materials may be available from slope-wash or slide materials.	Good
SR-7	Helicopter landing is impossible. No motorable access road exists. The site is located 25 to 30 km NNE from the Chainpur airport. Construction materials: Concrete aggregates are not available, and as a result a quarry site is necessary. Rock type comprises gneiss according to the geological map. The site is located in the uppermost in the Seti River basin.	Good
LR-1	Helicopter landing is possible. The site is located along the planned motorable road. At present, it takes about two days to reach the site from Surkhet on foot. Rock type is well foliated mica schist of meta sedimentary rocks, having N 30 W / 25 W geological structure. Construction materials: Concrete aggregates are available from the river bed, and impervious core materials are available from laterite clay at a few places on the left bank.	Fair
CR-1	Helicopter landing is possible. A motorable road is currently under construction and completed from Baitadi up to Gokulesharwar about 35 km to the NE. Rock type is massive, hard and pure quartzite, having N 70 E / 50 N geological structure. Construction material: Concrete aggregates are available from terrace deposits lying downstream of the left bank. Remarks: The site is located in the uppermost of the Chamliya River, a tribatary of the Mahakali River	Good

Table 3.2.1 RESULTS OF GEOLOGICAL FIELD INVESTIGATION CARRIED OUT IN PHASE II (3/5)

Scheme	Description of Location and Geology	Geological Conditions
CR-2	Helicopter landing is possible. Condition of the accessibility is the same as CR-1 Site. Rock type is massive, hard-dolomitic limestone, having N 30 / 70 E. Dipping direction is toward the upstream reaches. Construction materials : Concrete aggregates are available from river terrace deposits. Remarks : Basement rock mainly consists of limestone, which may have problems of seepage and solution.	Fair
BR-3B	A motorable road under construction exists on the left bank of the Bheri River via Bredahari to Jajarkot. Rock type is schist and phyllite of meta sedimentary rocks, having N 50 to 60 W/N-E geological structure. Construction materials: Concrete aggregates are available from river terrace deposits, and impervious core materials are available from laterite clay widely distributed around the project site. Remarks: The site is newly proposed as an alternative of BR-3A (originally BR-3 site).	Fair to Good
KR-1A (Karnali bend)	Helicopter landing is possible. A motorable road now under construction running about 20 km NW-SE from Surkhet exists to the site. Rock type is hard massive quartzite, having N 15 W/30 E geological structure on both the diversion structure and power house sides. Construction material: Concrete aggregate is available from river terrace deposits. Remarks: Some lineaments including active fault are distributed in the vicinity of the project area, and the waterway of the scheme runs the shortest route of the U-shaped bend of the Karnali River.	Good
TR-1	Helicopter landing is not possible. Rock type is schist and phyllite of meta sedimentary rocks. Construction materials: Concrete aggregates are not available, and a quarry site is therefore necessary.	Fair to Good
BR-1 (diversion scheme)	Helicopter landing is possible. The intake site is located 7 km downstream of the Bheri permanent bridge. A motorable access road is available from Nepalganj to Surkhet, from which the diversion site can be easily reached by 5 km long walk on the foot track. Bed rock consists of Siwalik formation, sandstone, mudstone and conglomerate. The formation is poorly consolidated, and surface rock is easily weathered. Especially mudstone is subject to slaking action. Geological structure is N 45 W/65 E. Construction materials: Concrete aggregates are available from river terrace deposits, and impervious core materials are available from residual soil derived from weathered rocks. Remarks: The most difficult issue affecting the scheme is that the planned power house area lies in the national park.	Poor

Table 3.2.1 RESULTS OF GEOLOGICAL FIELD INVESTIGATION CARRIED OUT IN PHASE II (4/5)

Scheme	Description of Location and Geology	Geological Conditions
SR-6	Helicopter landing is not possible. A motorable access road exists up to Dipayal, and extension of this road to Sopheboga is currently under construction, passing 10 km north of the site. Rock type is schist and phyllite of meta sedimentary rocks.	Fair to Good
SR-3	Helicopter landing is not possible. A motorable access road is now under construction between Khodpe and Chainpur along the right bank of the Seti River. Rock type is schist and phyllite of meta sedimentary rocks.	Fair to Good
SR-1A (West Seti)	Helicopter landing is possible. The existing motorable road, which passes downstream of the dam site, is available to reach the power house lying between Bhatkoda and Dipayal. A 10 km long walk is necessary to reach the diversion site. Rock type is massive, hard gneissose schist with green schist. Geological structure is N 75 W / 80 to 90 S. Construction materials: Concrete aggregates are available from the river bed.	Good
THR-1	Helicopter landing is not possible. A motorable road now under construction will run upstream of the intake site. The road is completed only for a distance of less than 5 km from Budar toward Silgadi. Rock consists of Siwalik formation, sandstone with shale, conglomerate and mudstone, having N 60 to 70 E/20 to 30 N geological structure. Construction material: Concrete aggregates will be obtained from river bed or river terrace deposits, and impervious core materials are available from weathered surface deposits. Remarks: The helicopter survey in Phase II identified a landslide on the slope located at the left bank near the intake site. Main Boundary Thrust active fault is located upstream of the diversion site.	Poor
KR-4	Helicopter landing is not possible. The site is located at the upper reaches of the Karnali River, far from any existing motorable road. Rock type consists of schist and phyllite of meta sedimentary rocks.	Fair to Good
HKR-1	Helicopter landing is not possible. Accessibility is very poor as in the case of the KR-4 site. Rock type is schist and phyllite of meta sedimentary rocks.	Fair to Good
TR-2	Helicopter landing is not possible. A motorable road currently under construction will be extended up to Dailekh, 30 km south of the site. Rock type consists of schist and phyllite of meta sedimentary rocks.	Fair to Good
BR-4	Helicopter landing is not possible. A motorable access road is currently under construction between Chhinyu and Jajarkot along the Bheri River. This road connects the existing road at a midway point between Nepalganj and Birendranagar. Rock type is schist and phyllite of meta sedimentary rocks.	Fair to Good

Table 3.2.1 RESULTS OF GEOLOGICAL FIELD INVESTIGATION CARRIED OUT IN PHASE II (5/5)

Scheme	Description of Location and Geology	Geological Conditions
BR-5	Helicopter landing is not possible. The condition of motorable access road is the same as that of BR-4. Rock type is schist and phyllite of meta sedimentary rocks.	Fair to Good
BR-6	Helicopter landing is not possible. The site is located downstream of Dunai and the BR-8 site. A motorable access road is not available. Rock type is gneiss according to the geological map.	Good
BR-3A (BR-3)	Helicopter landing is possible. An existing motorable access road reaches the intake site. Rock type is Siwalik formation, sandstone, mudstone and conglomerate. Especially mudstone is susceptible to slaking and weathering. Geological structure is N 65 E/35 S. Remarks: Wide, flat cultivated land extends along both banks upstream of the diversion site. If a high dam is constructed at the site, valuable flat land for agriculture in the Sulkhet valley would be inundated.	Poor
MKR-1	Helicopter landing is possible. A motorable access road to the site does not exist, as in the case of the KR-4 and HKR-1 sites. Rock type is massive, hard quartzite, having N 5 W / 20 E geological structure.	Good

Table 3.2.2 LIST OF THE DETAILED GEOLOGICAL MAPS

Report No.	Description
1	Geological Report of Manakot, Talkot, and Bhuli Areas by T.P. Adhikary, 1978/1979. (Bajura and Bajhang Districts) Topo No. 62 G/6 used for the SR.7 site.
2	Geological Map of Nepalganj, Surkhet and Sallyan Area by G.S. Thapa, Topo. No. 62 H/15, & H/16 used for the BR.3B site.
3	Geological Map of Nepalganj-Surkhet Area by N.B. Kayastha Topo No. 62 H/10 & H/11 used for the BR.1, BR.3A and KR.3 sites.
4	Geology of Part of Baitadi-Darchula Area, far western Nepal. (with Geochemical Result), by S.B. Shrestha, 1980. Topo No. 62 C/10 used for the CR.2 site.
5	Geological Report of Part of Surkhet-Dailekh Area, by S.B. Shrestha, 1973. Topo No. 62 H/10 used for the BR.1 and BR.3A sites.
6	Geology of a portion of Dailehk and Acham Districts of Bheri and Karnali Anchal, by K.D. Bhattarai. Topo No. 62 H/9 used for the LR.1 site.
7	The Geology of Jumla, Tibrikot and Mugu Map Area, (Western Nepal) by R.N. Yadav, J. Jha, 1975. Topo No. 62 K/3 used for the TR.4 site.
8	Reconnaissance Geological Traverse along the Mugu Karnali River, Mugu and Humla Districts, western Nepal by S.L. Karmacharya, 1989. Topo No. 62 K/2, K/6, K/10 used for the HKR.1, MKR.2 and MKR.3 sites.
9	Geological Report of Part of Achham-Dailekh Area, by S.B. Shrestha, 1975. Topo No. 62 G/8
10	Report on Geological and Geochemical Investigation of Mineral Resources of Part of Dadeldhura Granitic Massif, Dadeldhura and Baitadi Districts, Mahakali Zone Vol. 2, by P.R. Joshi, 1978. Topo No. 62 C/7, 8, 11, 12, 15, 16

Table 4.2.1 RESULT OF STATISTICAL ANALYSIS

Site	Formula used	Return Period (Year)		
		50	75	100
BR-1	Okamoto	40	46	48
		(0.04)	(0.05)	(0.05)
	M.C.J	66	73	79
		(0.07)	(0.07)	(0.08)
	H.P.C	60	64	68
		(0.06)	(0.07)	(0.07)
LR-1	Okamoto	53	56	60
		(0.05)	(0.06)	(0.06)
	M.C.J	74	77	80
		(0.08)	(0.08)	(0.08)
	H.P.C	62	66	69
		(0.06)	(0.07)	(0.07)
CR-2	Okamoto	28	32	34
		(0.03)	(0.03)	(0.03)
	M.C.J	61	64	67
		(0.06)	(0.07)	(0.07)
	H.P.C	59	63	66
		(0.06)	(0.06)	(0.07)
SR-3	Okamoto	205	225	235
		(0.21)	(0.23)	(0.24)
	M.C.J	205	225	240
		(0.21)	(0.23)	(0.24)
	H.P.C	150	165	175
		(0.15)	(0.17)	(0.18)

Note : M.C.J Ministry of Construction, Japan
H.P.C Himalayan Power Consultants

Table 4.2.2 **ESTIMATED VALUES OF DESIGN SEISMIC COEFFICIENT BASED ON THE MAXIMUM ACCELERATION**

Estimate Value	Basis for Estimation
R = 0.6 (each site)	The estimated maximum acceleration by the statistical analysis is controlled by the near field earthquake
Amax =	Maximum acceleration by attenuation model BR-1 86 gal by M.C.J. LR-1 85 gal by M.C.J. CR-2 76 gal by H.P.C. SR-3 224 gal by M.C.J. Statistical analysis result (100 years) BR-1 79 gal by M.C.J. LR-1 80 gal by M.C.J. CR-2 67 gal by M.C.J. SR-3 240 gal by M.C.J.
a eff =	a eff = R. Amax / 980 = BR-1 0.05 LR-1 0.05 CR-2 0.05 SR-3 0.15

Table 4.2.3 BASIC SEISMIC COEFFICIENT FOR THE SEISMIC RISK ZONES OF INDIA

Seismic risk zones of India	Basic horizontal seismic coefficient, $\alpha 0$
V	0.08
IV	0.05
III	0.05
II	0.02
I	0.01

Note : The design values of horizontal αh

$$\alpha h = ß.I. \alpha 0$$

The value of ß for dams shall be taken as 1.0.
The value of importance factor, I for dam (all types) shall be taken as 2.0.
For under ground structures and foundations at 30 m depth or below, the basic seismic coefficient may be linearly interpolated between between α and 0.5 α 0.

Table 4.2.4 ESTIMATED VALUES OF THE DESIGN SEISMIC COEFFICIENT BASED ON THE MAXIMUM ACCELERATION

Basis for evaluation	Design horizontal seismic coefficient	
Aseismatic design code for Nepal	BR-1	0.075
	LR-1	0.12
	CR-2	0.12
	SR-3	0.075
Indian standard	BR-1	0.10
	LR-1	0.10
	CR-2	0.16
	SR-3	0.16
Estimates of maximum acceleration	BR-1	0.05
	LR-1	0.05
	CR-2	0.05
	SR-3	0.15
Suggested value for each site	BR-1	0.10
	LR-1	0.12
	CR-2	0.16
	SR-3	0.16

Note : Those values of the design seismic coefficient should be changed in proportion as importance.

FIGURES

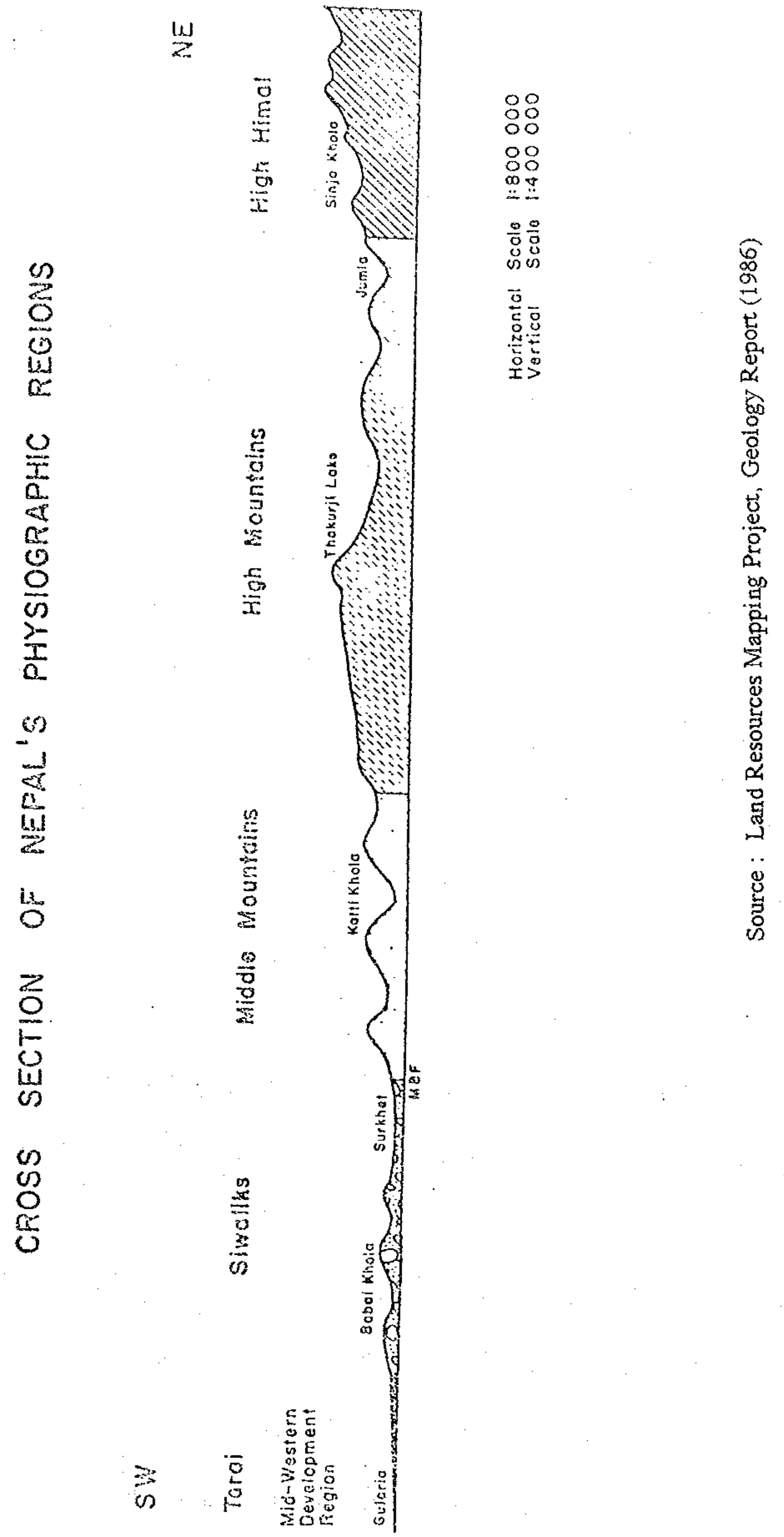


Figure 1.1.1 **Cross Section of Nepal's Physiographic Regions**

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

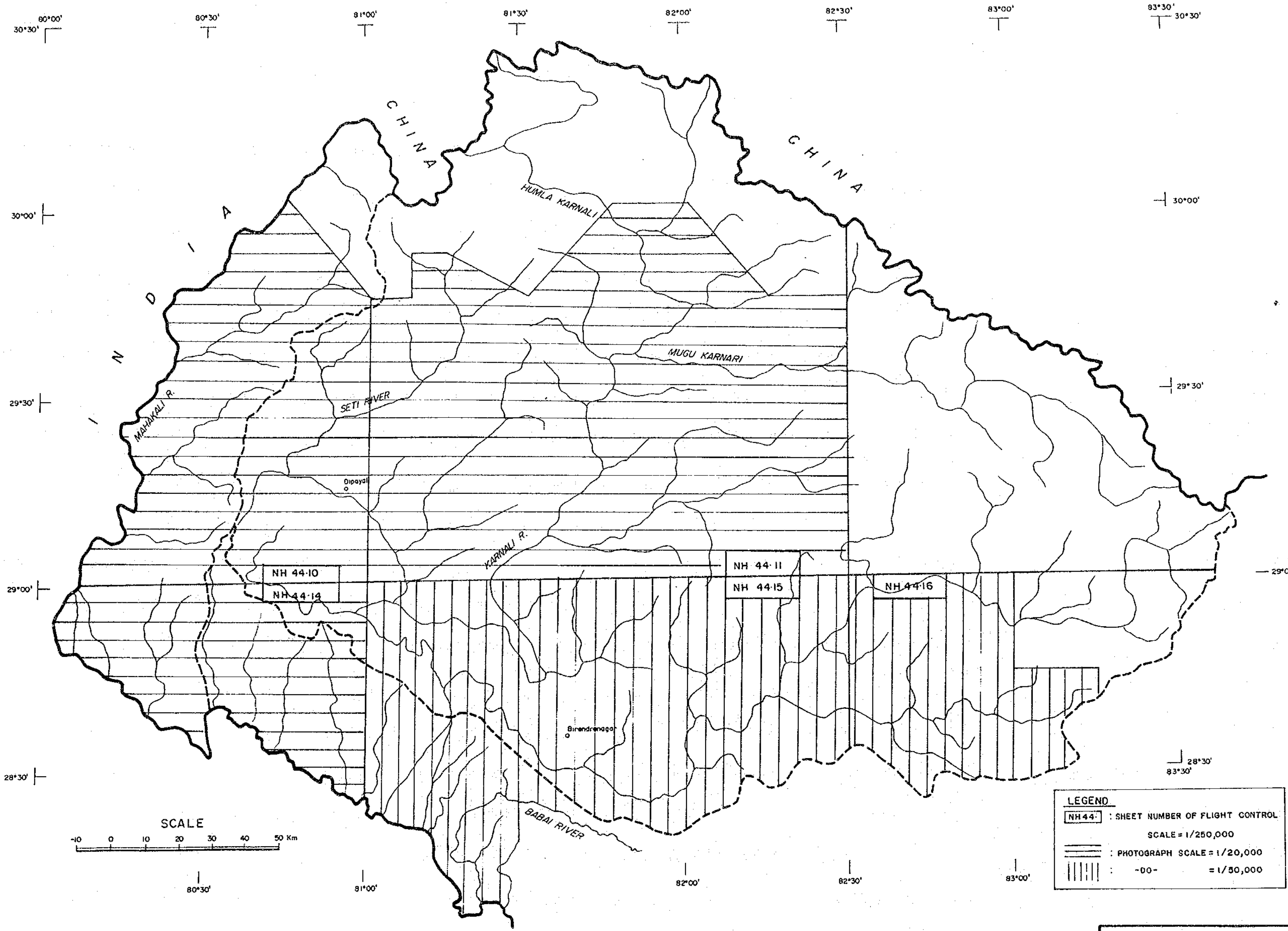


Figure 1.1.2 Index Map of Aerial Photographs Available in the Study Area

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

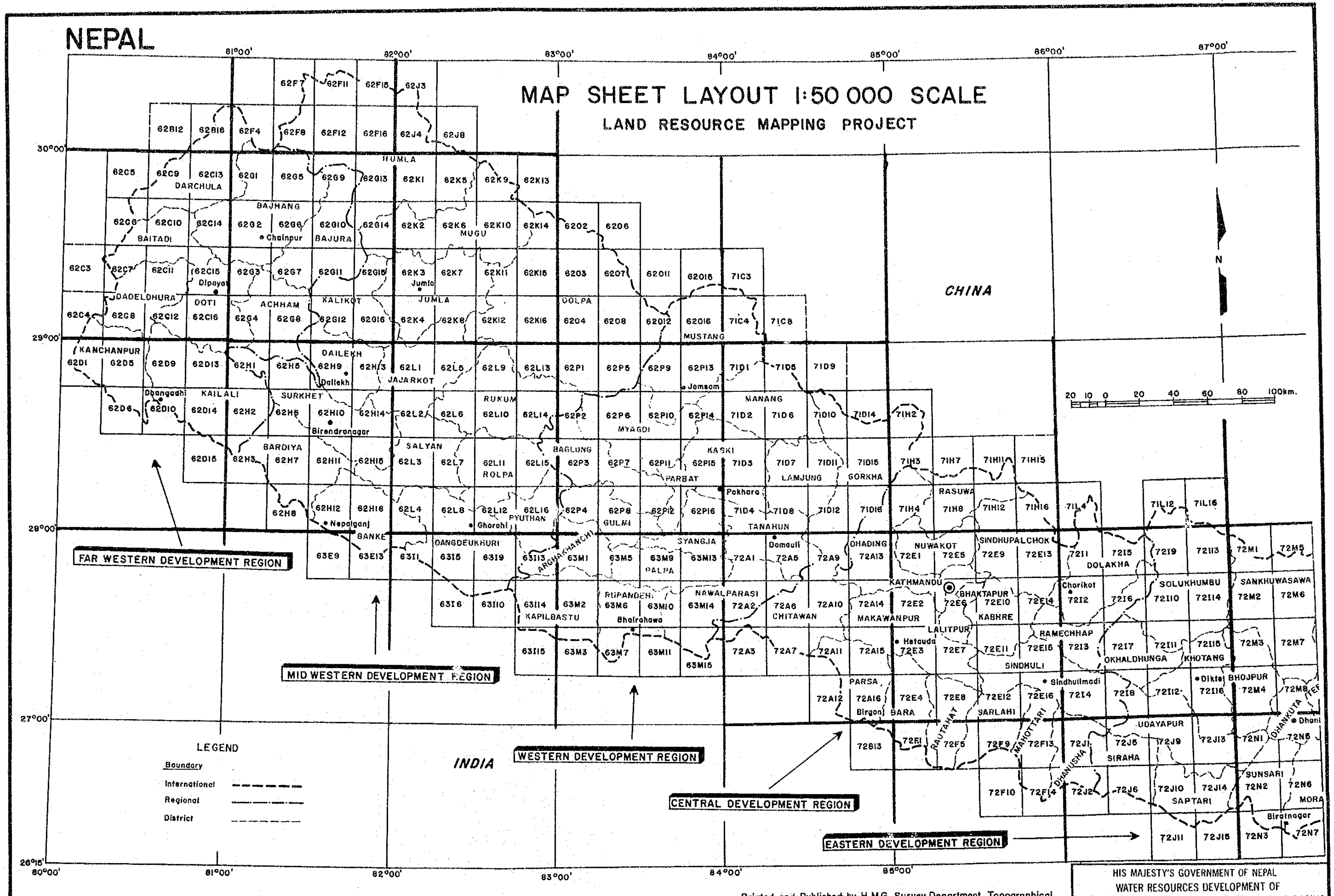


Figure 1.1.3 Index Map of 1: 50,000 Scale Topographic Maps

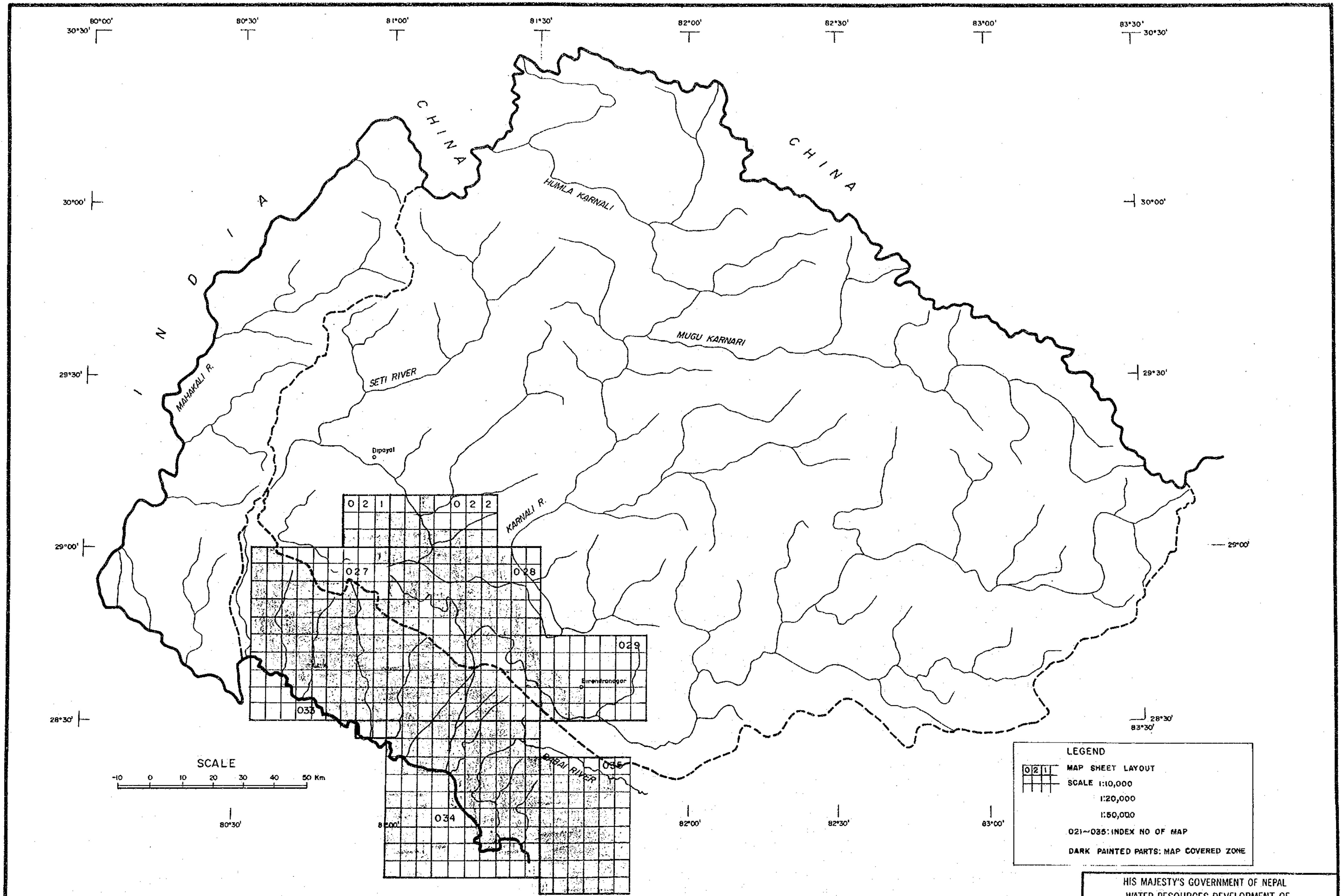


Figure 1.1.4 **Index Map of 1: 10,000 Scale Topographic Maps**

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

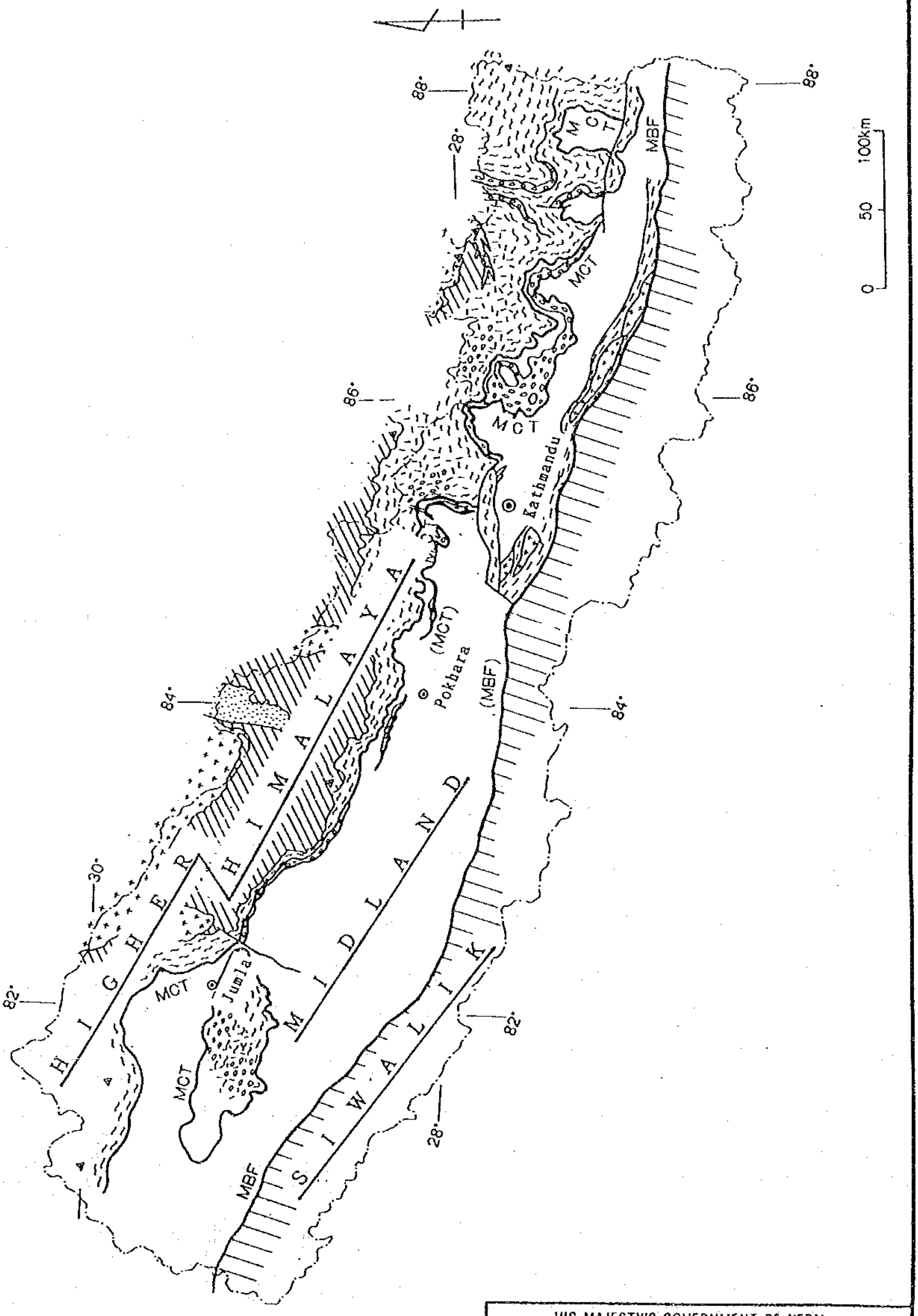


Figure 2.1.1 **General Geologic Map of Nepal Showing Three Zones**

HIS MAJESTY'S GOVERNMENT OF NEPAL WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

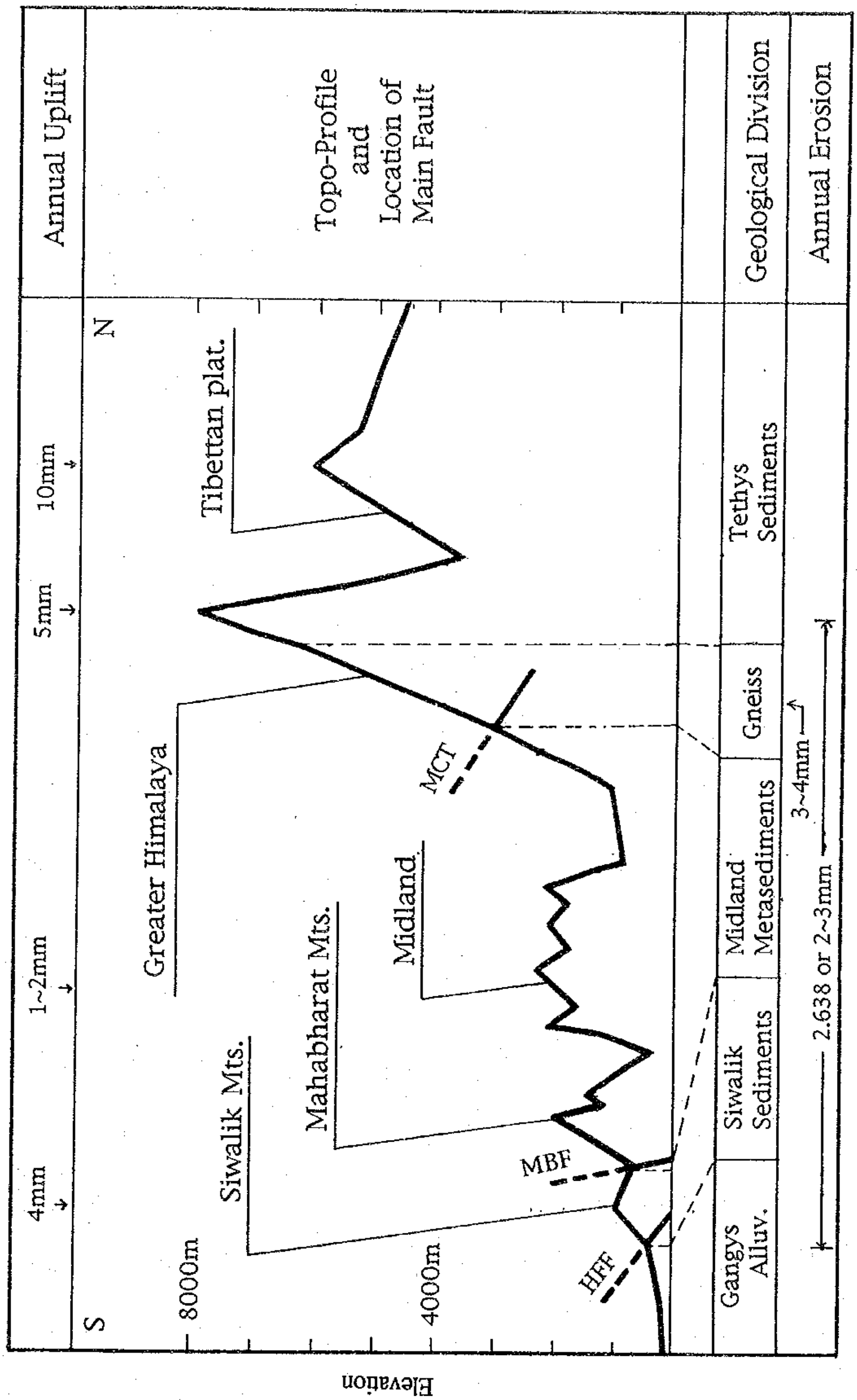


Figure 2.2.1 Schematic Profile of Erosion Rates

HIS MAJESTY'S GOVERNMENT OF NEPAL WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

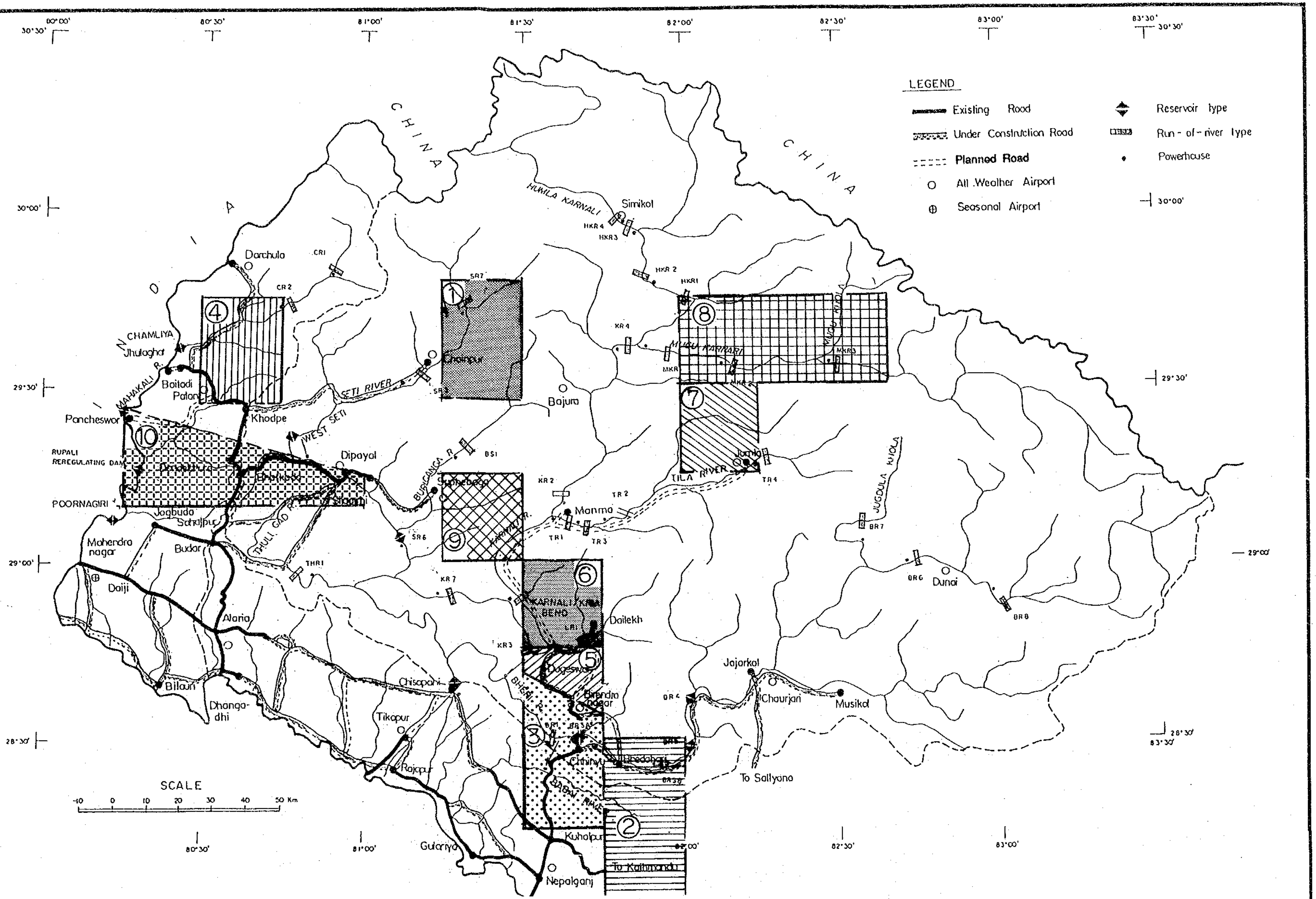


Figure 3.2.1 Detailed Scale Geological Maps for Hydropower Potential Schemes

①～⑩ : Geological Report No. (Refer to Table 3.2.2)

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

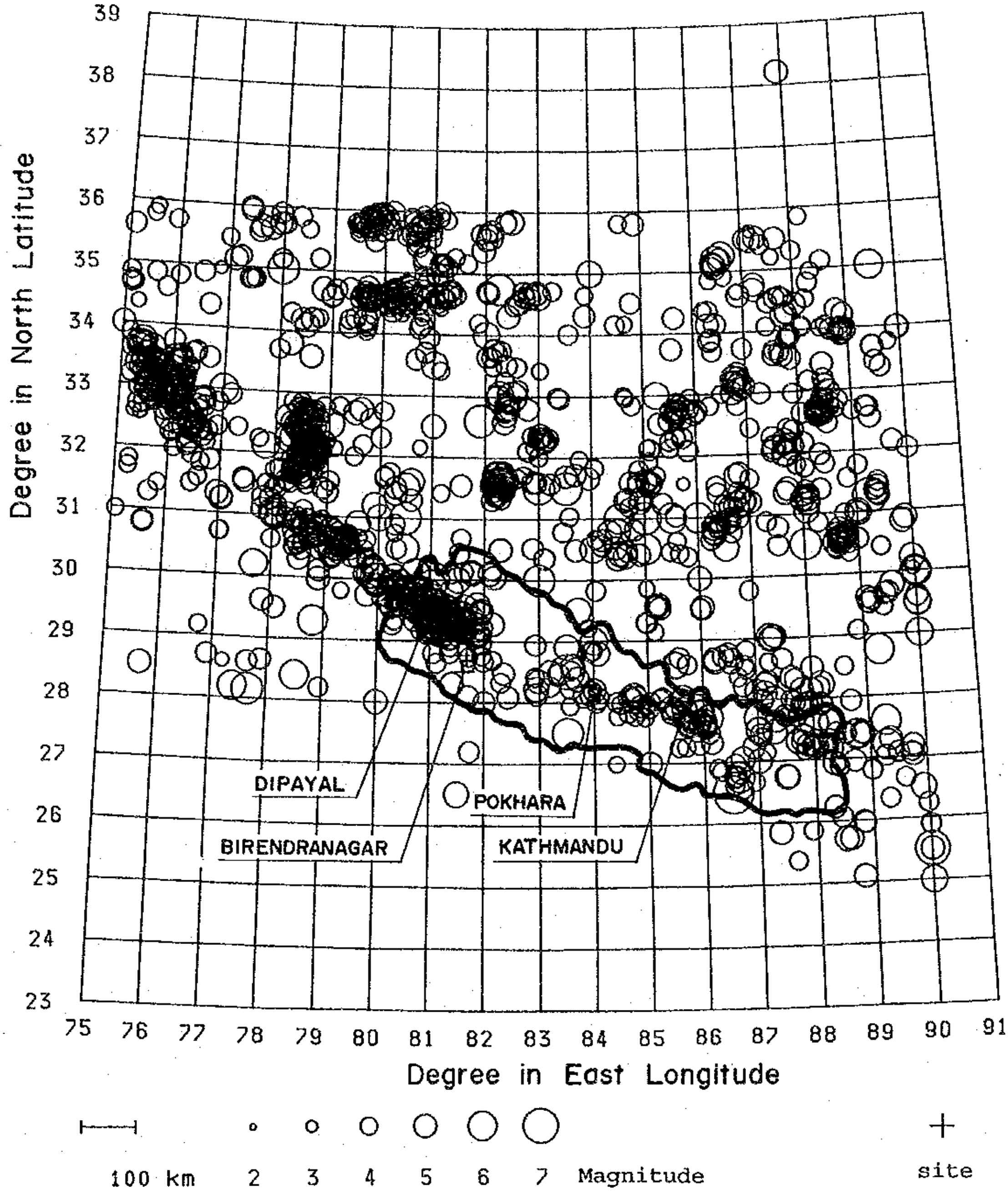
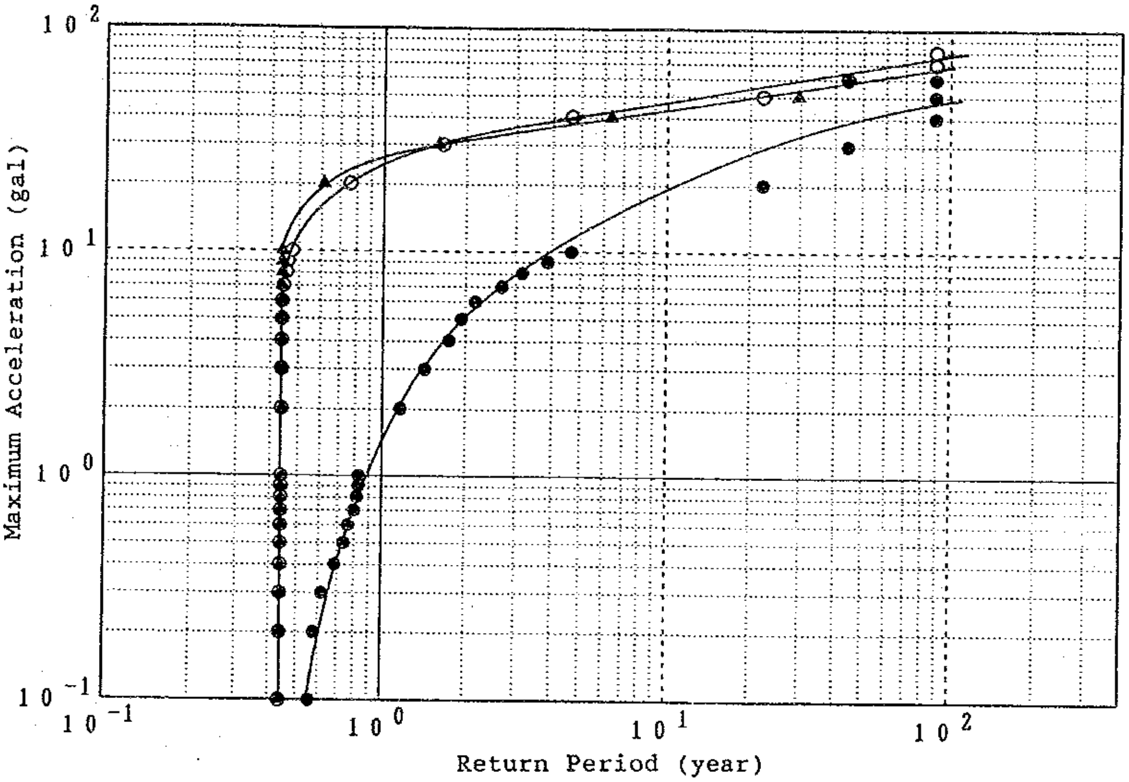


Figure 4.2.1 Epicentres of Earthquake Events (1905 to 1993)

HIS MAJESTY'S GOVERNMENT OF NEPAL WATER RESOURCES DEVELOPMENT OF THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY



Note M.C.J. : Ministry of Construction, Japan
H.P.C. : Himalayan Power Consultants

Figure 4.2.2 Return Period of Maximum Acceleration for BR-1

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

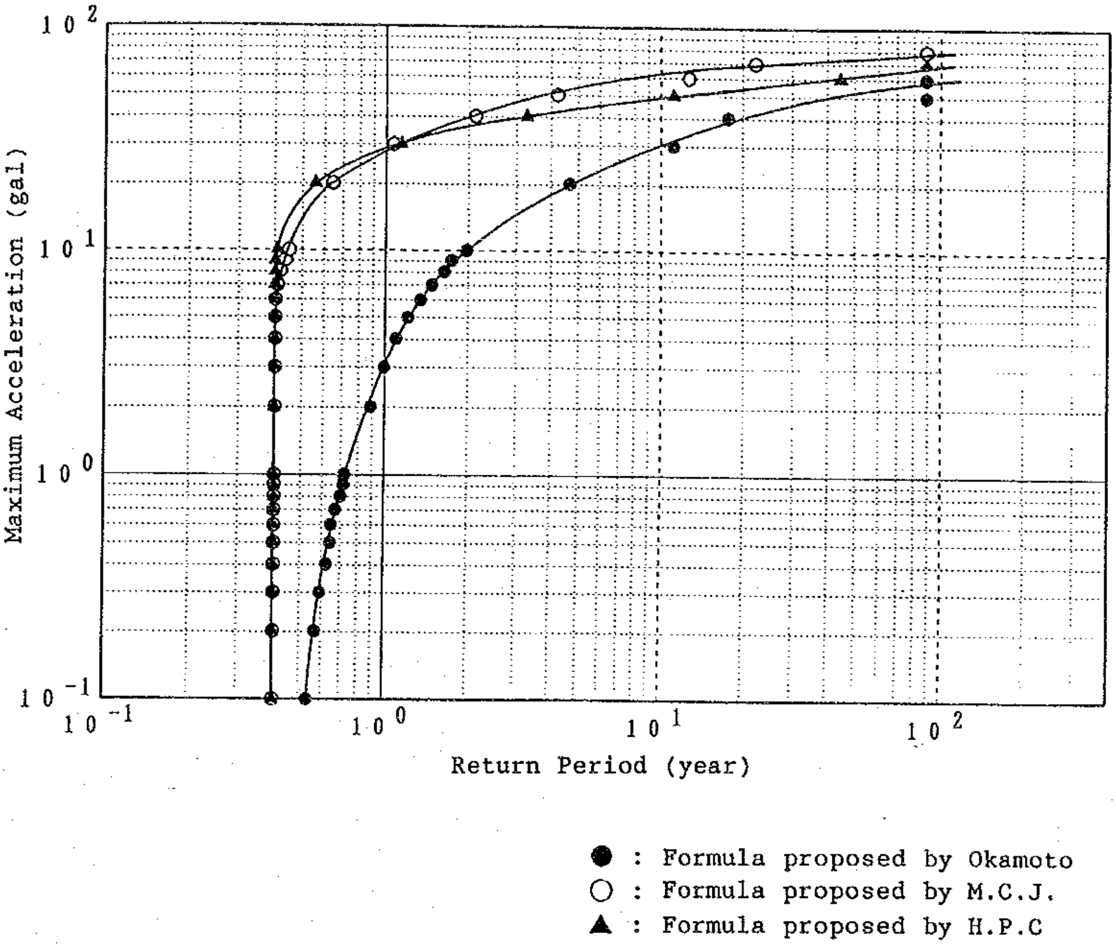


Figure 4.2.3 **Return Period of Maximum Acceleration for LR-1**

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

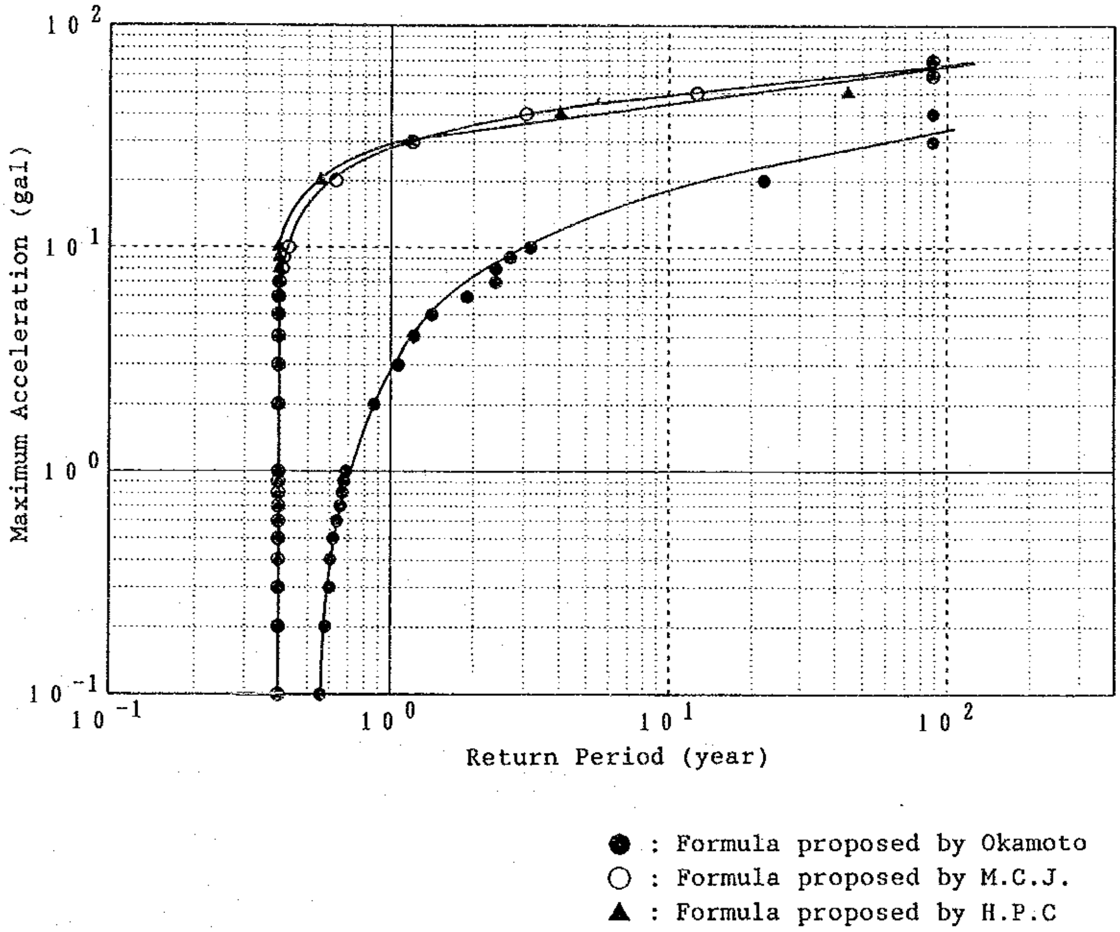


Figure 4.2.4 **Return Period of Maximum Acceleration for CR-2**

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

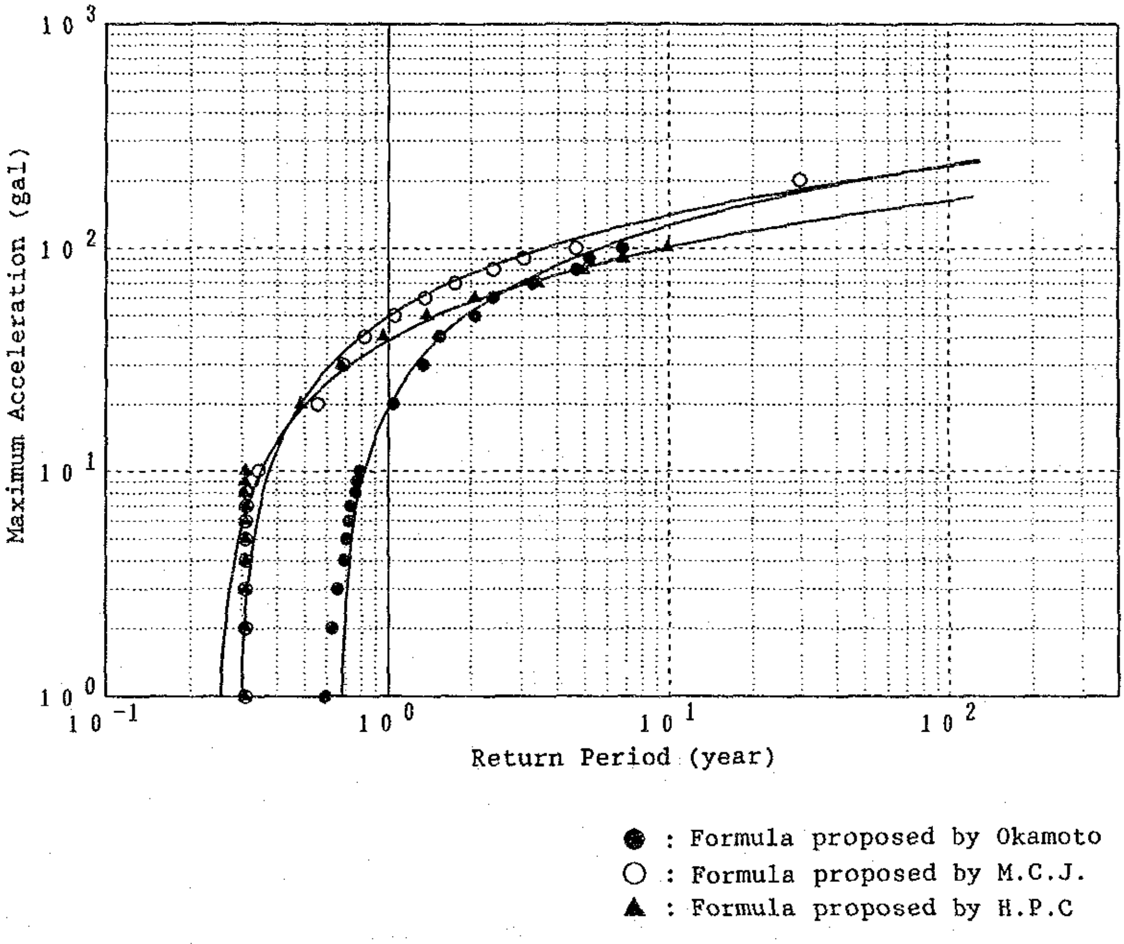


Figure 4.2.5 **Return Period of Maximum Acceleration for SR-3**

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

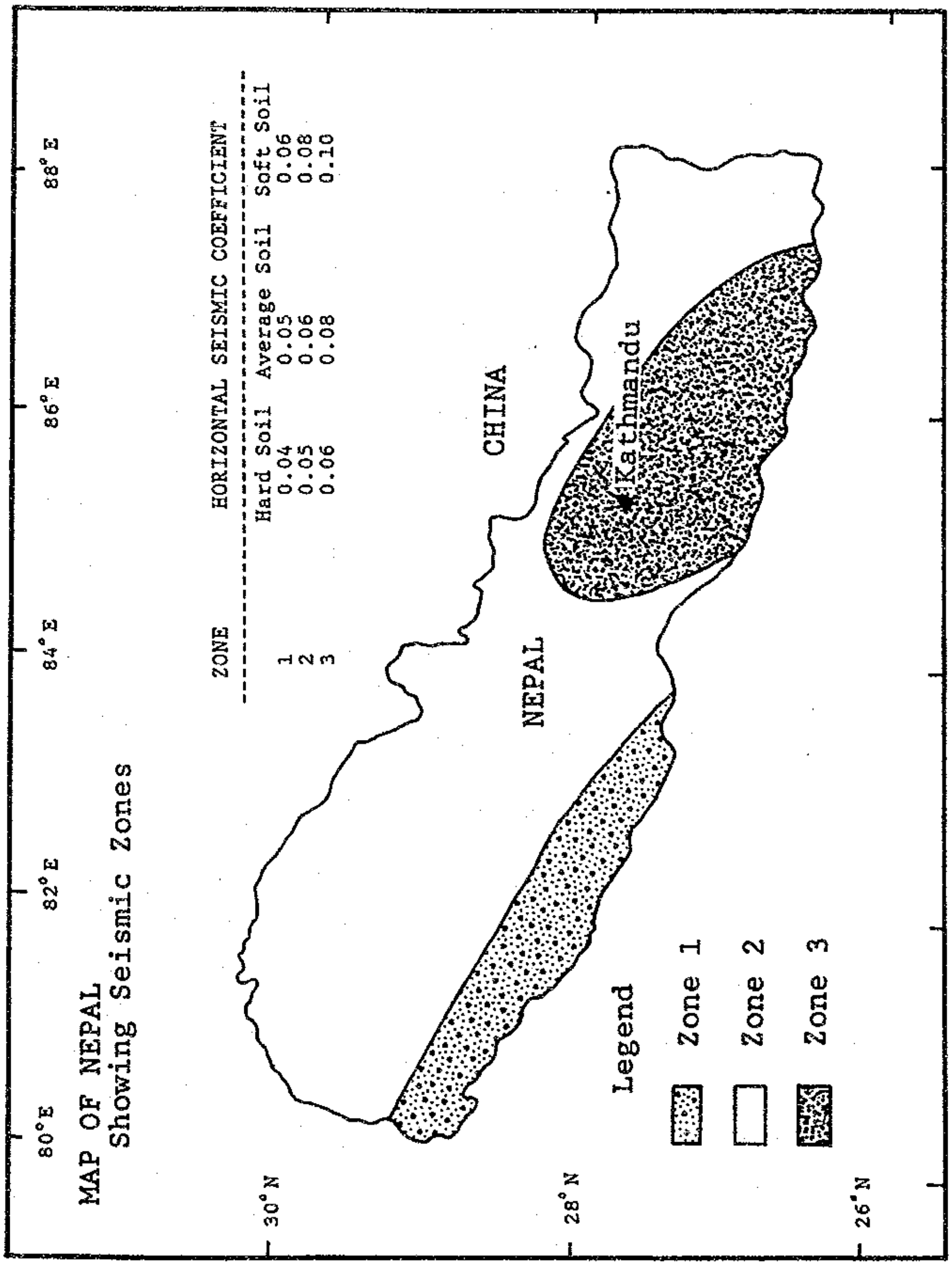


Figure 4.2.6 Seismic Risk Map for Nepal

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY

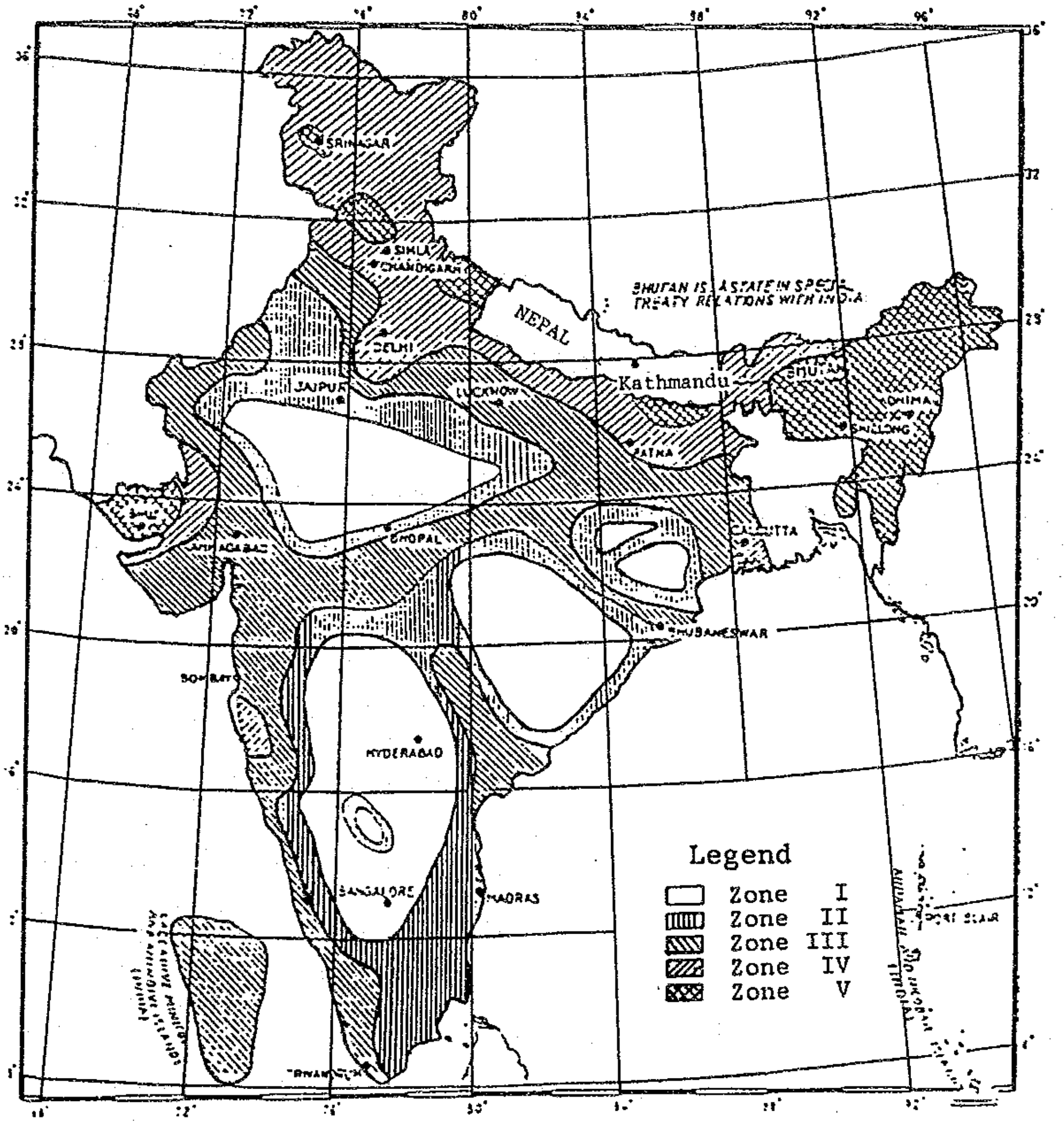


Figure 4.2.7 Seismic Risk Map for India

HIS MAJESTY'S GOVERNMENT OF NEPAL
WATER RESOURCES DEVELOPMENT OF
THE UPPER KARNALI RIVER AND MAHAKALI RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY