6. DISASTER ANALYSIS AT KULEKHANI RESERVOIR

6.1 General

6.1.1 History of Kulekhani Hydropower Project

The Kulekhani hydropower system is located in Makwanpur district, Central region of Nepal at about 30 km south-west of Kathmandu City as shown in Figure 6.1.1.

The Project is consisted of the No.1 power station with an installed capacity of 60 MW, the No.2 power station of 32 MW and a reservoir with 85 million m^3 of gross storage with a 114 m height of rockfill dam. The watershed area of Kulekhani reservoir is 126 km^2.

In 1956, just after completion of the construction works of Tribhuvan Highway, hydroelectric power the development of Kulekhani Khola was first suggested by the Swill-Nepal forward team. The plan at that time was a diversion of Kulekhani Khola to Rapti River to make use of a high water head between the two rivers in the upstream without seasonal regulating reservoir.

In 1974, the feasibility study for the Kulekhani Hydropower Project was conducted by the JICA, in which the implementation of the Kulekhani No. 1 Hydropower Project including a rockfill dam, a reservoir and an underground power station were recommended. The utilised water head was about 550 m. The construction work was commenced in 1977 according to the recommendation .

In 1979 during the construction of the Kulekhani No.1 Hydropower Project, the feasibility study on the Second Kulekhani Hydropower Project was carried out by the JICA. The study recommended timely construction of the No. 2 power station in accordance with the rapid growth of the estimated future electric power demand. The project was planned at the downstream of the No. 1 power station. In addition, a tributary intake in the Mandu Khola was planned to provide supplemental water for power generation. The construction work was started in 1981 based on the recommendation in the feasibility study.

In May 1982, The operation of the Kulekhani dam and the No. 1 power station were commenced. The construction took five years under the financial assistance from the UNDP, the Kuwait Fund, the IDA, and the OECF of Japan. The total construction cost was estimated at US$ 68.0 million at the price level of 1977.

In December 1986, the operation of the Kulekhani No.2 power station was commenced, which included a 5,848 m-long headrace tunnel, a 843 m-long penstock and a power house equipped with 32 MW power generators under the OECF finance. The project cost was reported at 12.15 billion Japanese yen at the price level of 1982.

6.1.2 Soil Conservation Activities in the Kulekhani Watershed

During the construction of the Kulekhani dam, a huge amount of clay was required for core materials of the rockfill dam, and the hill between Palung Khola and Bisingkhel Khola, located in Marukhu about 4 km upstream from the dam site, was selected as a borrow pit. While quarrying the core materials from the borrow pit, vegetation of the area was completely destroyed and the steep-sloping barren area was left exposed and eroded, which directly contributed to sedimentation to the reservoir. Considering such a devastated condition around the borrow pit, the UNDP and the FAO assisted a watershed management project in co-ordination with the DOSC to implement the Kulekhani Watershed Management Project in 1981, which included various soil conservation and watershed management activities to recover the bare area in the borrow bit.

After 1987, the FINNIDA followed the technical and financial assistance provided by the UNDP and the FAO, and the second stage of the Kulekhani Watershed Management Project was started. Various activities like engineering measures in combination with biological measures were demonstrated to recover the borrow pit, and it was successfully restored to be the full-green-covered and stabilised area. The project was completed in 1994. This borrow pit is currently used as the Kulekhani Demonstration Centre.

6.1.3 Disaster Prevention Activities related to the Kulekhani Hydropower Project

Serious flood damages were observed after the commencement of operation in the Kulekhani Hydropower stations in 1984 and 1986. In September 1984, during the construction period of the No.2 power station, a heavy storm continued for 3 days recorded a total rainfall of 725.5 mm. The storm corresponded to a return period of about 32 years. In August 1986, two years after the 1984 flood, another heavy storm took place; one day rainfall of 296 mm was observed at Nibuwatar, which corresponded to about a 30 year return period. These storms caused severe damages along the waterway of the Kulekhani No.1 and No.2 hydropower stations as shown below:

1) landslide on the slope of the valve house of the No.1 power station,
2) landslide on the slope of the penstock block No.7 of the No.1 power station,
3) riverbed aggradation at the penstock bridge of the No.1 power station,
4) debris flow on Mandu river at the intake of the No.2 power station,
5) riverbed aggradation at the tailrace of the No.2 power station.

In 1992, the Kulekhani Disaster Prevention Project (KDPP) was realised by the NEA to solve the above matters under the financial assistance of the OECF, Japan. In the course of the disaster prevention works, however, an unprecedented storm of July 1993 was occurred and the following severe damages were observed:

1) A penstock bridge of the No.1 power station was washed out by the debris flow of Jurikhet Khola,
2) A tributary intake and a regulating headpond of the No.2 power station at Mandu river was completely buried by the debris flow of Mandu Khola.

Due to the above damages, the operation of the both of No.1 and No.2 power stations were force to stop for 5 months from July to December 1993. The urgent rehabilitation measures were conducted in the Kulekhani Disaster Prevention Project under the NEA as the additional works.

In May 1996, the detailed engineering study for permanent restoration measures for the Kulekhani power stations were commenced as the second phase of Kulekhani Disaster Prevention Project (KDPP-II) under the financial assistance of the OECF, Japan. The permanent measures for restoration of the power facilities are included as follows:

1) Construction of sloping intake structure of the No.1 power station to avoid clogging intake of the reservoir by sediment accumulation,

2) Construction of embedded intake and regulating headpond of the No.2 power station to escape the further debris flow of Mandu Khola,
3) Construction of check dams on Palung and Darkot Khola to mitigate sediment inflow into the Kulekhani reservoir.

The construction stage will be commenced on November 1996, and it will be completed on December 1997.

6.2 The Basin Characteristics

6.2.1 Topography

The Kulekhani watershed lies in the north-eastern part of Makwanpur District in the Central Development Region of Nepal. Tribhuvan Highway passes through the upper part of the basin from the north to the south. The basin is composed of rugged terrain, and numerous hills and valleys. The watershed area is drained by Palung Khola from the west to the east in the centre of the watershed, and many tributaries flowing from the north, the south, and the west merge into Palung Khola. The elevation varies from 1,534 m at the dam crest to 2,621 m at the peak of Simbanjang of Mahabarat Range which is located on the southern boundary of the watershed.

Figure 6.2.1 shows the slope map of the watershed, which was quoted by "Master Plan Study on Sediment Control Kulekhani Watershed," November, 1994, NEA (hereinafter referred to as "the NEA master plan"). The map was prepared based on the topographic map with a scale of 1:50,000 in which the whole basin was divided into 1 cm^2 grids and the contour intervals inside each grid were counted. The slope was classified into five categories as follows:

Slope category	Slope condition	Contour interval (nos./ 1cm^2)	Slope angle (deg.)
I	Very steep	more than 13	above 40
II	Steep	7 to 13	25 to 40
III	Moderately steep	4 to 7	16 to 25
IV	Gentle slope	1 to 4	4 to 16
V	Flat	0 to 1	below 4

The slope map indicates that the wide flat land spreads throughout the middle part of the watershed mainly around Palung, Tistung and Chitlang. These areas are well cultivated and densely populated. River gradients of tributaries become gentle in the flat valley and the flow into the Kulekhani Reservoir. Such topographic characteristics may contribute to regulate the delivery of sediment discharge to the reservoir.

6.2.2 Geology

Figure 6.2.2 shows the geological map of the Kulekhani watershed. The geological structure in the Kulekhani watershed are divided into Phulchauki Group and Bhimphedi Group. Phulchauki Group consists of Kulekhani Formation, the Palung granite and Marukhu Formation. Bhimphedi Group consists of Tistung Formation, Sopyang Formation, Chandragiri Formation and Chitlang Formation.

Kulekhani Formation is a well-bedded alternation of fine-gained biotic schist and micacenous quartzites. Rock slides observed around Phedigaon were located in the schist of Kulekhani Formation.

Marukhu Formation consists of phyllites and marble. Phulchouki Group begins with Tistung Formation and is composed of slate, quartzite, and phyllite. Sopyang Formation is composed of soft-weathered phyllitic slate and limestone.

Chandragiri limestone contains some phyllite and quartzite. Limestone is generally weathered on the surface. Chitlang Formation mainly consists of phyllitic slate and the intercalation of quartzite and calcareous bands.

Granite of Palung Massif is the only igneous rock in the study area. Granite is deeply weathered and permeable. It contains sand, gravel, cobble, and boulder, etc., derived from physical weathering of granite and decomposition of mica.

Geological condition in the study area can be broadly divided into the granite zone and the schist zone (non-granite).

The granite zone which occupies the left bank side of the Palung mainstream has a steep gradient of mountain slope. On the July 1993 disaster, debris flows occurred in many tributaries originating from the granite zone. The debris flow materials which contained a fair amount of boulders have formed the debris fans of all dimensions at the confluence of the mainstream with Kitini Khola, Chalkhu Khola, and so on.

On the other hand, comparing with the granite zone, the schist zone has a gentle mountain slope and a smaller relative displacement to ridge from piedmont. The debris flows occurred in the Phedigaon area during the July 1993 disaster. Apparently changing of landforms have not been recognised in other schist zone. It is assumed that in order to be deep weathering layer in schist zone, many of fine materials have been transported to the downstream and deposited in the reservoir.

6.2.3 Landuse

The present land use condition is shown in Figure 6.2.3 and summarised as follows:

Land use pattern	Area in ha.	Share in %
Sloping agricultural land	4,254	34.0
Level terrace	237	1.9
Valley terrace	713	5.7
Orchard	55	0.4
Forest	5,455	43.6
Shrub	1,147	9.2
Grazing	200	1.6
Rock field	50	0.4
Reservoir	216	1.7
Landslide	18	0.2
Others	155	1.3
Total	12,500	100.0

Source: Sediment Survey of Kulekhani Reservoir, December, 1993, DOSC

According to the investigation by the DOSC, the forest area is about 44% of the entire watershed, whereas the sloping agricultural land is 34%. The above two categories are the major land use pattern (they are in total 78% of the entire watershed).

According to the land use map, the landslide area is 0.2% of the watershed by the estimation in 1984. Based on the aerial photograph investigation on the land use condition after the 1993 disaster, however, the landslide or slope failure areas have increased to 6.8 km^2 which is 5.4% of the entire watershed. Major landslides are observed in the southern part of the watershed covered by the forest in the granite mountain.

6.3 Damage Assessment due to the 1993 Disaster

On 19th and 20th of July, 1993, an unprecedented storm and flood hit Nepal including the Kulekhani Project area. The rainfall of 540 mm per day was observed on July 19 at Tistung, located in the northern edge of the catchment area of the Kulekhani reservoir. That was the recorded maximum one-day rainfall in Nepal. The flood inflow into the Kulekhani reservoir was estimated based on the intermittent record of reservoir water level. The estimated inflow volume for 24 hours from 16:00 July 19 to 16:00 July 20 was calculated at 52 million m^3. By distributing the volume according to the design hydrograph, the peak discharge was estimated at 1,340 m^3/s.

The storm and the debris flow on the Rapti river basin including the route of water way of the No.1 power station and the tributary intake site and outlet of the No.2 power station were so severe that the power generation could not be operated due to severe damages to the structures.

6.3.1 Damages to the Structures of the Kulekhani Hydropower Projects

There are two major places severely damaged by the storm and the debris in the 1993 disaster; the penstock bridge of the No.1 power station, and the tributary intake of the No.2 power station. The details of the damages are described as follows:

(1) Penstock bridge of the No.1 power station

Photo-1of Kulekhani in Appendix contrasts the penstock bridge before and after the storm of July 1993. Penstock bridge, having 99 m long between anchor block No.9 and No.10, was located at El. 1,108 m on the Jurikhet river with a catchment area of about 2 km^2.

The penstock of 57 m long on the right bank side was washed away and 24 m long on the left bank was bent towards downstream by the debris flow at 21:30 on July 19, 1993. By losing the penstock bridge, power generation of No.1 power station as well as No.2 power station were not possible until restoration of the penstock line. After the penstock line was disconnected, the Kulekhani reservoir water discharged from the end of the remaining penstock pipe with a high pressure flow of 28.7 m^3/s. The high pressure discharge hit heavily the left bank, and discharged continuously for 20.5 hours until the butterfly valve of the valve house located at El. 1,438 m, was closed at 17:00 on July 20.

Some countermeasures to protect the penstock bridge has been done previously as shown in Figure 6.3.1. Among the four check dams on upstream of the penstock bridge, three check dams made of gabion covered by concrete were washed away as shown in Photo-2 of Kulekhani in Appendix. The concrete check dam (J-1) was slightly damaged at the wing wall as shown in Photo-3.

Before the flood of July 1993, about two-third of the sediment trapping capacity of Check dam J-1 was still remained, however, it was fully stored by the debris of July 1993, and could not save the penstock bridge.

(2) Mandu head pond and intake structures of the No.2 power station

The violence of the debris flow at the Mandu river was unbelievable. Tremendous amount of big boulders were yielded by the basin, and rushed down to the Rapti river up to Hetauda passing the intake structures of the Mandu river. Photo-4 compares the Mandu headwork before and after the flood of July 1993. From those pictures, nobody could imagine the original structures. It indicates the tremendous power of nature.

6.3.2 Damages to the Kulekhani Reservoir and the Watershed

The issue about sedimentation in the Kulekhani reservoir was at first revealed by Department of Soil Conservation (DOSC) based on the results of echo-sounding survey in the reservoir. The DOSC reported that a 7.71 million m^3 of sedimentation was deposited in the reservoir during the 1993 monsoon. The main sediment deposition was observed in the dead storage and it was estimated that the remaining capacity of the dead storage was about 3.81 million m^3, which might be filled with more or less 7 years.

The results of sediment survey indicated that some countermeasures are urgently required to prevent sediment inflow to the reservoir. There is a concern that the power intake structures might be completely buried by the sediment in the reservoir if no countermeasures are made immediately.

Nepal Electricity Authority carried out Master Plan Study on Sediment Control for Kulekhani Watershed in November 1994. The study revealed that the sediment yield in the watershed was 22 million m^3 and the sediment deposition in the reservoir was 4.8 million m^3 during the 1993 monsoon, which was revised of the preliminary figures of 7.71 million m^3 revealed by DOSC. The sediment yield by respective tributary was estimated as shown in Figure 6.3.2, and the location of slope failures in the watershed is shown in Figure 6.3.3.

The major sediment sources were identified as Gharti, Darkot and Khanigaon Khola. Most of them are located on the southern part of the watershed of Granite zone.

Figure 6.3.4 shows the profile of the reservoir sedimentation. The sediment level at the intake of the No.1 power station was El.1,459.3 m as of September 1994, and the remaining height up to sill elevation of the intake structure of El.1,471 m was only 11.7 m.

6.4 Sedimentation Trend in Kulekhani Reservoir

Sedimentation trend is analysed based on the survey data from March 1993 to November 1995 carried out by the DOSC and the NEA. The analysis is made for basic plan formulation of the IDPP for the Kulekhani watershed.

6.4.1 Accumulated Sediment Deposition in Kulekhani Reservoir

Figure 6.3.4 in previous section shows the trend of sedimentation within the reservoir.

The sediment profile in the reservoir is estimated based on the results of the echo-sounding survey in March and December, 1993 carried out by the DOSC, and in October, 1994 and November, 1995 carried out by the joint operation of the DOSC and the NEA. The reservoir profile in 1971 was assumed by the reservoir plan of 1:10,000 scale.

The location of survey lines for echo-sounder is shown in Figure 6.4.1. There are 35 survey lines within the reservoir including major tributaries such as Darkot, Chitlang and Bisingkhel Khola. Table 6.4.1 shows the lowest point of the reservoir, which means the lowest sediment level of the sections for each survey period.

The sediment deposition volumes from 1981 to November 1995 were estimated by the Study Team as follows:

Trend of Reservoir Sedimentation within Kulekhani Reservoir

Year and Month	Gross Storage Capacity	Effective Storage Capacity	Dead Storage Capacity	Accumulated Sediment Deposition
	(mil.m^3)	(mil.m^3)	(mil.m^3)	(mil.m^3)
1981	85.0	73.0	12.0	0.0
Mar.1993	74.7	64.0	10.7	10.3
Dec. 1993	67.9	62.5	5.4	17.1
Oct. 1994	68.0	62.6	5.4	17.0
Nov.1995	67.3	62.7	4.6	17.7

Source : Estimated by the Team based on the data from the DOSC and the NEA.

Based on the estimated figures above, the accumulated sediment deposition for 15 years from 1981 to 1995 was calculated at 17.7 million m^3, which was about 20% of the original gross storage.

It is remarkable thing that the accumulated sediment volume from 1981 to March 1993 for 12 monsoon seasons are assumed at 10.3 million m^3, which is equivalent at 0.858 million m^3/year of sediment deposition, in other word it is said that the sediment denundation rate was 6.89 mm / km^2 / year without severe event like the 1993 rainstorm.

The annual average sediment deposition within the reservoir for 15 years, which is taken into account the severe rainstorm of July 1993, is estimated at 1.18 million m^3, which is calculated for average sediment deposition for 15 monsoon season from 1981 to 1995. The watershed denundation rate is calculated to be 9.37 mm/km^2/year. And the master plan shall be assessed based on the above annual average sediment deposition.

6.4.2 Procedure of Estimation of Annual Sediment Volume

The sediment volume from March 1993 to November 1995 was estimated by the Study Team applying the following procedure, which was previously introduced by the DOSC:

(1) Measurement of sectional area

Based on the echo-sounding results, a cross sectional area for each survey section was measured by the DOSC and the NEA for each survey period. The estimated sectional areas are shown in Table 6.4.2. It is noted that the area was measured below the high water level of El. 1,530.2 m in each section.

(2) Calculation of average depth of section

Based on the estimated sectional area, the average depth of each cross section was calculated as follows:

Average depth (m) = Sectional area (m^2) / Survey length (m)

Survey length means a length of survey line at water level of El. 1,530.2 m. The distance was surveyed by the NEA in November, 1995 by an electric distance meter. For all the survey period, the same length of cross section is applied to estimate the average depth.

(3) Measurement of surface area

After estimating the average depth of cross sections, a surface area between cross sections at elevation of 1,530.2 m shall be measured. In the Study, however, the areas at elevation of 1,530.2 m were quoted from the report of "Sedimentation Survey of Kulekhani Reservoir," October, 1994, prepared by the DOSC. For measurement of the surface area, it is noted that the same figures are applied for each survey period so that the surface area at high water level would not change except for the upstream area of reservoir. In addition, the decreasing area in the upstream is already taken into account by the measurement of cross sectional area by fixing the survey length. Therefore, the surface area between cross sections should not be changed by a survey period to avoid double counting for aerial reduction due to sedimentation. Table 6.4.2 shows the divided surface area at elevation of 1,530.2 m between survey lines.

(4) Calculation of divided volume

Based on the average depth of sections and the divided surface area between cross sections, the volume of reservoir divided by survey lines is calculated as in the following manner:

Divided volume (m^3) = Divided surface area (m^2) x
(Average depth of D/S section (m) +
Average depth of U/S section (m)) / 2

The results are shown in Table 6.4.2. Based on the procedures above, the storage volume of each divided section was calculated. By accumulating the divided volumes, the remaining gross storage for each period is estimated.

6.4.3 Reservoir Sedimentation after the 1993 Disaster

According to the procedures mentioned in Section 6.4.2, the annual sedimentation volumes within the reservoir were calculated as follows:

Survey period	Total sediment (million m3)	Sediment in dead storage (million m3)	Sediment in effective storage (million m3)
Mar. to Dec.1993	6.79	5.27	1.52
Dec.93 to Oct.94	-0.15	-0.01	-0.14
Oct.94 to Nov.95	0.70	0.78	-0.08

The results were something wrong in estimating a sediment deposition during the monsoon in 1994, in which the sediment deposition shows a negative value.

The discrepancy might occur due to the time retarding for fine materials to settle to the sediment level, and many fine materials would be floating near the reservoir bottom for a long time. At the time of the survey in December, 1993, about 6 months after the flood, many fine materials were still not settled at the bottom, and the echo-sounding line indicated rather higher positions with less density. On the other hand, in October, 1994, many fine materials might be settled at the bottom, and the sediment level was lower than a year ago.

The remaining storage in longitudinal distribution is shown in Figure 6.4.2. According to the figure, major part of storage remained is at the downstream part of the reservoir up to 4 km from dam, which is just downstream of the confluence with Chitlang Khola. About 85% of the remaining storage exist on the downstream part.

6.4.4 Observed Sedimentation Process during Three Monsoons

The sedimentation within the reservoir due to the 1993 flood was extremely a big amount which was estimated at 6.79 million m^3. The sediment level at the lower part of the reservoir at survey line 1-2 was elevated up by about 20 m in one monsoon season, and the sediment level reached just 10 m below the sill of the power intake, which was originally located at about 40 m higher than the riverbed.

In the next monsoon in 1994, the severe head cutting phenomenon was found on the upstream part of the reservoir, particularly upstream from survey line 24 - 25, located about 5.5 km upstream from the dam site. Due to the head cutting phenomenon, the sediment level at the upper part of the reservoir was lowered by 3 to 5 m. Such a phenomenon generally occurs for a few seasons after an extreme flood. Since many sediments was transported by the flood, many unstable materials are left in the course of the river. Such materials will be gradually brought to the downstream by normal floods and finally reach to the reservoir. The total sediment deposition in the 1994 monsoon was estimated at 0.15 million m^3 in negative value which means almost no sediment inflow from the upstream is observed during the 94 monsoon.

During the monsoon of 1995, the same phenomenon was observed along the whole river stretch of Palung Khola. Particularly, the sediment detaining zone in Palung valley, where the riverbed was fully buried by silt and sand and the sediment spread over with 0.5 to 1 km wide near the confluence of Palung Khola, Gharti Khola, Phedigaon Khola, and Bangkoria Khola, was almost cleared by river flow as well as sand collecting activities after two years from the disaster. As a result, the riverbed was lowered by a few meters in two years. Many deposited materials must be transported to the downstream. The sediment deposition in the reservoir is estimated at 0.7 million m^3. It is assumed that some sediments yielded by the storm of July 1993 would still remain in the upstream of the reservoir, but that the entire river stretch is gradually stabilised and the sediment inflow into the reservoir is gradually decreased. The annual sediment volume in the 1995 monsoon with 0.7 million m^3 is almost double as the annual average sediment deposition into the Kulekhani reservoir of 0.355 million m^3 estimated by the NEA master plan report.

6.4.5 Justification of Design Sediment Volume

The design annual sedimentation defined by the NEA master plan seems to be too small based on the recorded sediment deposition with 17.7 million for 15 years. Based on the preliminary assessment by the Study Team, the annual sediment deposition with in Kulekhani reservoir is estimated at 1.18 million m^3/year, as explained in Section 6.4.1. In this section, the design annual sediment yield shall be justified.

It is known that there is a strong relationship between peak discharge and sediment transportation volume. In the case of Kulekhani reservoir, there is no gauging station in the basin, and it is not possible to develop the correlation between the discharge and sediment inflow.

On the other hand, the peak discharge can be estimated based on the rainfall data. In case of Kulekhani watershed, hourly raingauge stations are established by the Kulekhani Watershed Management Project by the DOSC at Tistung and Simlang. The data is available from 1993. The long term daily rainfall observation is also available at Daman and annual maximum daily rainfall from 1981 is available.

Considering the availability of rainfall data, the correlation between annual maximum daily rainfall and annual sedimentation volume are estimated based on the following data:

Year	Annual maximum daily rainfall at Tistung (mm)	Annual Sediment Deposition in Kulekhani Reservoir (m3)
1993	540	6,790,000
1994	60	-148,000
1995	104	702,000

The correlation between annual maximum daily rainfall and annual sediment deposit volume is developed as shown below:

$$SV = 1200.841 \times R^{1.373301}$$

where,
SV : Annual sediment volume within Kulekhani reservoir (m^3),
R: Annual maximum daily rainfall (mm)

According to the formulae above, annual sediment volume from 1981 to 1992 was assumed based on the annual maximum daily rainfall at Daman as shown in Figure 6.4.3. The calculated accumulated sediment volume from 1981 to 1995 was 15.2 million m^3, which is almost same as observed sediment volume of 17.7 million m^3.

Based on the justification above, the accumulated sediment volume within Kulekhani reservoir with 17.7 million m^3 seems to be reasonable, and the design sediment volume in Kulekhani reservoir shall be applied at 1.18 million m^3/year (17.7 million m^3 / 15 years), instead of 0.355 million m^3 proposed by the NEA master plan.

6.5 Sedimentation Material in Kulekhani Watershed and Reservoir

The sedimentation material along the river course and in the reservoir were sampled and gradation analysis were carried out in the Study. Objectives of the material investigation is to find out the origin of sediment material as well as to concern the effective countermeasures to mitigate sediment inflow into the reservoir. Figure 6.5.1 shows the location of sampling sites which are consisted of 17 sites along the river course in the watershed and 4 sites in the reservoir.

6.5.1 Sedimentation along the river course

Figure 6.5.2 shows the results of grain size distribution of 17 investigation sites. The photographs of the sampling sites are provided in Data Book. The longitudinal profile of respective sampling site with representative basin geology is shown in Figure 6.5.3, and the general characteristics and the results of grain size distribution is summarised in Table 6.5.1. The mechanism of sediment erosion and transportation in the Kulekhani watershed were assessed based on the above Figures and Tables and the findings are summarised below:

(1) There is less contents of fine materials such as silt and clay remained in the whole river stretch in the watershed. It is because, the overall watershed is formed rather steep in topography which is indicated most of the fine materials are transported to the downstream.

(2) Sand is the dominant material along the Palung mainstream upstream from the confluence of Khanigaon Khola. It seems that the major sediment source in the stretch is the southern part of the basin of granite mountain. The river gradient in the stretch is about 1% and the material tends to trap in the channel so that the sediment tractive force is rather small.

(3) Gravel is the dominant material in the upstream area of the basin particularly in the northern part which is consisted of Schist in geology. This is normal phenomenon according to the river morphological theory.

(4) In the southern part of the basin which is consisted of the granite in geology, sand is the dominant material remained along the stream even in the upstream portion. This seems that the mountain is so fragile and the boulders and gravel are fractured and gradually transported to the downstream.

(5) Less sand is found on the upstream of the reservoir along the mainstream due to steep gradient of the river with 1/30, and most of fine sand may have been transported to the reservoir.

6.5.2 Sediment Deposition in the Kulekhani Reservoir

Figures 6.5.4 through 6.5.7 show the drill core report in the reservoir, BH-1 through BH-4. The photographs of core samples are attached in Data Book. The grain size distribution are assessed for all the samples and the results are summarised in Table 6.5.2. The detailed gradation charts are attached in Data Book. Based on the investigation results above, the sediment profile in Kulekhani reservoir is estimated as shown in Figure 6.5.8.

In the BH-1, which is located on the upper part of the reservoir, about 6 km upstream from the dam, fine sand and gravel are the dominant material, which shares about 75%. Among them, fine quart and feldspathic type of sand shares 50 % of the sedimentation, which is quite suitable for construction material, are rich around the BH-1. The silty material are also found with 25% of the sediment material.

The top 1.5 m of the sediment is represented by fine material like silt in BH-2, which is located on upper part of the reservoir about 4.5 km upstream from the dam. Fine sand and coarse materials shares about 60 %, and the remaining 40% is silt.

In the BH-3, which is located in the lower part of the reservoir under the LWL, no coarse sand and gravel are found. About 70% of the collected material are silt. The deposition of sediments is found to be of cyclic nature with the percentage of sand increasing with depth within the cycle such as 0.00 m to 2.5 m, and 5.00 m to 8.00 m in depth.

Near the intake, BH-4, the top 12 m of the sediment is represented by clayey silt with the percentage of clay varying from 16 to 20. Below 12 m in depth, the sediment is mostly silt. About 90% of the sampled material are silt or clay.

Based on the observation results above, the followings are concluded:

(1) The size of the sediments consistently decreased from the upstream part of the reservoir to its downstream part.
(2) Fine sand and gravel, which is available for construction material, are located within the range of effective storage, upper part of the reservoir about 5 km upstream from the dam.
(3) The surface portion of sediment below the effective storage with about 2 m is generally covered by the silty materials.
(4) Silt and clay are the dominant materials in the lower part of the reservoir below the dead storage.

6.6 Major Issues for Kulekhani Watershed and Reservoir

The situation of the Kulekhani watershed was dramatically changed for the last forty years from the national and regional viewpoints. In this section, the current situation and needs in the Kulekhani watershed are assessed based on the historical background of development and future development potential in the watershed.

Before 1950s, the Kulekhani watershed was quite rich in natural resources such as water, land, forest, and wildlife. People's life in the watershed was based on self sufficiency in food and energy. The society in this area was relatively isolated from other areas like Kathmandu and Hetauda. The area was like an independent small and beautiful area with less population surrounded by rich natural resources.

After the construction of Tribhuvan Highway, the situation of the Kulekhani watershed has been changed. This area became a very important area from the national viewpoint as the route between Kathmandu and India. Tribhuvan Highway changed the Kulekhani watershed into a high development potential area from the viewpoint of the national economy. Since the watershed is located just adjacent to Kathmandu City and it is connected by the motorable road, the economic tie between Kathmandu and the Kulekhani watershed was dramatically strengthened.

In agriculture development, the farmers were much encouraged to produce cash crops for income generation due to the advantage in marketing potential through Tribhuvan Highway. Because of the opportunities for income generation and the easy access to the other areas through Tribhuvan Highway, the population in the Kulekhani watershed was rapidly increased, but at the same time the forest was degraded by high pressure on firewood and fodder consumption and land development for extension of agricultural activities due to high population growth and economic development.

In 1982, the First Kulekhani Hydropower Project was completed and the national importance of the Kulekhani watershed was established. The hydropower development activities in the Kulekhani watershed were also realised due to the geographical advantage by Tribhuvan Highway and the closer location from Kathmandu, the major electricity consuming centre.

The construction of the dam, reservoir and hydropower station in the Kulekhani watershed changed the situation. Since the Kulekhani hydropower station was one of the most important infrastructures in the nation, there was strong demand for conserving the environment to sustain and maintain the Kulekhani hydropower station.

Such conservation demand was generally directed to the regulation of development activities in the area. The residents in the area were strongly controlled from the other area by the conservation needs. On the other hand, development potential in the Kulekhani watershed was much enhanced by the Kulekhani reservoir, such as tourism development and aqua culture development. As a result, many development activities are found in the Kulekhani watershed such as tourism in Daman, an alternative road construction from Kathmandu to the Kulekhani dam along Chakkhel Khola, aquaculture farm in the Kulekhani reservoir, slate mining industry in the Phedigaon area, horticulture research in Daman, and cash crop production in the whole watershed.

Under the above condition, the Study Team focused on the three major issues concerning the critical condition and the importance of disaster prevention issues for the Kulekhani reservoir for plan formulation of the IDPP for Kulekhani watershed as listed below:

1) Losing dead storage volume of the Kulekhani reservoir,
2) Sustaining peak operation of the Kulekhani hydropower stations for the national power demand, and
3) Dilemma between conservation and development in the watershed.

The detailed issues are discussed as follows:

6.6.1 Losing Dead Storage Volume

It is a common sense that sediment deposition into a reservoir must occur in all reservoirs in the world due to natural function of a river which is to transport water and sediments. All dams and reservoirs in the world will end their lives in some future by sediment depositions unless appropriate countermeasures are taken. A hydropower dam, when its reservoir has been fully filled up with sand, is usually used as the run-of-river type of hydropower station without regulating capacity, although its value is far less than the seasonal regulating type.

In the case of the Kulekhani reservoir, the life span is subject to the loss of dead storage. The intake structure is designed at El. 1,471.0 m of its sill elevation which is at 69 m lower than the high water level of the reservoir. When the sediments reach to that elevation, power generation will no longer be possible due to the sand entering the intake. The gross head of the Kulekhani No. 1 power station is 550 m and quite high, civil and mechanical structures such as headrace tunnel, penstock and turbine will be seriously eroded by the sand flown with diverted sandy water with high head. And the damage to such structures would be enormously severe. Moreover, if a big flood like the 1993 disaster attacks the reservoir, the whole waterway will be filled by sand and it will be not possible to drain the stored water in the reservoir of about 60 million m^3 except from the spillway at El. 1,519 m, which means that the reservoir water below El. 1,519 m of about 40 million m^3 will have no outlet of high depth with more than 40 m. The bottom outlet was installed at the lower part of the reservoir but the portal section at El. 1,461 m was almost clogged by accumulation of sediments, so it is not possible to drain the reservoir water through the bottom outlet.

Figure 6.6.1 shows the trend of decreasing dead storage as well as gross storage due to the sedimentation for the last fifteen years and the expected future sedimentation into the dead storage. It is noted that the future assumption is made by just extending the past trend and there is no detail assessment in the assumption.

According to the previous trend of decreasing dead storage, the loss of dead storage was faster than the designed one. It is generally designed as the fifty-year life time for dead storage, but all dead storage volume will be lost within the next several years. This will result in having serious effects on the power facilities, and the power generation activities will be difficult to continue by the Kulekhani power stations, which will be a big loss for the national economy.

The most serious issue is, therefore, to lose dead storage volume, and timely countermeasures are required for the continuation of power generation activities.

6.6.2 Sustaining Peak Operation of Kulekhani Hydropower Stations

The second serious issue in the Kulekhani reservoir and the hydropower stations is to decrease the effective storage of the reservoir. The original effective storage for power generation was 73.3 million m^3, but it became 62.7 million m^3 at present because 10.6 million m^3 of the storage was replaced by sediments. It means that power generation capacity in the dry season from November to May decreases with 20.6 GWh by the sediment deposition within the Kulekhani reservoir. The loss of electricity must be continued in the future unless dredging works are carried out.

The major role of the Kulekhani hydropower stations is to supply peak load in the dry season. The other power stations have no seasonal regulating capacity and the power supply capacity in the dry season has decreased due to the decrease in river flow. The Kulekhani power stations will run in full power in this period to cover the decreased power generation from the other stations. This important role in the national power supply can be played only by the Kulekhani hydropower stations as they have a huge storage. In the rainy season from June to October, the Kulekhani reservoir is trying to store water up to the high water level and the power stations concentrate power generation during the dry season by using all stored water.

Figure 6.6.2 shows the seasonal power generation pattern for the Kulekhani hydropower stations, which indicates clearly their role in the national power supply. Considering this role, maintaining the storage is quite important against the further sediment deposition.

Off-peak operation in the dry season also so far has become one of the important roles of the Kulekhani hydropower stations, but the role can be replaced by the other run-of-river hydropower plants with less investment. However, the peak operation in the dry season can be played by only Kulekhani or thermal power plants. Operation costs of thermal power plants are quite expensive to buy multi-fuel, diesel, and gas, and all the materials have to be imported and the supply condition from India is not stable.

Accordingly, to guarantee the peak operation during the dry season is the most important role of the Kulekhani hydropower, and it was estimated that the minimum required storage for four-hour peak operation for seven months from November to May was at 48 million m^3, based on the NEA master plan study as shown in Figure 6.6.3.

The second issue for the IDPP for the Kulekhani Hydropower Project is, therefore, how to guarantee the four-hour peak operation. It is not only to stop sediment inflow but to maintain the reservoir and to manage power generation from the viewpoint of the national power supply in addition some measures to the NEA master plan.

6.6.3 Dilemma between Conservation and Development Needs

The Kulekhani watershed is one of the most important basins in the viewpoints of the national and regional economy in Nepal. All the activities in the watershed will be directly or indirectly affect the life span and the reliability of power generation, and consequently the cities, particularly Kathmandu City, will be affected.

On the other hand, there is high potential in agriculture development like cash crop production for the Kathmandu market. The situation is highly beneficial to the villagers in the watershed and the living standard in the watershed must be much higher than other rural areas in hills due to the fertile soil, richness in water, and a good access to the big market.

Intensive economic activities tend to degrade the environmental conditions: the forest is degraded, terrace farming expands to steep slopes, irrigation canal networks extend to the slopes in the watershed, and so on. Such activities will cause soil erosions, landslides, and slope failures. The eroded soil in the watershed flowed into streams and reach to the reservoir. The phenomenon threatens power generation of the Kulekhani reservoir. From the viewpoint of the villagers in the upstream, the siltation of the reservoir is not serious issue, but soil loss from terrace cultivation area, bank erosions of streams, and landslides and slope failures along trails and canal routes are the serious issue for maintaining their life.

9.37 mm / km^2 / year of sediment yield is quite high basin denundation rate compared with the other areas in the world. For example, Kurobe River basin in Japan is the famous basin for high sediment yield where the annual sediment yield is estimated at around 7 mm / km^2 / year, which is the highest value in Japan.

The remarkable sediment yield is not only due to the development activities but mainly due to geological structures and topographic condition. However, some conservation activities must be effective to reduce the sediment yield in the watershed. Such high soil erosion rate must affects seriously to the agricultural activities and not limited to maintenance issues for Kulekhani Hydropower Project.

To mitigate soil erosions, bank erosions, landslides, and slope failures is, therefore, very important for both the national economy and the regional economy. The development activities in the watershed is the major factor for increasing sediment yield in the watershed. To deal with these conservation and development needs, an integrated water management approach should be taken into account.

The third issue for the Kulekhani reservoir is that the watershed condition is being degraded, particularly in terms of soil erosion. Some factors may be due to the increase in demand for food, fuelwood, and fodder to meet the growing population and expanding economic activities in the basin. However, the people's activities for development in the watershed should not be discouraged only because of the reason for sustaining the hydropower stations. The watershed management approach should take into account both the needs for development and conservation.

Table 2.2.1 Casualties and Their Caste by the 1993 Disaster

S.N.	Name	Caste	No. for Fig. 3.2.1	Name	Caste	Ltr. for Fig. 3.2.1
Dead People				Damaged Household		
1	Bhim Bahadur Biswakarma	Kami	1	NA	Tamang	a
2	Kamala Biswakarma				Kami	b
3	Ramlal Biswakarma				Kami	c
4	Bharat Biswakarma				Tamang	d
5	Mangali Biswakarma				Tamang	e
6	Gopal Biswakarma	Kami	2		Tamang	f
7	Methi Biswakarma				Tamang	g
8	Kajibhai Biswakarma				Tamang	h
9	Thulo Baini Biswakarma				Tamang	i
10	Sani Biswakarma				Chhetri	j
11	Bishnu B. Basnyat	Chhetri	3		Chhetri	k
12	Maiya Basnyat				Chhetri	l
13	Jivan Basnyat					
14	Nabin Basnyat					
15	Saran Basnyat					
16	Sanukanchi Tamang	Tamang	4			
17	Nanimaiya Tamang					
18	Belu Tamang					
19	Krishnamaya Tamang					
20	Sukalal Tamang					
21	Sukra B. Tamang	Tamang	5			
22	Yama Maiya Tamang					
23	Dalli Tamang					
24	Seti Tamang					
25	Sanukancha Tamang					
26	Sanukanchi Tamang					
27	Jhanka Nath Khanal	Brahmin	6			
28	Bhim Kumari Khanal					
29	Indira Kumari Khanal					
30	Laxmi Khanal					
31	Pramod Khanal					
32	Praladh Khanal					
33	Sarada Khanal					
34	Kapindra Khanal					
35	Ashish Khanal					
36	Abish Khanal					
37	Ganesh Bahadur B. K.	Kami	7			
38	Kanchi B. K.					
39	Ram Bahadur B. K.					
40	Sanubhai B. K.					
41	Ram Maya B. K.					
42	Sanunani B.K.					
43	Tulasi B. K.					
44	Batuli Tamang	Tamang	8			
45	Lila Tamang					
46	Ashok Tamang					
47	Kancha Tamang					
48	Pudke Moktan					
49	Thuli Moktan					
50	Dhana B. Tamang	Tamang	9			
51	Sanikanchi Tmang					
52	Maiya Tamang	Tamang	10			
53	Thulobabu Magar	Magar	-			
54	Bhim B. Tamang	Tamang	11			
55	Pode Tamang					

Table 6.4.1 Record of Sediment Investigation in Kulekhani Reservoir

Survey Line	Distance from dam (m)	Lowest point of reservoir				
		1971 (El.m)	Mar-93 (El.m)	Dec-93 (El.m)	Oct-94 (El.m)	Nov-95 (El.m)
1-2	700	1,436.5	1,439.8	1,457.9	1,459.3	1,457.5
3-4	970	1,449.5	1,445.1	1,458.2	1,458.5	1,458.5
5-6	1,470	1,447.5	1,450.0	1,458.8	1,459.8	1,460.5
7-6	1,650	1,449.0		1,459.5	1,462.0	1,461.0
9-8	1,900	1,451.5	1,454.5	1,460.7	1,463.8	1,461.8
9-10	2,100	1,454.0	1,454.8	1,462.3	1,464.3	1,464.0
11-10	2,200	1,455.0	1,458.3	1,463.2	1,465.0	1,464.3
12-13	2,800	1,462.5	1,463.4	1,467.5	1,470.8	1,470.5
12-15	2,870	1,463.5	1,467.2	1,469.7	1,471.2	1,472.0
15-14	2,980	1,465.5		1,470.5	1,473.1	1,474.5
16-15	3,130	1,468.0	1,471.6	1,473.3	1,475.7	1,480.0
17-16	3,370	1,471.0	1,473.6	1,476.5	1,478.9	1,481.0
18-19	4,560	1,487.5	1,490.4	1,494.3	1,496.3	1,496.1
20-21	4,920	1,495.0	1,494.5	1,495.4	1,499.7	1,497.8
22-23	5,240	1,497.0	1,499.2	1,501.0	1,502.5	1,500.5
24-25	5,430	1,497.8	1,500.5	1,506.0	1,503.0	1,503.5
28-27	5,590	1,499.0		1,509.7	1,506.4	1,506.5
30-29	5,810	1,500.0	1,505.6	1,511.6	1,512.6	1,509.0
31-32	6,030	1,502.5		1,519.5	1,514.7	1,511.8
34-33	6,230	1,504.5	1,509.7	1,520.0	1,515.8	1,514.6
36-35	6,370	1,505.5	1,511.2	1,522.5	1,519.5	1,517.3
38-37	6,720	1,509.5	1,521.4	1,526.0	1,525.2	1,525.5

Source : 1) data for 1971, Mar.1993, Dec.1993 and Oct.1994:
"Master Plan Study on Sediment Control for Kulekhani Watershed", Nippon Koei, Nov.1994
2) data for Nov.1995:
"Draft Report on Sedimentation Survey of Kulekhani Reservoir", Nepal Electricity Authority, Dec.1995
3) data for 1971: estimated by topographic map (1:10,000)
4) data for Mar. & Dec.1993, Oct.1994, Nov.1995 : surveyed by echo sounder

Table 6.4.2 Estimation of Average Sediment Level in Kulekhani Reservoir

Survey Line	Distance from dam	Survey Length	Area below wl.1530.2 m				Average water depth at Wl.1530.2m					Average sediment level			
			Mar-93	Dec-93	Oct-94	Nov-95	Mar-93	Dec-93	Oct-94	Nov-95		Mar-93	Dec-93	Oct-94	Nov-95
IT - SP	0	408.45				19,366				47.41	0				1482.79
1-2	700	622.19	36,580	33,091	33.401	34.454	58.79	53.18	53.68	55.38	700	1471.41	1477.02	1476.52	1474.82
3-4	970	540.67	20.923	19.690	20,211	20,328	38.70	36.42	37.38	37.60	970	1491.50	1493.78	1492.82	1492.60
5-6	1,470	369.56	20,022	17,554	18,858	19,053	54.18	47.50	51.03	51.56	1,470	1476.02	1482.70	1479.17	1478.64
9-8	1,900	412.47	18,018	17,086	16,440	16,806	43.68	41,42	39.86	40.75	1,900	1486.52	1488.78	1490.34	1489.45
9-10	2,100	480.95	20,494	20,224	19,929	19,910	42.61	42.05	41.44	41.40	2,100	1487.59	1488.15	1488.76	1488.80
11-10	2,200	369.17	20,429	18.605	17,971	18.357	55.34	50.40	48.68	49.72	2,200	1474.86	1479.80	1481.52	1480.48
12-13	2,800	270.58	12,098	11,377	11,174	10,854	44.71	42.05	41.30	40.11	2,800	1485.49	1488.15	1488.90	1490.09
12-15	2,870	317.54	13,244	11,087	10,817	11,342	41.71	34.92	34.06	35.72	2,870	1488.49	1495.28	1496.14	1494.48
16-15	3,130	246.66	10,841	10,156	10,047	9,699	43.95	41.18	40.73	39.32	3,130	1486.25	1489.02	1489.47	1490.88
17-16	3,370	376.84	15,623	15,374	14,929	13,896	41.46	40.80	39.62	36.87	3,370	1488.74	1489.40	1490.58	1493.33
18-19	4,560	203.31	5,508	5,116	5,099	5,197	27.09	25.16	25.08	25.56	4,560	1503.11	1505.04	1505.12	1504.64
20-21	4,920	413.27	9,419	8,958	8,949	9,413	22.79	21.68	21.65	22.78	4,920	1507.41	1508.52	1508.55	1507.42
22-23	5,240	170.74	2,949	2,570	2,815	2,905	17.27	15.05	16.49	17.01	5,240	1512.93	1515.15	1513.71	1513.19
30-29	5,810	161.74	2,746	2,011	2,207	2,335	16.98	12.44	13.65	14.44	5,810	1513.22	1517.76	1516.55	1515.76
34-33	6,230	116.52	1,747	1,020	1,296	1,543	14.99	8.75	11.12	13.24	6,230	1515.21	1521.45	1519.08	1516.96
36-35	6,370	82.35	976	541	469	731	11.85	6.57	5.70	8.87	6,370	1518.35	1523.63	1524.50	1521.33
38-37	6,720	110.45	342	414	551	290	3.10	3.75	4.99	2.63	6,720	1527.10	1526.45	1525.21	1527.57

Source : 1) Sedimentation Survey of Kulekhani Reervoir, December-1993, DOSC
2) Sedimentation Survey of Kulekhani Reservoir, October-1994, DOSC
3) Draft Report on Sedimentation Survey of Kulekhani Reservoir, December-1995, NEA

Table 6.5.1 Grain Size Distribution of Sediment Material in the Kulekhani Watershed

Site No.	Location	River System	Basin Geology	Elevation (El.m)	Grain size distribution Silt / Clay (<0.074 mm) (%)	Sand (0.074 - 2 mm) (%)	Gravel (>2 mm) (%)	Site Condition	Assumed River gradient	Remarks
1	Sarban	Palung K.	Granit & Schist	1535	3	27	70	Upstream end of Kulekhani reservoir	1/50	
2	Ghattedada	Palung K.	Granit & Schist	1620	3	31	63	Confluence of Palung K. and Tistung K.	1/30	
3	Kulgaon	Palung K.	Granit & Schist	1650	1	77	22	Confluence of Palung K. and Khanigaon K.	1/50	
4	Okhargaon	Palung K.	Granit and Schist	1735	1	64	35	Outlet of Palung Valley	1/100	
5	Palung bridge	Palung K.	Granit and Schist	1750	1	44	55	Confluence of Palung K. and Kitini K.	1/100	Sand quarry
6	Palung	Palung K.	Granit and Schist	1790	1	31	68	Confluence of Palung K., Garti K., and Phedigaon K.	1/100	Sand quarry
7	Bhotekarai	Garti K.	Granit	1800	3	50	47	Upper end of Palung valley in flat portion.	1/100	
8	Phatbazar	Phedigaon K.	Schist	1805	5	33	62	Upper end of Palung valley in flat portion.	1/50	
9	Phedigaon	Phedigaon K.	Schist	1815	2	7	91	On the plateau which is covered by debris	1/20	
10	Bhotekoria	Bhotekoria K.	Schist	1810	2	18	80	Upper end of Palung valley in flat portion.	1/30	
11	Khanigaon	Khanigaon K.	Schist	1830	2	7	91	Upper part of Khanigaon K.	1/20	
12	Kunchal	Kunchal K.	Schist	1700	3	9	88	Upper part of Tistung valley in flat portion	1/40	
13	Tistung	Tistung K.	Schist	1705	5	15	82	Center of Tistung valley	1/80	
14	Bisinkhel	Bisinkhel K.	Schist	1700	2	13	85	Middle reach of Bisinkhel K. in flat portion.	1/50	
15	Chitlang	Chitlang K.	Schist	1720	1	7	92	Center of Chitlang valley	1/50	
16	Shimrang	Chitlang K.	Schist	1575	3	37	60	Upstream edge of the reservoir on Chitlang K.	1/50	
17	Kitini	Kitini K.	Granit	1845	2	60	38	Middle reach of Kitini K.	1/10	

Table 6.5.2 Grain Size Distribution of Sediment Material in the Kulekhani Reservoir

Site No.	Layer No.	Depth (m)	Thickness of Layer (m)	Grain size distribution		
				Silt / Clay (<0.074 mm) (%)	Sand (0.074 - 2 mm) (%)	Sand and Gravels (>2 mm) (%)
BH-1	1	0.00 - 1.50	1.5	5	46	49
	2	1.50 - 2.65	1.15	23	68	9
	3	2.65 - 4.00	1.35	12	13	75
	4	4.00 - 8.00	4	33	67	0
	5	8.00 - 9.55	1.55	43	57	0
	Total		9.55	26%	55%	19%
BH-2	1	0.00 - 1.00	1	40	59	1
	2	1.00 - 1.50	0.5	30	63	7
	3	1.50 - 2.50	1	40	59	1
	4	2.50 - 3.15	0.65	40	18	42
	5	3.15 - 3.75	0.6	23	49	28
	6	3.75 - 4.90	1.15	38	27	35
	7	4.90 - 5.30	0.4	21	21	58
	8	5.30 - 5.70	0.4	9	29	62
	9	5.70 - 7.15	1.45	40	30	30
	10	7.15 - 7.50	0.35	19	56	25
	11	7.50 - 8.20	0.7	75	17	8
	12	8.20 - 9.50	1.3	67	23	10
	13	9.50 - 9.70	0.2	70	28	2
	14	9.70 - 10.50	0.8	48	22	30
	Total		10.5	43%	35%	22%
BH-3	1	0.00 - 1.25	1.25	80	20	0
	2	1.25 - 2.50	1.25	68	32	0
	3	2.50 - 6.00	3.5	85	15	0
	4	6.00 - 7.00	1	72	28	0
	5	7.00 - 8.00	1	60	40	0
	6	8.00 - 9.00	1	82	18	0
	7	9.00 - 10.00	1	19	81	0
	Total		10	72%	28%	0%
BH-4	1	0.00 - 0.75	0.75	90	10	0
	2	0.75 - 1.50	0.75	90	10	0
	3	1.50 - 2.00	0.5	90	10	0
	4	2.00 - 2.50	0.5	90	10	0
	5	2.50 - 4.00	1.5	90	10	0
	6	4.00 - 5.50	1.5	95	5	0
	7	5.50 - 6.50	1	95	5	0
	8	6.50 - 8.00	1.5	95	5	0
	9	8.00 - 9.00	1	95	5	0
	10	9.00 - 9.50	0.5	95	5	0
	11	9.50 - 11.00	1.5	97	3	0
	12	11.00 - 12.00	1	90	10	0
	13	12.00 - 13.00	1	98	2	0
	14	13.00 - 19.00	6	90	10	0
	15	19.00 - 20.00	1	72	28	0
	Total		20	91%	9%	0%

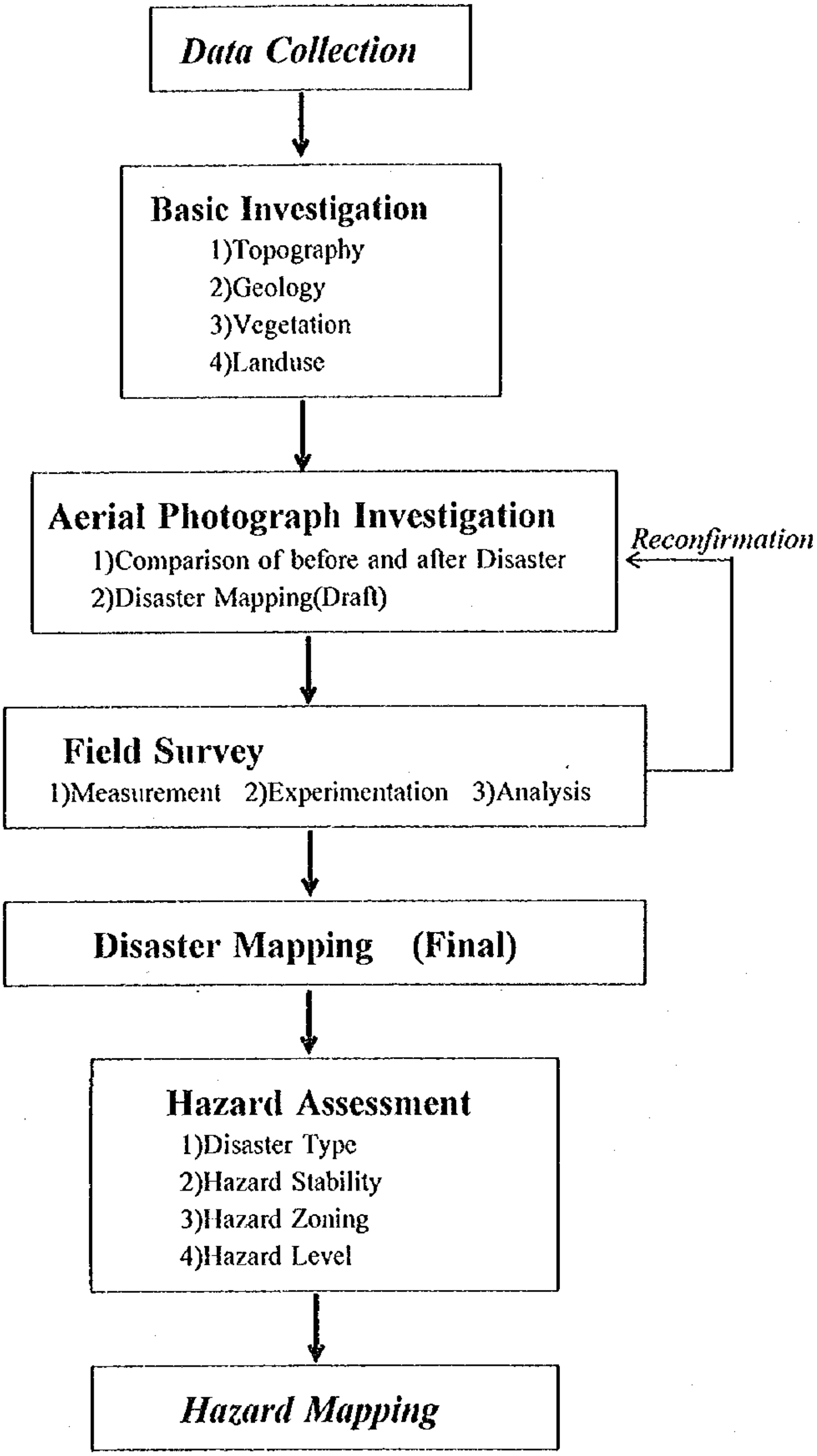
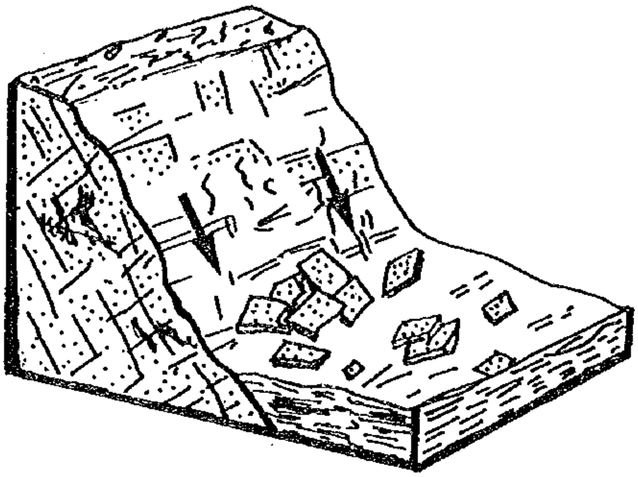


Fig. 1.1.1
Procedures to Disaster Analysis for Community

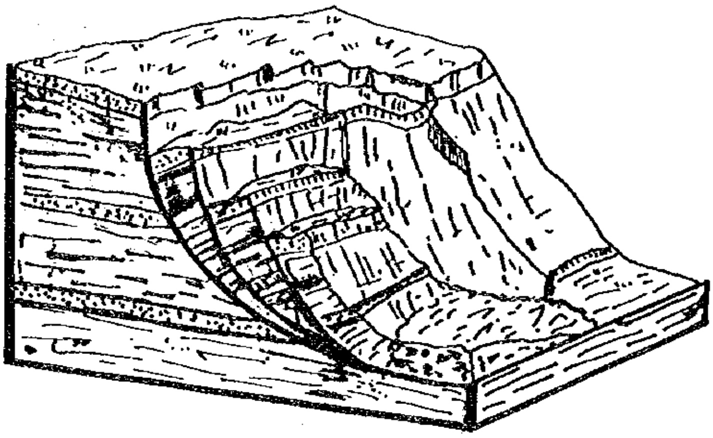
His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



Plane Slide



Slump Slide

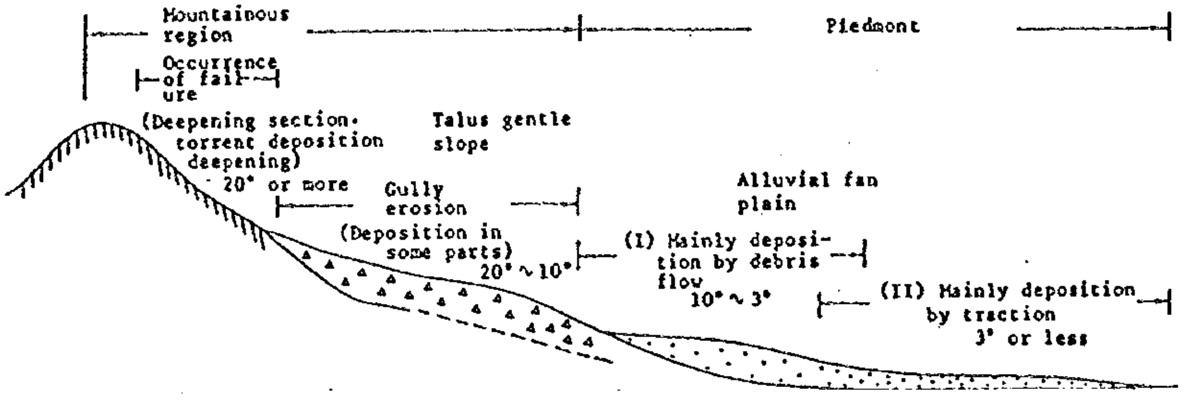
Source: The Role of Extreme Weather Events, Mass Movements, and Land Use Canges in Increasing Natural Hazards. ICIMOD

Fig. 1.3.1
Sketch of Major Types of Landslide

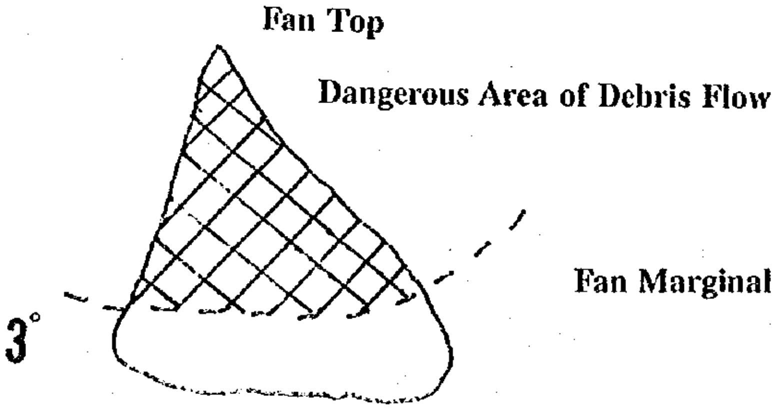
His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



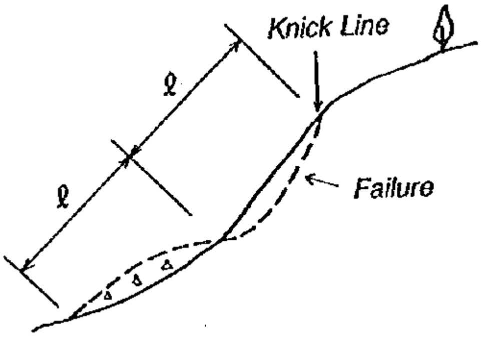
A Schematic Model of Occurrence, Loading and Deposition of Debris Flow(Source by IMAMURA)



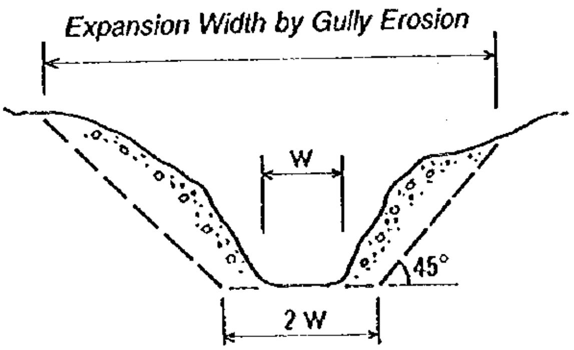
Dangerous Area of Debris Flow

Fig. 1.3.2
Typical Mechanism of Debris Flow

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation
THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY

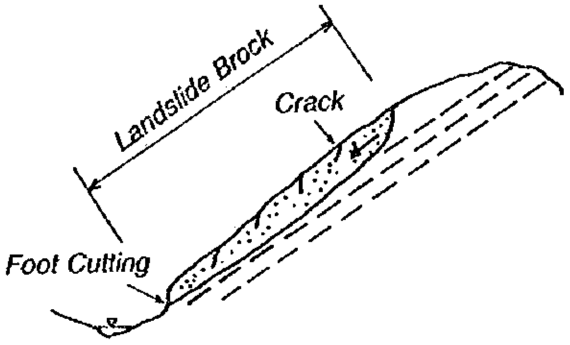


Estimated Reaching Area of Failure

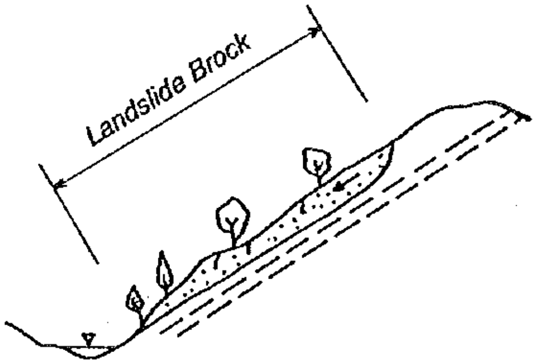


Estimated Expansion Width by Gully Erosion

Fig. 1.3.3
Typical Zones for Failure and Gully Erosion



Hazard Level A



Hazard Level B

Fig. 1.4.1
Hazard Level for Landslide

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

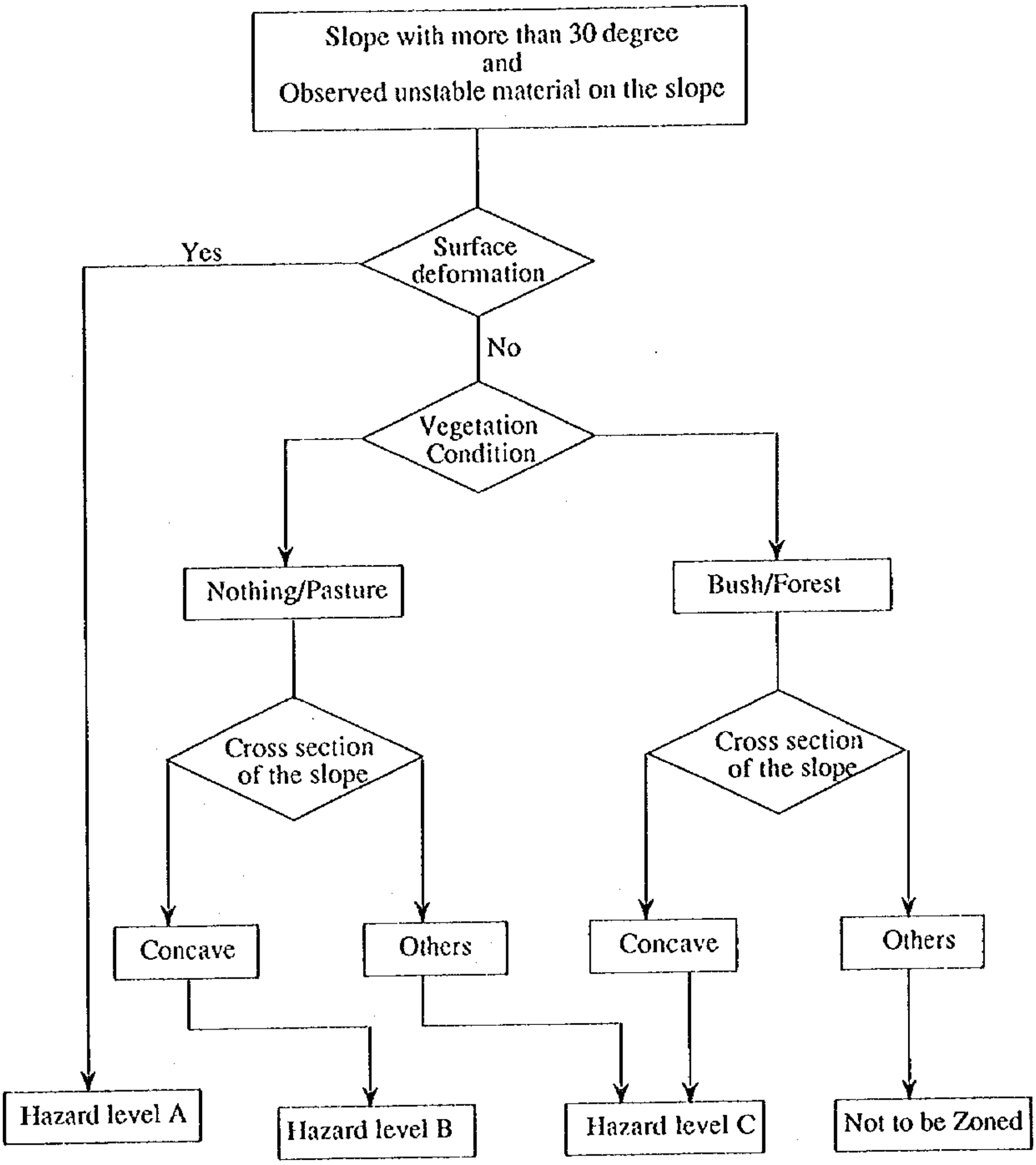


Fig. 1.4.2
Flowchart of Hazard Assessment for Failure

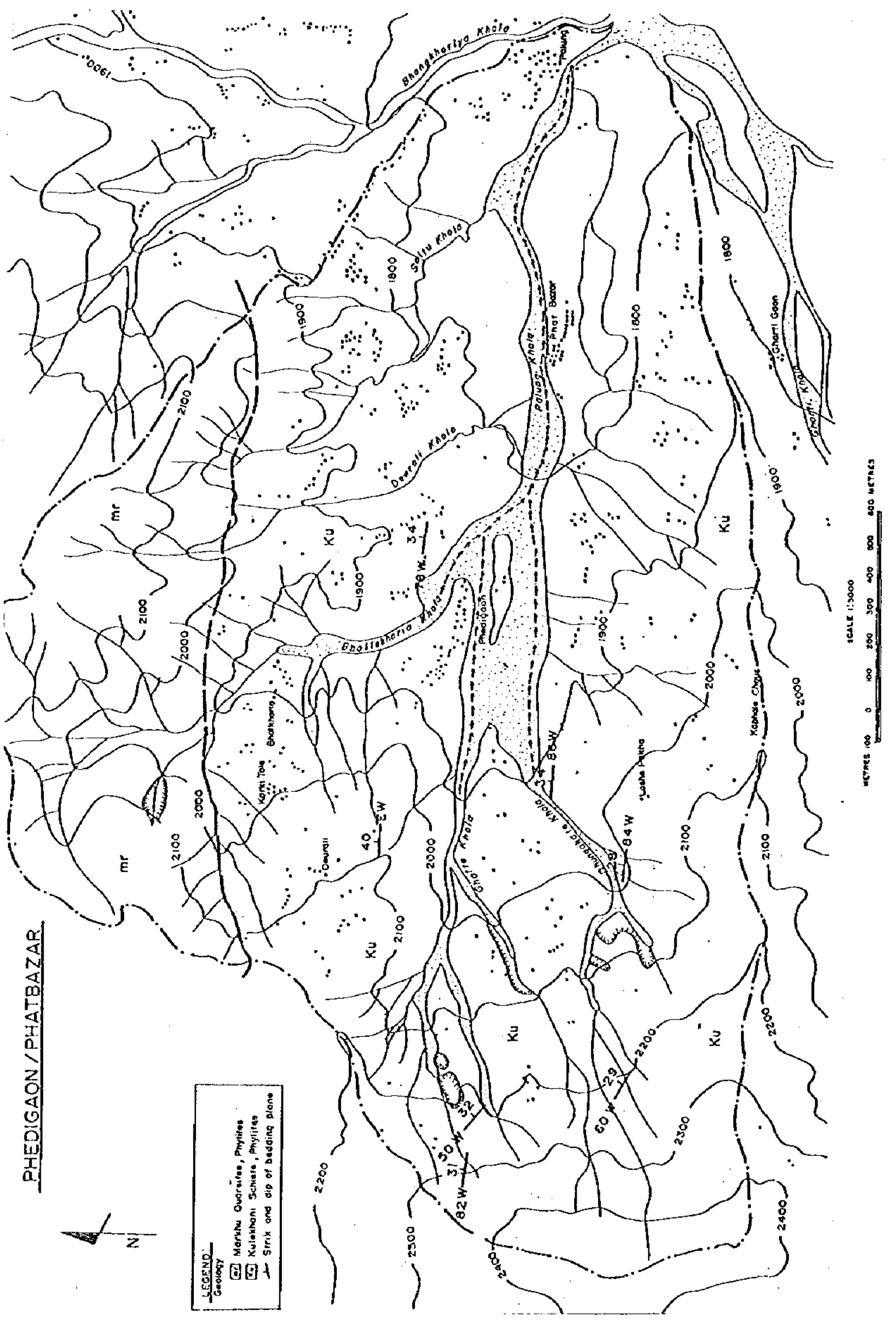


Fig. 2.1.1
Topographic Map of Phedigaon/Phatbazar Area

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation
THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY

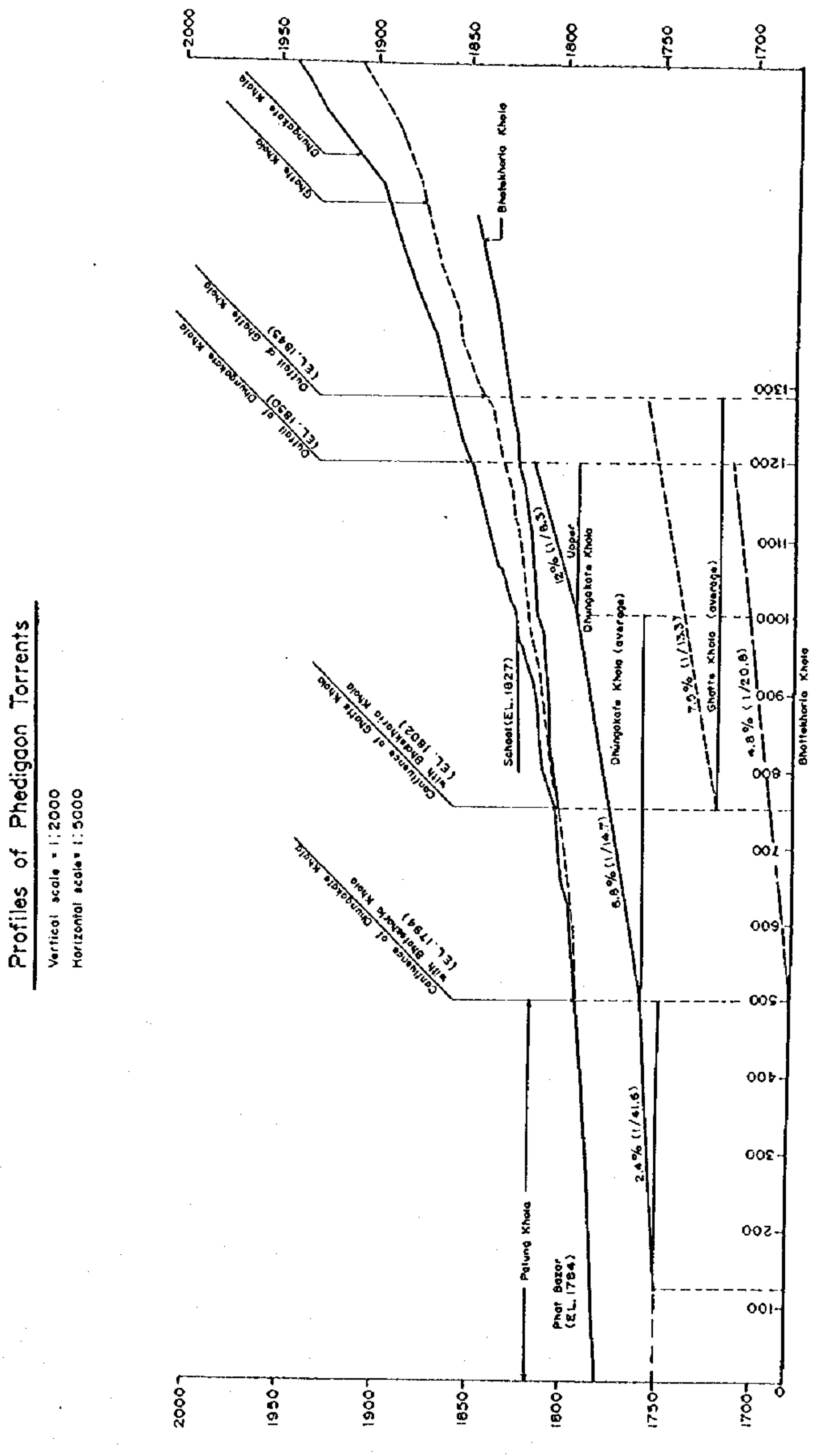


Fig. 2.1.2
Profiles of Phedigaon Torrents

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

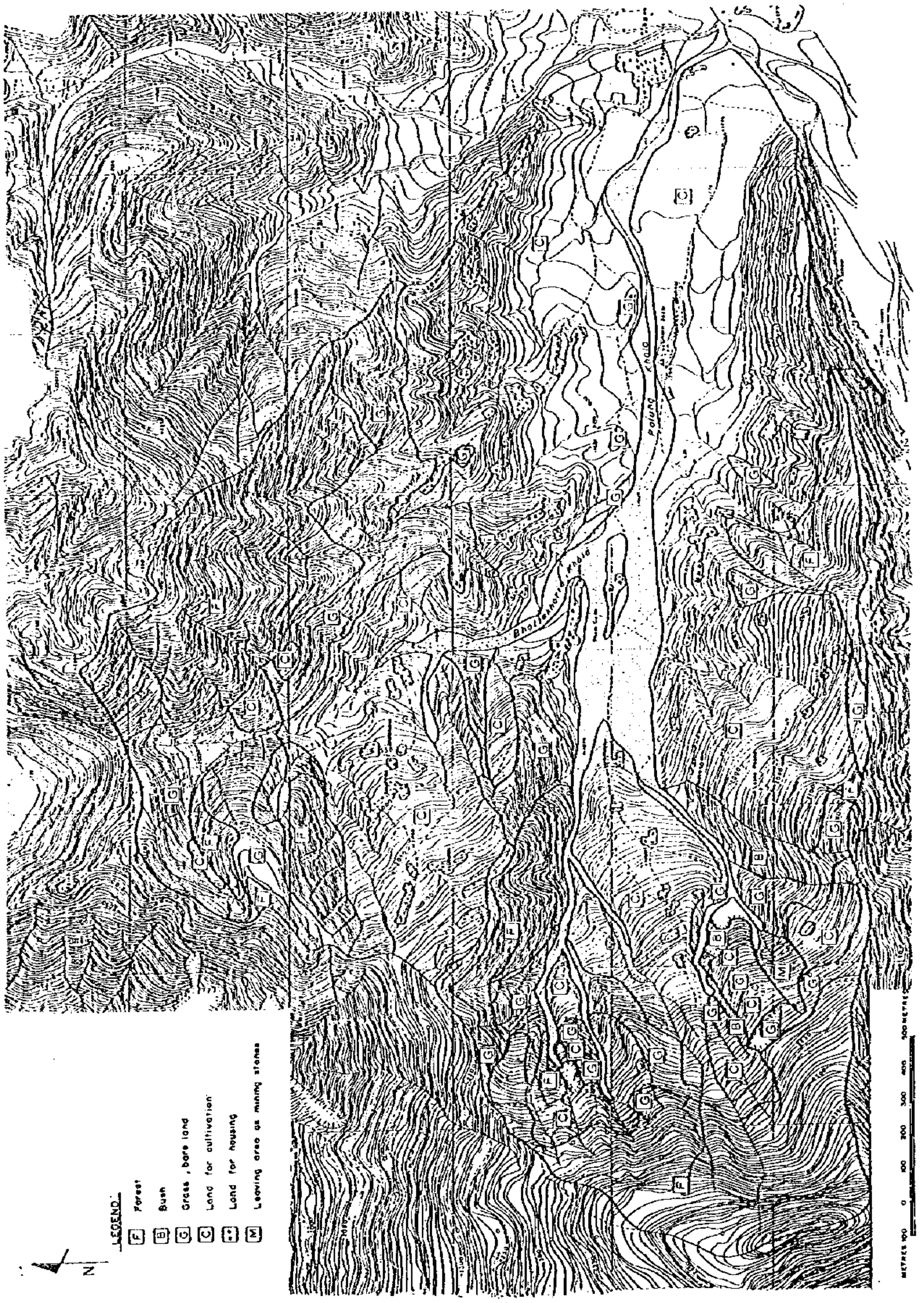


Fig. 2.1.3
Land Use Map

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

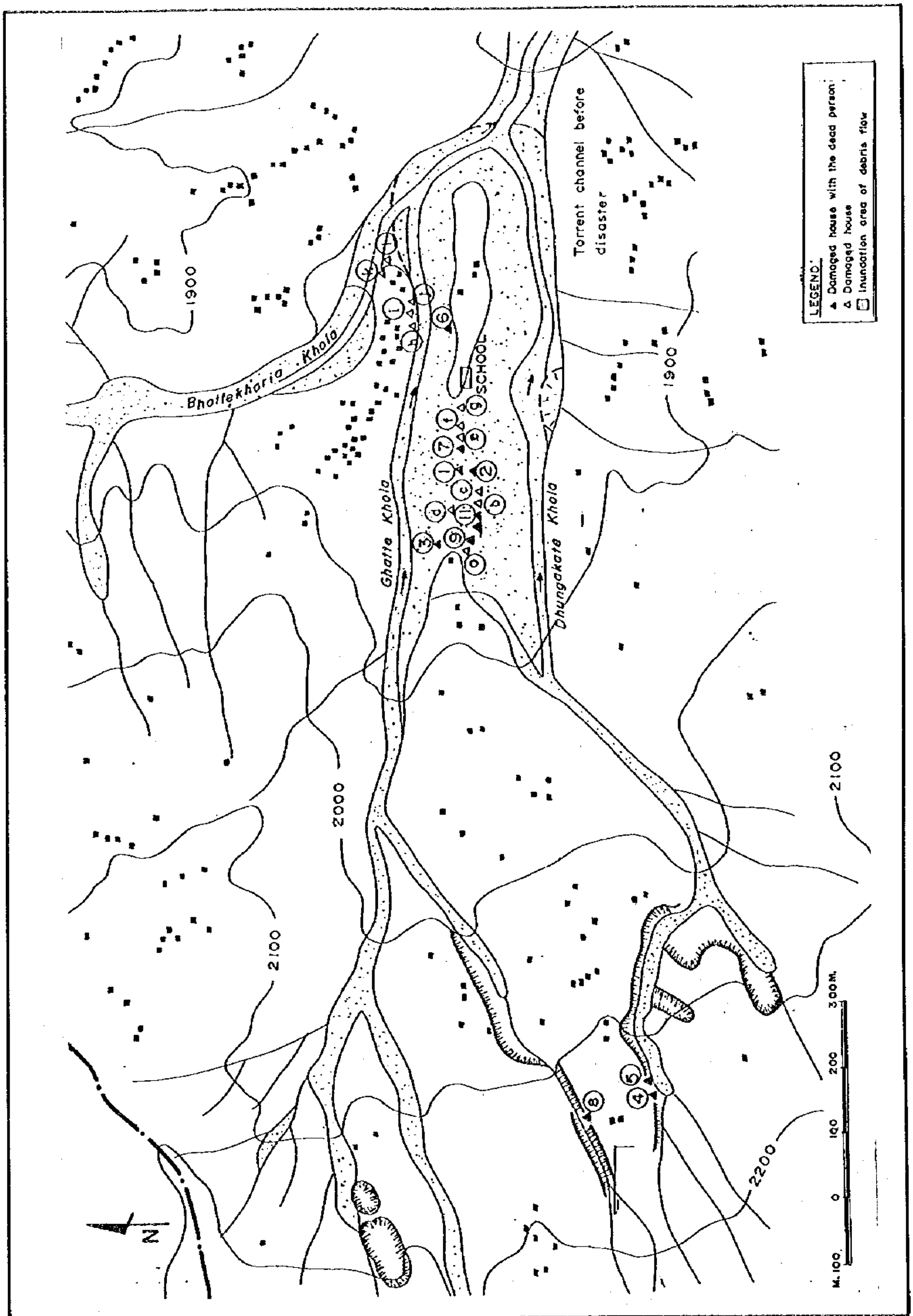


Fig. 2.2.1
Location of Damaged Houses due to the 1993 Disaster

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

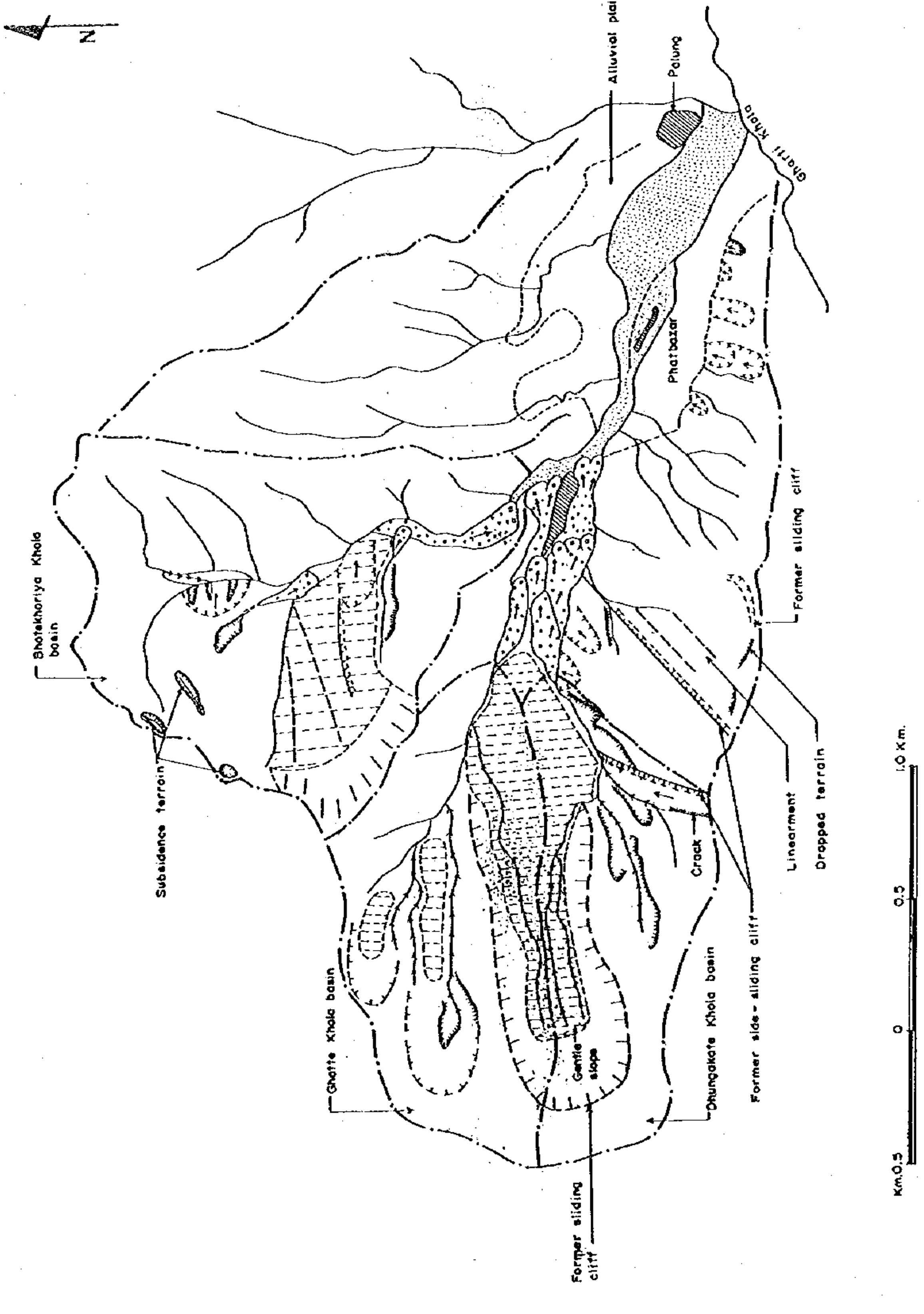


Fig. 2.2.2
Aero Photo Investigation Map

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation
THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY

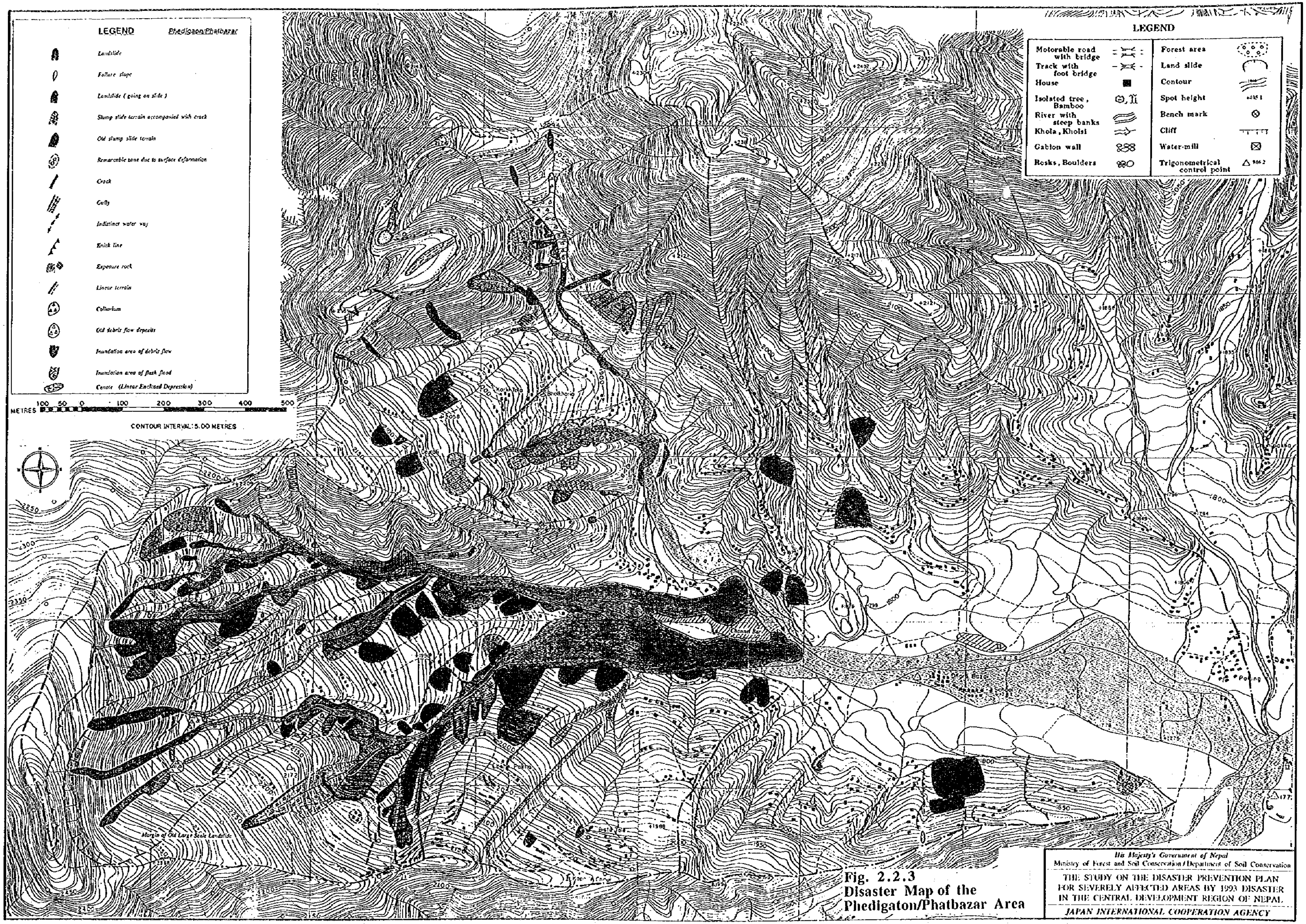


Fig. 2.2.3
Disaster Map of the Phedigaton/Phatbazar Area

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation / Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

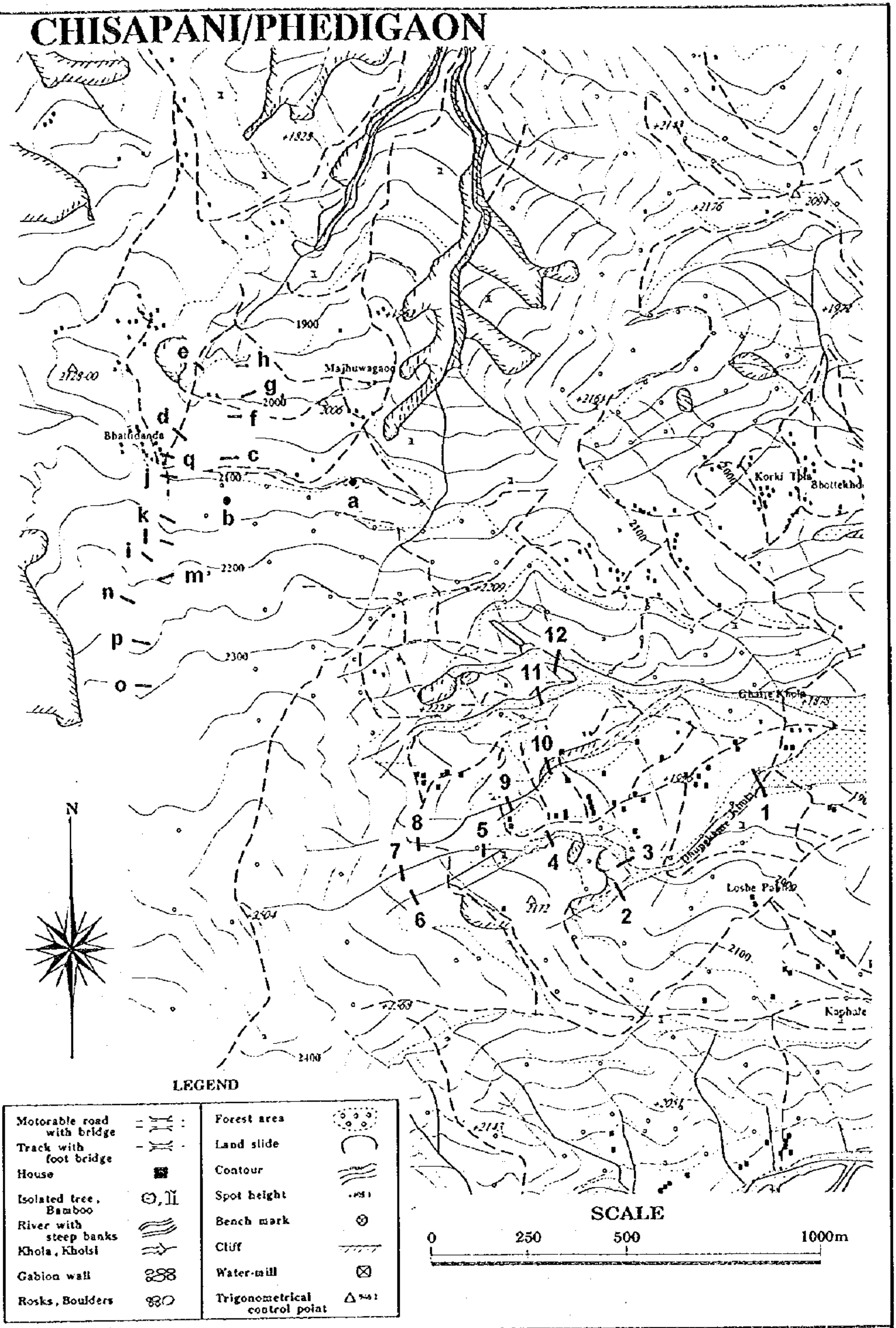


Fig. 2.2.4
Location Map of Cross Sectional Survey for Gully Erosion

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

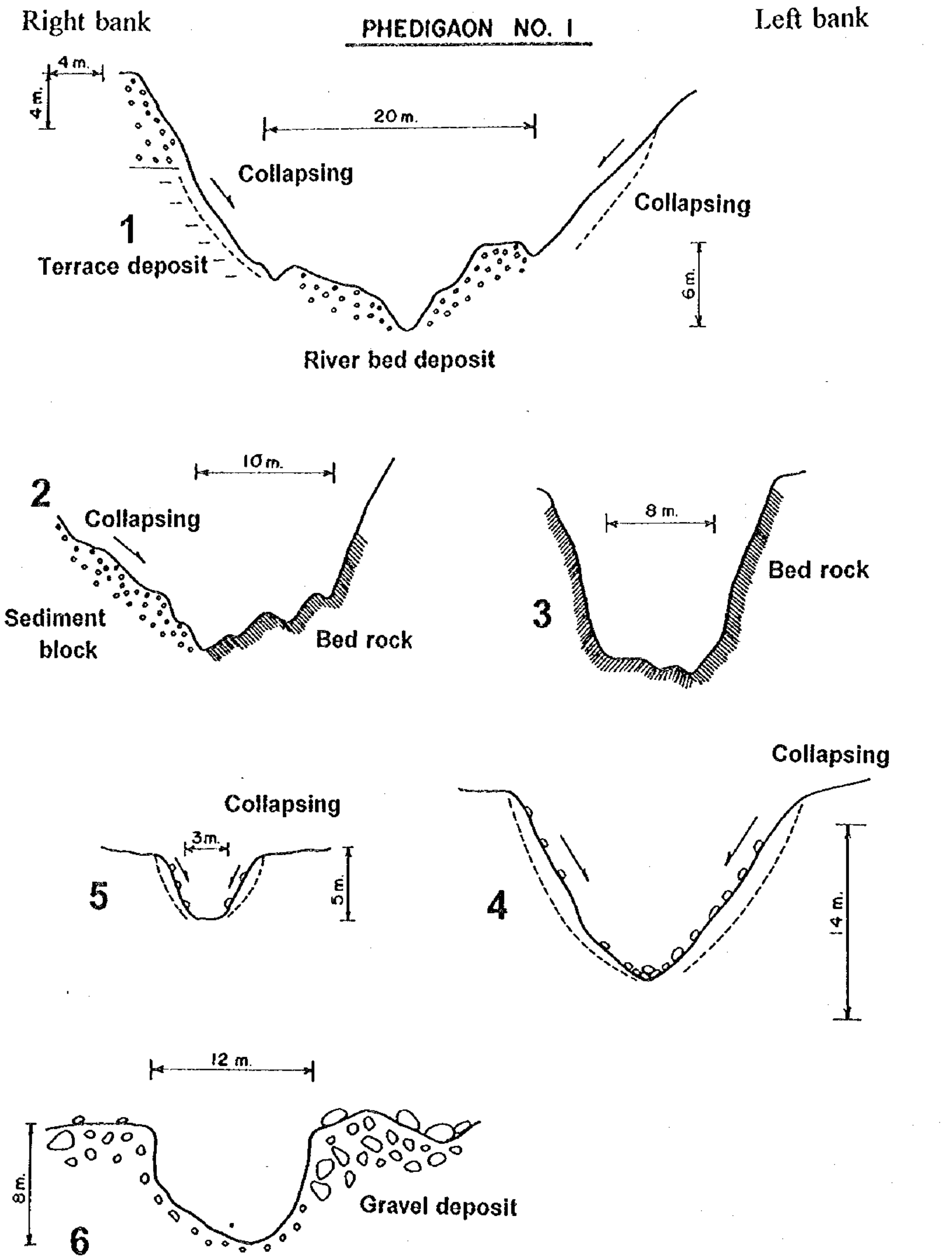


Fig. 2.2.5
Cross Sections of The Gullies in Phedigaon (1/3)

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

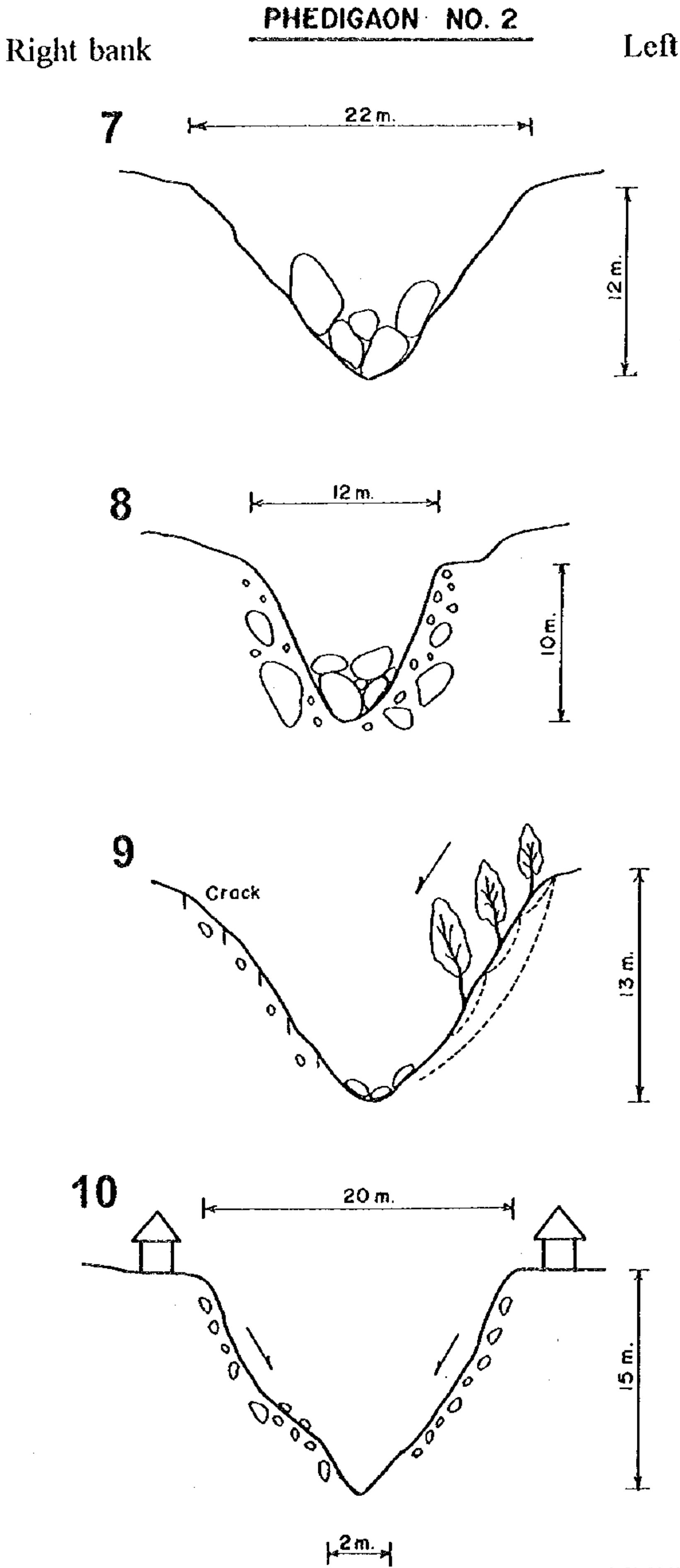


Fig. 2.2.6
Cross Sections of The Gullies in Phedigaon (2/3)

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation/Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

PHEDIGAON NO. 3

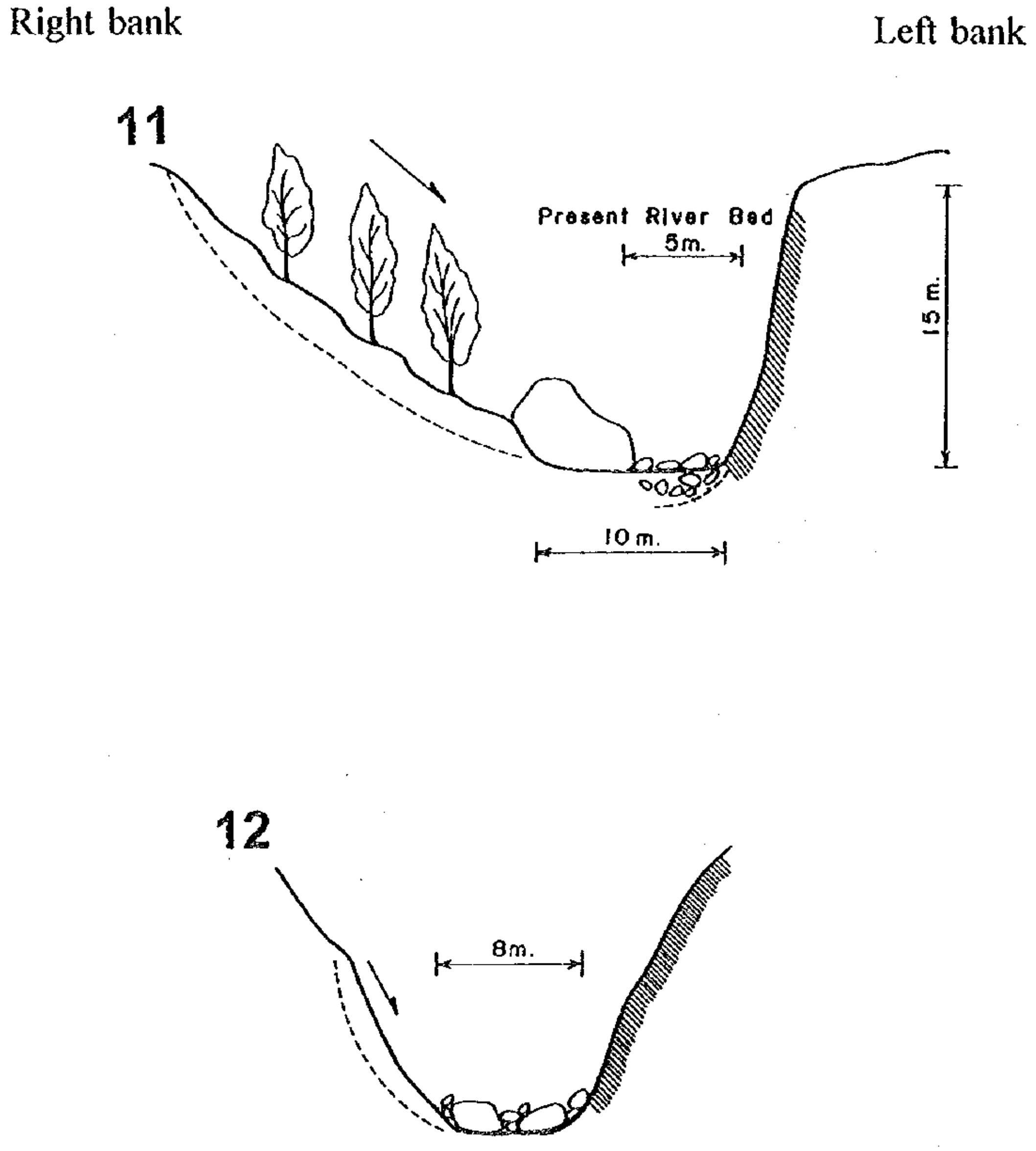


Fig. 2.2.7
Cross Sections of The Gullies in Phedigaon (3/3)

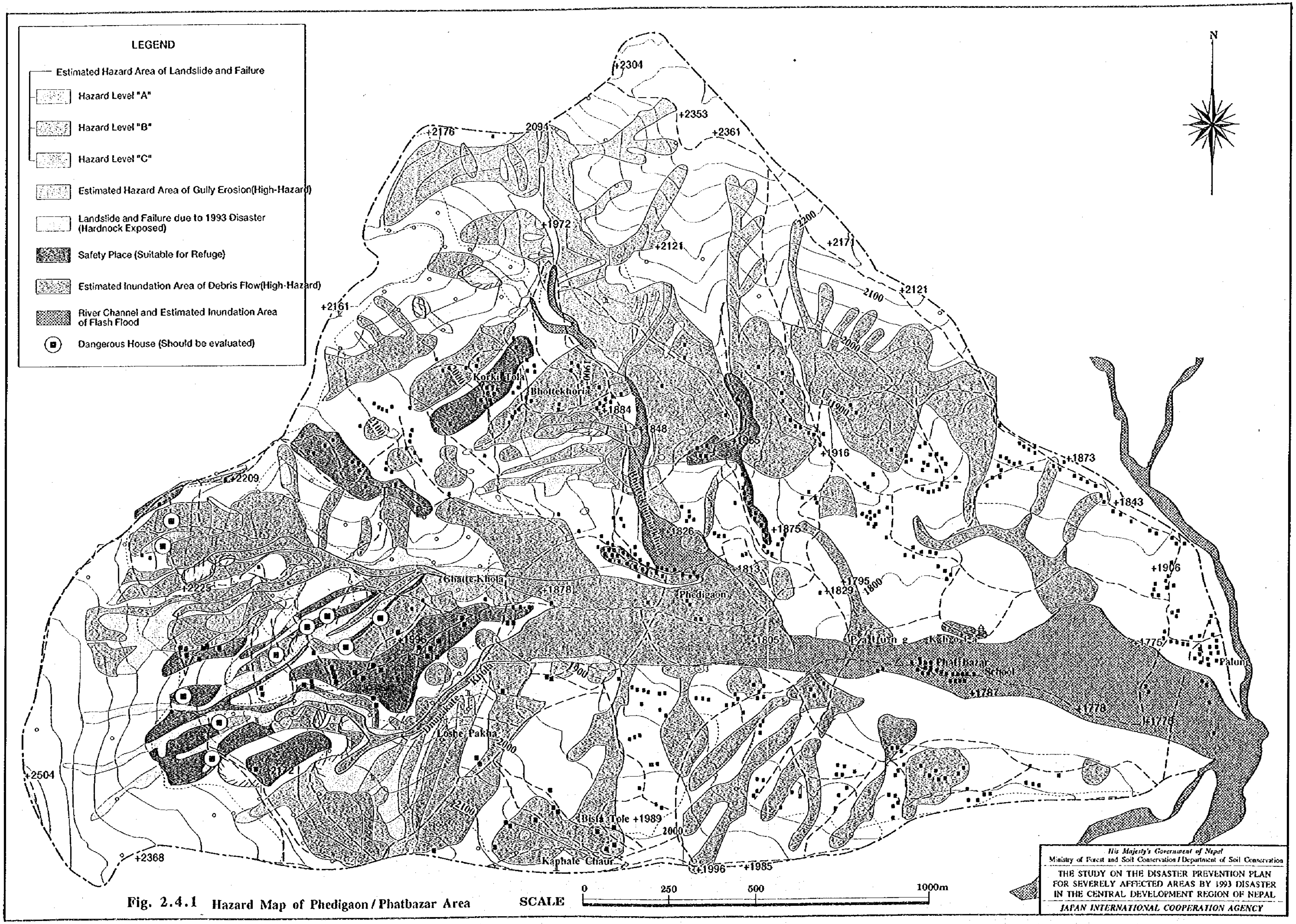


Fig. 2.4.1 Hazard Map of Phedigaon / Phatbazar Area

His Majesty's Government of Nepal
Ministry of Forest and Soil Conservation / Department of Soil Conservation

THE STUDY ON THE DISASTER PREVENTION PLAN
FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER
IN THE CENTRAL DEVELOPMENT REGION OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY