CHAPTER 6

INFRASTRUCTURE DISASTER PREVENTION PLAN FOR MAHADEVBESI BRIDGE

6. INFRASTRUCTURE DISASTER PREVENTION PLAN (IDPP) FOR MAHADEVBESI BRIDGE

6.1 General

The IDPP for the Mahadevbesi Bridge is expected to demonstrate that experience and knowledge of river/sediment control engineering would contribute to the safe passage of sediment-loaded floodwater at the bridge site, because similar types of bridge destruction had occurred at places at the time of the 1993 disaster. Exemplifiable approaches coming in majority from sediment control engineering will be set up and hereby an appropriate application of techniques can be transferred so that Nepal would less depend on foreign assistance for technology and financing.

It is obvious that damage of the bridges and disconnection of important highways for a long time would be fatal to the development of national or regional economy. Upon the occurrence of 1993 disaster, Prithivi Highway was actually cut off in the adjacent district to Kathmandu because three bridges including the Mahadevbesi Bridge were washed away thoroughly due to the onslaught of overwhelming floodwater accompanied by an enormous amount of debris/sediment from the upstream areas. Urgent import of bailey-truss for the bridges using a chartered flight from Hong-Kong barely enabled to restore traffic on the arterial road, Prithivi Highway. Without such an urgent rehabilitation measure it must have been impossible to connect Kathmandu with other cities and to transport food, fuel and all other commodities during the periods of rainy seasons subsequent to the 1993 disaster.

The development of bridge protection technique against debris/sediment flows, particularly of arterial road bridges is really significant in terms of effective countermeasures and should be deeply taken into account for the future, although such damage as occurring along a road due to slope failures or landslides might be temporally rehabilitated with a relative ease because they are ordinary events of road damage that can be treated with intensive mobilisation of heavy construction equipment.

In this chapter, necessary countermeasures from the river/sediment control engineering point of view will be discussed to secure the safe management and maintenance of the Mahadevbesi Bridge.

6.2 Basin Topography and Geology

The Agra Khola is the main tributary of the Mahesh Khola, one of the major tributaries of the Trishuli River in Central Nepal. The Agra Khola drainage basin is located in the Mahabharat Range. The total drainage area is 112 km^2. The elevation varies from 600 m at the confluence with the Mahesh Khola to 2400 m at the watershed boundary of 21 km. All the streams of the Agra watershed are in their youth stage. The Agra Khola has dendritic and radial drainage patterns (Figure 6.2.1).

The Agra Khola is formed by six small streams flowing down from south to north. Its major tributaries are the Chalti Khola and Mel Khola, the catchment areas of which are 12.9 km^2 and 32.8 km^2, respectively. The ridges of the catchment areas are steep. The river gradient is about 25° in the first parts of all these streams. The middle portions of the streams have gentle slopes of about 4°, and the slopes decrease to 1.5° in the last sections, about 12 km from the confluence with the Mahesh Khola.

The Agra Khola basin is occupied mainly by quartzite, schist, phyllites, limestone, and marbles of the Bhimphedi Group. Granites are also exposed in part of the western basin. Rocks are intensely faulted, folded, and jointed.

There are many large landslides in the part of the headwaters. These landslides are mostly distributed in the Kulekhani Formation. Slides in this basin have four main types: plane rock slide, wedge failure, debris slide, and deep-seated rotational slide. Plane rock slide is especially common on the dip slope, whereas wedge failure is observed mostly on the counter dip slope. In the area occupied by phyllites, shale, and schist, thick residual soil is formed by prominent weathering on which dominating plane or rotational weathered rock slide and debris slide are found.

According to Khanal (1993), landslides and slope failures occurred in the years of 1954, 1970, and 1974 due to heavy rains in the Agra basin. It is considered that most of landslides and slope failures that took place in the 1993 disaster are a continuation of the expansion of past ones.

6.3 Assessment of Damage due to the 1993 Disaster

The former Mahadevbesi Bridge was a three-span bridge with steel girders and concrete decks. The three piers and the super-structure on the left side were washed away. The right side pier and the super-structure between the abutment and the right side pier have remained, but the pier was severely damaged due to the strike of boulders on the surface of concrete and the reinforcement bars were exposed and bent.

According to the survey carried out by Snowy Mountain Engineering Corporation, Australia (SMEC), it was not sure how the bridge was broken down. Some witnesses reportedly said that the super-structure was knocked off by a large driftwood. On the other hand, others said that the piers collapsed first and the super-structure fell down subsequently.

Photo 6.1, which was taken from a helicopter just after the July 1993 disaster by the DPTC, indicates that the major stream flows deviated from the right bank toward the left bank to a considerable degree, immediately upstream of the Mahadevbesi Bridge. Judging from this picture it is assumed that the pier on the left side must have been first destroyed by the striking of boulders and sediment contained in anomalous floodwater.

Photo 6.2 shows the bridge's damaged pier, which is located on the right side, inner side, of the flood course. The pier was severely damaged by erosion of the sediment material including boulders with a diameter of more or less than onemeter. It is also assumable that this anomalous floodwater must have been a hydraulic bore which has terrible kinetic energy to convey even big boulders.

There is an opinion or comment that so-called debris flows which convey big boulders and sediment in a form of massive transportation must have given a fierce attack on the bridge structures. However, debris flow in usual sense of terminology cannot take place on such a gentle river bed gradient of 1 % where the Mahadevbesi Bridge is located. The Study Team is dissident on this point. From the result of our field survey and geomorphological analysis it may be safe to say that so-called debris flows never happened in the river channel adjacent to the Mahadevbesi Bridge but the occurrence of a particular flow like a hydraulic bore must have generated in the river channel immediately upstream and spontaneously raised river bed during a big flood must be another factor to be reckoned with. The origin of boulders accumulated near the bridge has become clear;

that is, they came from the river terraces situated at a few kilometres upstream of the bridge.

Disastrous events such as landslides, slope failures in the basin of the Agra Khola of which confluence with the Mahesh Khola is just located at the Mahadevbesi Bridge side are reported to have taken place from time to time in the past. Events in 1954, 1970 and 1974 are recorded to be conspicuous, giving rise to serious damage of the infrastructure and others. In this sense, it can be said that the 1993 disaster happened to occur on an extremely large scale on the elongation of past disastrous events. Emphasis therefore should be put on the necessity of countermeasures against sediment-loaded floodwater which may include big boulders.

6.4 River Channel Condition

In order to conform the conditions of river channels, the Study Team carried out field investigation from the headwaters of the Agra Khola up to the confluence with the Mahesh Khola where the Mahadevbesi Bridge is located. Figure 6.4.1 shows the geological / geomorphological conditions and the longitudinal profiles are given in Figure 6.4.2.

1) Chalti Khola

In the upper most reaches of the Chisapani Khola, the river width is about 4 to 5 m and the average riverbed gradient is more than 15°, and some big and small cascades are formed. There are a little sediment deposits on the river bed due to transportation by debris flows. The river bank is eroded and landslides continue to happen.

In the middle reaches of the Chalti Khola several large collapses are found. Existence of remarkably weathered rocks prevails on the surface of slopes. Aggravated characters of the bedrock will give rise to further extensive landslides. On the foot of existing collapses is seen a huge amount of colluvial deposits. The river bed is covered with thick deposits of debris flows and accordingly the width of river bed becomes wide, varying from 50 m to 150 m. The thickness of debris flow deposits is estimated to be 3 m to 4 m at least. The river bed gradient varies 6° ~ 8° on average and 3° near the confluence with the Agra Khola in its uppermost reaches. The mean size of river bed material is 20 cm ~ 30 cm and the maximum size is 1.5 m around. Accumulation of big boulders which are the remnant of debris flows is seen at places.

2) Agra Khola section (from the confluence with the Chalti Khola to the confluence with the Mel Khola)

Landslides are seldom found on the mountain slopes and river banks in this section. The river bed gradient is about 2° to 3°, rather gentles than that of the Chalti Khola. The river bed material consists of pebble with a size of about 10 cm and its thickness is estimated at 0.5 to 1.0 m. Big boulders are hardly found in this section.

3) Agra Khola section (from the confluence with the Mel Khola to the Mahadevbesi Bridge)

In this section, the river bed gradient is 1.5° to 2.0°, the major components of river bed material change from pebble to sand. In the incised meandering course of this valley some of boulders are found that consist mainly of white round boulders of granite. Some of schist and quartzite boulders are mixed with granite boulders. According to the result of sieve analysis carried out by the DPTC (1993), the average size of boulders is about 2.0 m and the maximum size is 3.5 m. Downstream of this section, rather large-scale landslides are found on both banks. They are assumed to have taken place due to the undercutting of the river bed, particularly at bent corners of the river course. A large portion of collapsed earth still remains at the foot of slid slopes as colluvial deposit a cone shape.

4) Understanding of the process of sediment transportation along the Agra Khola.

On the basis of the above-mentioned results, the yielding and transportation of sediment can be understood as follows:

i) The sediment yielded in the Chalti Khola basin seems to be washed out downstream in a form of debris flow and sediment-loaded floodwater. The major part of sediment, however, seems to have deposited in the lower segment of the Chalti Khola before merging with the main stream of the Agra Khola.

ii) In the section of the Agra Khola between the confluence with the Chalti Khola and the confluence with the Mel Khola, it seems that the form of sediment transport was sediment-loaded flow or bed-load, judging from the result of sieve analysis, field observation and the river bed gradient.

iii) In the downstream section of the Agra Khola between the confluence with the Mel Khola and the confluence with the Mahesh Khola where the Mahadevbesi Bridge is located, the major component of sediment is fine sand although a number of big boulders of granite exist on the river bed. It is hardly possible to understand that these big granite boulders have their origin in the uppermost basin of the Agra Khola, because of the fact that none granite boulder is found in the upstream section and large-scale landslide did not occur in the areas of granite upstream even on the occasion of the 1993 disaster.

iv) The origin of granite boulders that have flowed down to the site of the Mahadevbesi bridge during the 1993 disaster seems to be the alluvial terraces distributing along the lower reaches of the Agra Khola. Those alluvial terraces naturally contain granites boulders since previous geological eras.

6.5 Mechanism of the 1993 Disaster and Disaster Potential in Future

1) Mechanism of the 1993 Disaster

The yielding source of a huge amount of sediments can be attributed to the landslides in the upper reaches of the Chalti Khola and Agra Khola. Landslides that had been existing since a long time before the 1993 disaster must have become bigger than before and also plenty of landslides must have newly developed due to anomalous rainfall at the time of the 1993 disaster, but the distinction of old and new landslides is not always clear for lack of exact data. This suggests that geological and geomorphological situations are essentially vulnerable to slope failures and landslides.

In the uppermost reaches of the Agra Khola the hillslopes are very steep, showing 30° ~ 45° which is almost equal to or rather steeper than the internal friction angle of the soil or rock mass. It is obvious that such steep slopes of mountains are erodible and easy to fall down, even in case of heavy rainfall.

A geological layer called Kulekhani Formation is highly fractured and deeply weathered. Two to four sets of geological joints are remarkable in the quartzite and schist layers distributed in the Chisapani and Chaubas areas. The spacing of those joints varies from a few centimetres to tens of centimetres. Such characteristics of geological formation also imply the high-grade susceptibility of collapses in the rock mass.

The discontinuities of the rock mass and their intersections make good sliding surfaces. Plane rock slides are especially common on the dip-slopes, whereas wedge failures are observed mostly on the counter dip-slopes. Plane rock slides occurred on slopes that were close to the surface. They are generally large in comparison with the wedge failures. Consequently, old landslides which had been almost inactive have been aggravated and expanded tremendously.

Furthermore, prior to the heavy precipitation of 19 July 1993, the soil mass had been already wet and saturated. The overburden soil including organic rich soil lying over the bed rock is mostly thin (less than 3 m). Thus, in saturated or wet conditions, the overburden soil was washed out and slid.

Besides, none of the catchments has rainfall gauging stations, so the relationship between the rainfall intensity and the debris flow occurrence was difficult to examine. Sudden outbreak of the 1993 disaster was inevitable.

2) Disaster Potential in Future

From the following point of view, it seems that disaster potential in the future is very high.

i) The amount of sediment yielded by landslides in the Agra river basin was estimated at about 20 million m^3 in total at the time of the 1993 disaster. This estimate was conducted through aerophoto interpretation as well as field survey on spots by DPTC. According to the same estimate, it is reported that the sediment amount delivered from the Agra Khola basin to the downstream areas must be 1.3 million m^3 in total. The result of this estimate suggests that a considerable amount of sediment still remains in the basin.

ii) On the right bank of the Chalti Khola, there is found a rather clear symptom of land creeping which is formed even in the bed rock and has structural deformation in geomorphology. On the left bank of the Chalti Khola are also found several landslides which tend to creep gradually. Tension cracks that characteristically appear on the crown of creeping landslides prevail on the left bank of the Chalti Khola and Agra Khola upper reaches, the dimension of such cracks is 5 cm to 30 cm.

iii) Although there would not occur some big events of landslides in the river-channel from the confluence with the Chalti Khola up to the confluence with the Mel Khola, it is feared that in the river course downstream of the Agra Khola, in the section not so far from the Mahadevbesi Bridge, existing unsettled boulders and sediment would move downstream in case of big flood occurrence because of the incised meandering of floodwater as well as the unstable longitudinal profile of the river bed. Alluvial river terraces and their talus still have a potential to deliver sediments which may cause disastrous events due to outflows of debris/sediments.

iv) Deforestation, cultivation on hillslopes may exert a terrible influence on the potential of sediment-orientated disasters because steep hillslopes without vegetation are needless to say, very susceptible to erosion, and apt to cause landslides. The yielded sediment may aggravate the equilibrium of the river regime for a long time.

v) From the long-term point of view, disaster potential leading to disastrous events can be said to be augmented by deforestation and intensive cultivation. For the present, the disaster potential is continuously increasing. From the short/middle term point of view, the damage potential would derive from the sediment accumulation on the river bed. Boulders and sediment accumulated in the lower segment of the Agra Khola will be influential on the safety of the Mahadevbesi Bridge.

6.6 Overall Plan

6.6.1 Objectives

Taking the cause of formidable destruction of the Mahadevbesi Bridge into consideration, measures should be devised to protect the new bridge built at the same site from similar disastrous events. As synoptically discussed in Annex 1, Chapter 5.1 (General of Disaster Analysis at Mahadevbesi Bridges), the major cause of bridge destruction obviously stemed from the anomalous floodwater which accompanied a great deal of boulders and sediments. Although the major component of such destruction is not necessarily clear yet, nobody can discuss the event without considering the problems of sediment outflows from upstream. Hence, one of the most significant objectives evolved in this project is to control the sediment as much as possible.

Sediment control involves erosion control which prevents the yielding of sediment at its source areas on mountain slopes and also aims to properly adjust the transportation of sediment along the river channel as well as to bring about longitudinally and laterally equilibrated situations of the river. For the purpose of protecting the Mahadevbesi Bridge, the major objective of this project cannot but be put on the latter which are to adjust the river gradient and the river meandering.

6.6.2 Technical Framework

In order to set up the framework of engineering techniques necessary for the protection of the Mahadevbesi Bridge, it will be convenient to review the causes of the destruction of the bridge during the 1993 disaster. They can be brightly itemised as follows:

a) enormous amount of sediment outflows from upstream;

b) conspicuous accumulation of sediment on the river bed during the period of flood time;

c) shortage of cross-section under the bridge due to sediment accumulation;

d) lateral migration of floodwater toward the left bank near the bridge; and

e) striking of boulders and drift wood on the bridge structures.

Among these possible causes of bridge breakdown, b) and c) seem to be the chief ones leading to the direct destruction of the bridge.

So-called debrisflows that are usually generated in steep torrents with several degrees of gradient seem to have not struck the bridge. Instead, floodwater or super concentrated sediment water which is heavily loaded with boulders and sediment is supposed to have been generated in the upstream channel adjacent to the Mahadevbesi Bridge. That must have been like a hydraulic force generated by repeated blockades of the channel with debris/sediment and washing them out by floodwater.

The technical framework, accordingly, shall be disposed to eliminate such injurious components of sediment-load floodwater. The following are the key points to be reckoned with for the formulation of countermeasures.

i) From the long-term point of view, it is essential to reduce the yielding of sediment in its source areas. But in a wide extent of areas, intensive land use of hill slopes, geologically and geomorphologically worst situations as well as the poorest circumstances in the basin interfere in this essential principle. There is little hope to succeed in the prevention or reduction of sediment yielding through the improvement of vegetation, for the time being. As for the protection of the Mahadevbesi Bridge, this way of consideration is far from the effective measures.

ii) Many residuals of sediment flowed out in the 1993 disaster still remain in the main channel and the tributaries of the Agra Khola. They are ready to move downstream on occasion of the next coming flood. Not only on the river bed but also at the foot of collapsed hill slopes there exists a lot of unsettle sediment. Transportation of such sediment should be controlled to attain the safety of the bridge because longitudinal as well as lateral profiles of the Agra Khola are far from equilibrated situations. Although the river bed elevation around the bridge site seems to be descending at this moment to a considerable degree, it should be feared that the river bed could be suddenly raised, resulting in an unexpected consequence of high-water level and hereby causing damage to the bridge structures. Under such circumstances, sediment control works in the river channels through well designed checkdams and others are indispensable.

iii) In the lower segment of the main channel of the Agra Khola from the confluence with the Mel Khola to the bridge site, big boulders and sediment are found on the river bed, and the neighbouring river terraces consisting of colluvial deposits still have enough potential to supply such big granite boulders that will strike the bridge. It is urgently needed to detain them around the existing position so that they would not disturb temporarily settled situations of the river bed. Countermeasures in this segment of the river channel are much more important than those in the upper segments from a short-term viewpoint

iv) The sharp bent of the river course at about 500 m upstream of the bridge site exerts much unfavourable influence on the settlement of river equilibrium, horizontally as well as longitudinally up to the bridge site. As for this lowest segment it is substantially needed to check the river bed longitudinally with low dams and to regulate the flow direction with groundsills and spur dikes so that the floodwater may pass the bridge site without lateral migration or deviation of streams. Stabilisation of the river bed or an equilibrated profile in the lower segment of the Agra Khola must be prerequisite for the safe maintenance of the Mahadevbesi Bridge.

v) It is not worth programming and implementing those works as mentioned above unless definite steps are taken to conserve the river environment and to maintain the structures newly built. Selfish and greedy quarrying of stones and gravel from the river bed around the Mahadevbesi Bridge has become prosperous lately. It is clear that such kind of deed will give the worst effect on the natural equilibrium of the river itself, for instance. Apart from mechanical countermeasures all the administrative ways of river management should be examined as part of technical framework. Otherwise the engineering efforts will be in vain.

6.6.3 Overall Plan Formulation

Based upon the outlines of technical framework mentioned in preceding Section 6.6.2, the overall IDPP for the Mahadevbesi Bridge can be set up as shown in Figure 6.4.1. This plan does not necessarily include such a grand scope as being bearable against the most severe event like the 1993 disaster, but it will be formulated on a proper scale which may bear up the issue of the usual event of flood disasters. The scale in terms of flood probability may not exceed a 25-year return period.

The overall plan can be broadly classified into two categories: One is to control the sediment outflow from upstream and the other is to stabilise the river channel, particularly in the lower reaches. The accounts for each are as follows:

(1) Countermeasures to control the sediment

The outflow amount of sediment can be presumed to be nearly the same as the amount estimated by the DPTC in 1994 after the 1993 disaster. According to the report published by the DPTC, the total amount of sediment was estimated at 1.34 million m^3, while the suspended load was estimated at 1.12 million m^3. Then, the bed-load to be dealt with as an objective amount of sediment in this plan can be assumed to be 0.22 million m^3. This amount can be said rather small in a sense, as compared with the gigantic 1993 disaster. But this clearly depends upon the estimated amount of the wash load which is not so easy to estimate exactly. Hence, the objective amount of sediment of 0.22 million m^3 in this plan is presumable to be applied correspondingly.

Countermeasures to reduce sediment yielding on its source such as hillside works and tree-planting on hill slopes in the upper basin will not be included in this overall plan for the reason mentioned in Section 6.1.2 (refer to the paragraph (i)).

Check dams to detain and control further transportation of sediment downstream are to be arranged in the lower channel of the Agra Khola in this overall plan for the reason mentioned in Section 6.1.2 (refer to the paragraph (ii) and (iii)).

The number of check dams and their dimensions shall be designed so that the total control capacity of check dams would be not less than the estimated bed load amount of sediment. Considering the aim of this project, which is to protect the Mahadevbesi Bridge from sediment outflows, the proposed sites of check dams shall be disposed in the lower river channel downstream of the confluence with the Mel Khola.

Figure 6.4.1 shows the locations of check dams and the outlines of proposed check dams are shown below:

Outlines of Proposed Check Dams

Notation	Effective Height of Check Dam H (m)	Mean Width of Sediment Deposition B (m)	Original River bed Gradient (1/n)	Expected Capacity of Sediment Control E (m^3)
No.1 Check dam	4.0	6.0	1/40	38,400
No.2 Check dam	5.0	8.0	1/40	80,000
No.3 Check dam	4.0	8.0	1/40	51,200
No.4 Check dam	5.0	6.0	1/35	52,500
Total				222,100

In the above table, the expected capacity of sediment control E is roughly estimated by the equation $E = nBH^2$. And it is presumed that the amount of E would reconcile the amount to be controlled.

(2) Countermeasures to stabilise the channel

The river channel situated in the lowermost reaches of the Agra Khola between the sharp bent of the river course about 500 m upstream of the Mahadevbesi Bridge and the confluence with the Mahesh Khola is still unstable longitudinally as well as laterally. It is feared that the existing situations of the river regime would give injurious effects on the safe maintenance of the Mahadevbesi Bridge, as mentioned in Section 6.6.2 (refer to paragraph (iv)).

To cope with those unstable situations, it is needed to take countermeasures so as to stabilise the channel to a considerable extent as shown in Figure 6.6.2. The following structures are proposed.

- Groundsill No.1 with a view to controlling the excessive amount of sediment from upstream as well as conserving the existing river bed around a sharp bent of the river course.

- Groundsill No.2 with a view to consolidating the river bed upstream and lowering the river bed downstream so that it may reconcile the river bed gradient downstream as well as direct a proper course of the river channel.

- Several spur dikes on the right bank downstream with a view to checking and adjusting the direction of the floodwater so that a smooth passage of the floodwater at the bridge site can be secured.

They can be briefly tabulated as below.

Outlines of Proposed Groundsills and Spur Dikes

Notation	Nos.	Effective Height (m)	Length of Structure (m)	Existing River bed Gradient (%)	Planned River bed Gradient (%)
Groundsill/No.1	1	5.0	98.0	1.8	1.3
Groundsill/No.2	1	3.0	76.0	1.5~1.7	1.3
Spur Dike	5	2.0~3.0	9.0	-	-

Groundsill No.1 with an effective height of 5 m may substantively act as a low check dam although it is named a groundsill herein for convenience sake. It is expectable for this groundsill to detain sediment to some extent as well as to play sorting the size of sediment. This point may deserve much attention. Setting of groundsill No.2 combined with a series of spurdikes has nothing to do with quantitative control of sediment but is of significance to realise the establishment of a stable channel. The longitudinal design profile is shown in Figure 6.6.1.

In the sense of desirable application of bio-engineering, spur dikes made of gabions should be composed of "vegetated gabions" through the use of sprout-capable fanciness and simultaneously should be well managed and maintained even after implementation.

(3) Recommended additional countermeasures

In addition to the above-mentioned countermeasures, it is recommended to take some additional countermeasures into consideration. Desirably additional works to ensure the safety of the Mahadevbesi Bridge can be enumerated as follows:

i) What is of most importance among those works is to dismantle the old piers and the approach embankment on the right bank to keep flood discharge capacity.

ii) To protect the dismantled portion of the right bank it is needed to arrange a proper revetment as well as its foot-protection works.

iii) In order to protect the abutments and piers of the bridge from unexpected localised scouring, it is recommended to arrange the river bed covering works with stone-pitching and others.

iv) Some parcels of the land adjacent to the right bank abutment are recommended to form a small riverside park by way of combining with vegetated spur dikes in the river channel.

v) In terms of management and maintenance of the groundsills, the spur dikes and vegetation, it is necessary to build a management road which may be set out on the high-water channel along the river course from the bridge up to the groundsill upstream. Quarry of stones and gravel in this segment should be prohibited.

6.7 Priority Plan

6.7.1 Criteria for Selection of Priority Schemes

The criteria for the selection of priority schemes may consist of the following components.

a) Objective scale of natural disaster

As for the objective scale of such natural disasters as coming from floodwater, debris/sediment flows and landslides, it is actually convenient to express it in the return period in hydrology. The scale of heavy rainfall or flood discharge obviously exceeds the probability of the return period of 200-year or 300-year. Whereas, it may be reasonable to set it less than 30-year, because it is urgent for us to determine some priority schemes.

b) Scale of countermeasures envisaged

As for the countermeasures necessary for the protection of the bridge, it cannot be possible to formulate a large-scale flood/sediment control project since some of priority projects should be selected to materialise in the near future. Financial circumstances will also be a serious constraint.

c) Effectiveness of countermeasure structures

Effectiveness of countermeasures, particularly mechanical countermeasures for the present, should be deliberately examined. According to the facts experienced in the field of sediment control engineering, the effectiveness of sediment control structures located upstream far from the objectives of protection will not rapidly spread downstream. Usually it takes a long time, scores of years sometimes. Hence, the countermeasure structures should be located in the river channel near the bridge.

d) Accessibility for implementation

Accessibility to the sites of the structures is also of significance so long as the implementation matters are concerned. Poor accessibility without roads will naturally hinder rapid and economic implementation.

e) Managerial matters

The management and maintenance are, needless to say, important components upon selecting priority schemes. Schemes to be implemented prior to others should be located in the areas easy to manage.

6.7.2 Selected Priority Schemes

Judging from the above-mentioned criteria for the selection, priority schemes are to be confined to those works which stabilise the river channel in the lowest segment of the Agra Khola, that is, those structures shown in (2) countermeasures to stabilise the channel, in section 6.6.3.

Thus, the selected schemes include neither check dams nor hillside works, but the groundsill No.1 which will be arranged immediately downstream of a sharp bent of the river channel is expected to play the role of detaining and controlling the sediment from upstream for the time being. Hillside works in the upper basins are too far from the fact we face, since the devastated basins extend wide and the effect of those works cannot be expected in a short period of time.

Groundsill No.2 and spur dikes can lead to the establishment of a stabilised channel, both vertically and laterally settled, towards the site of the Mahadevbesi Bridge.

The locations of groundsills No.1 and No.2 are shown in Figure 6.7.1, and the preliminary designs of the structures are shown in Figures 6.7.2 and 6.7.3 respectively.

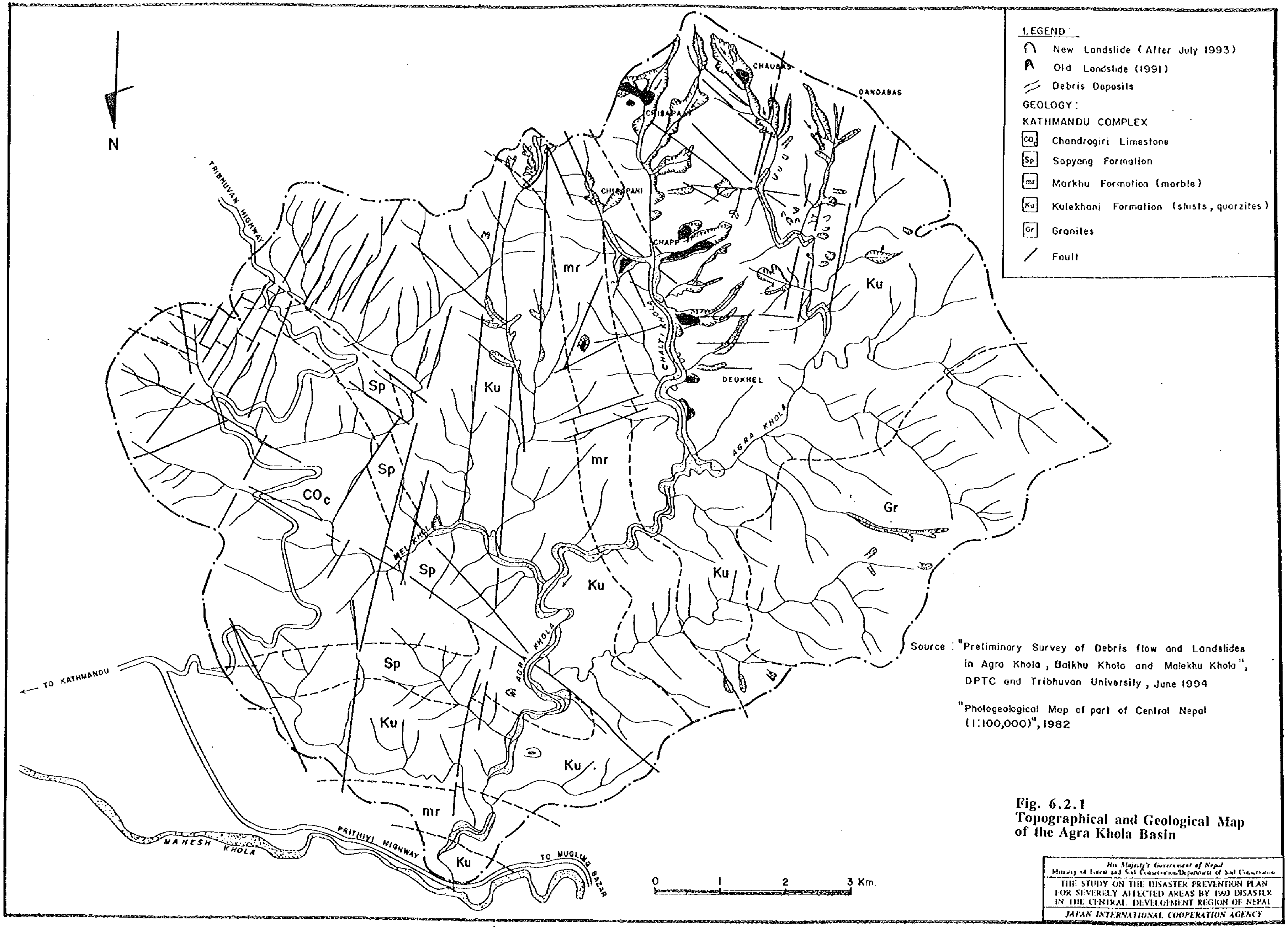

Fig. 6.2.1
Topographical and Geological Map of the Agra Khola Basin

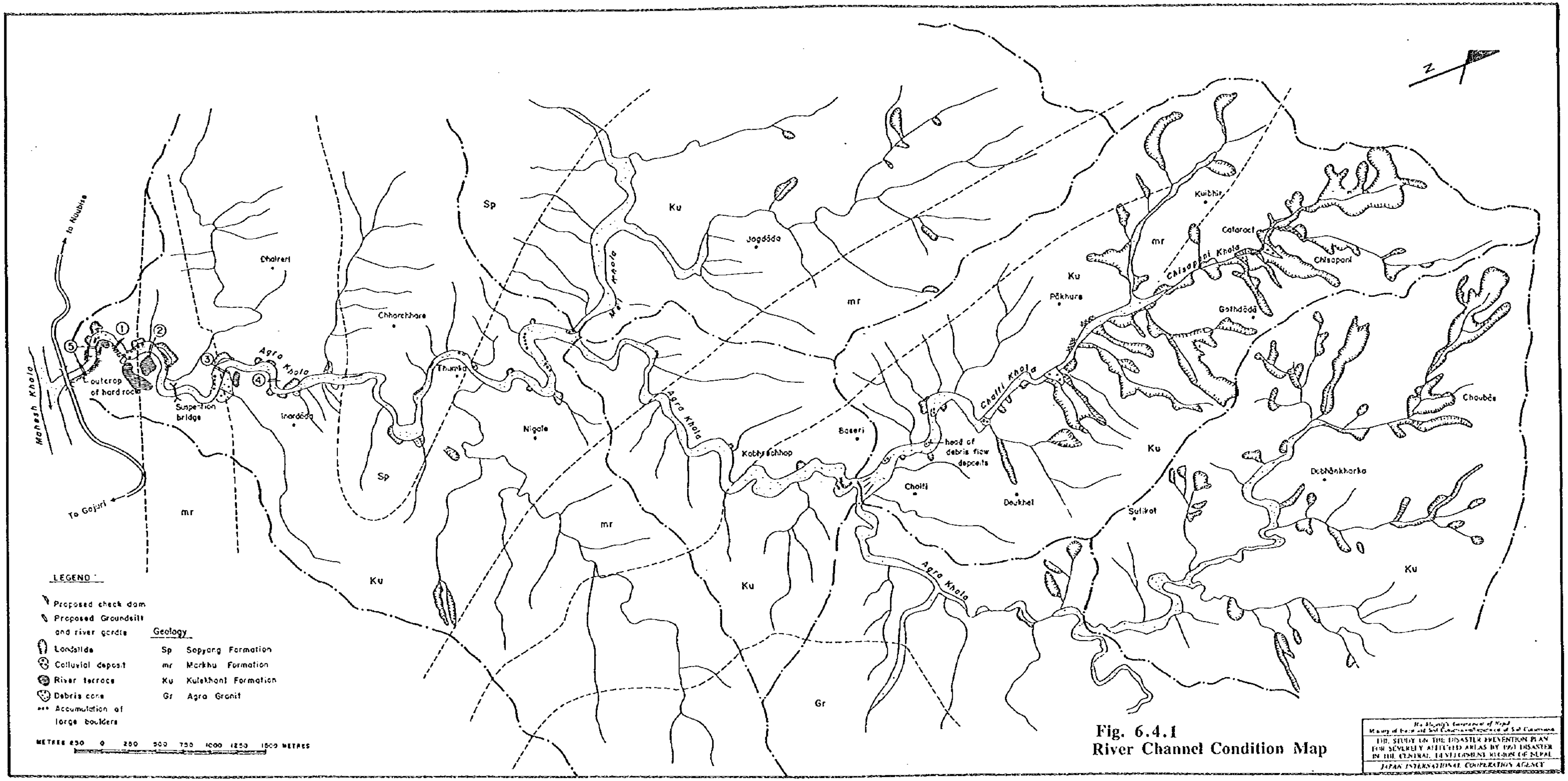

Fig. 6.4.1
River Channel Condition Map

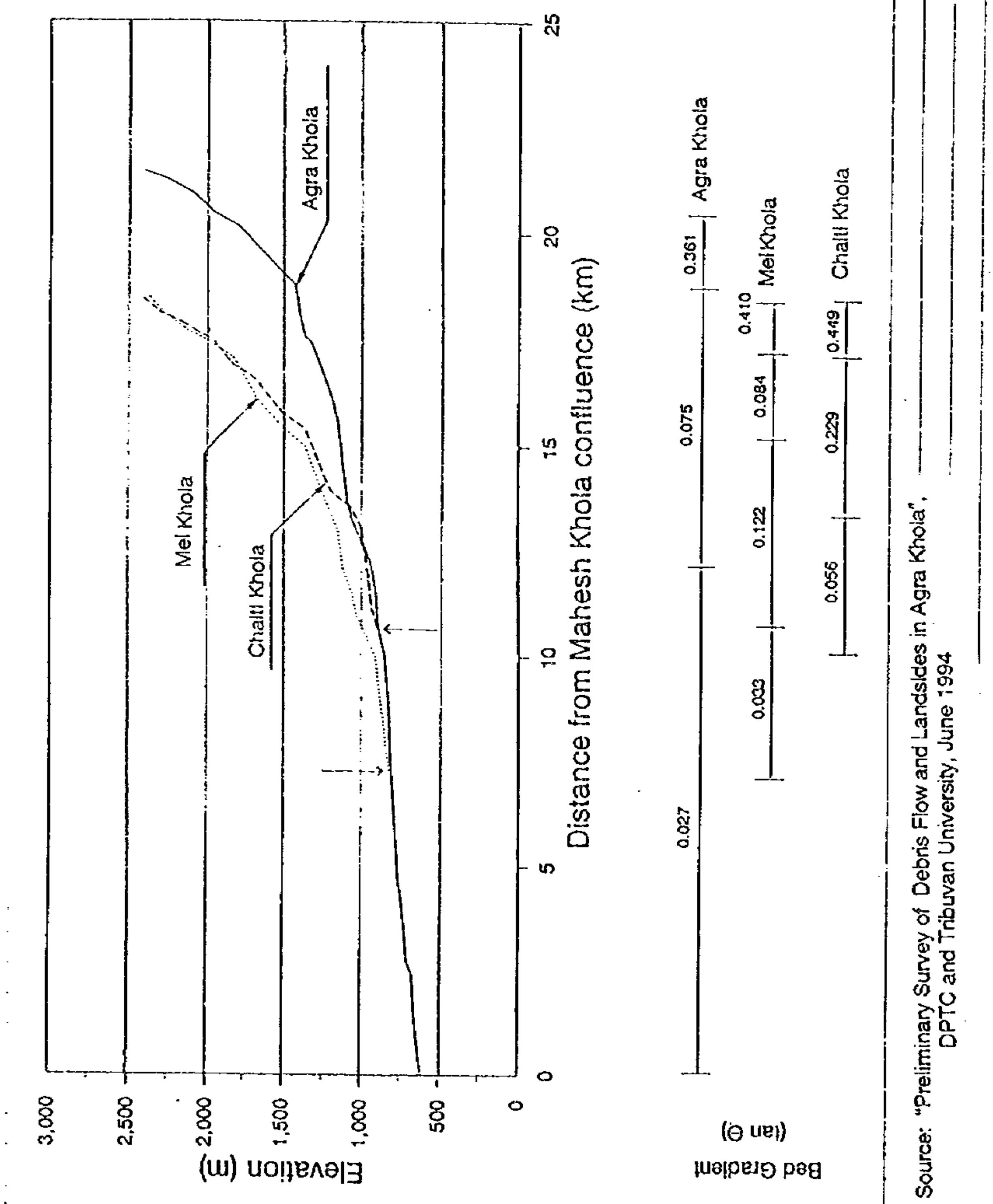

Fig. 6.4.2
Longitudinal Profiles of the Agra Khola, Mel Khola and the Chalti Khola

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

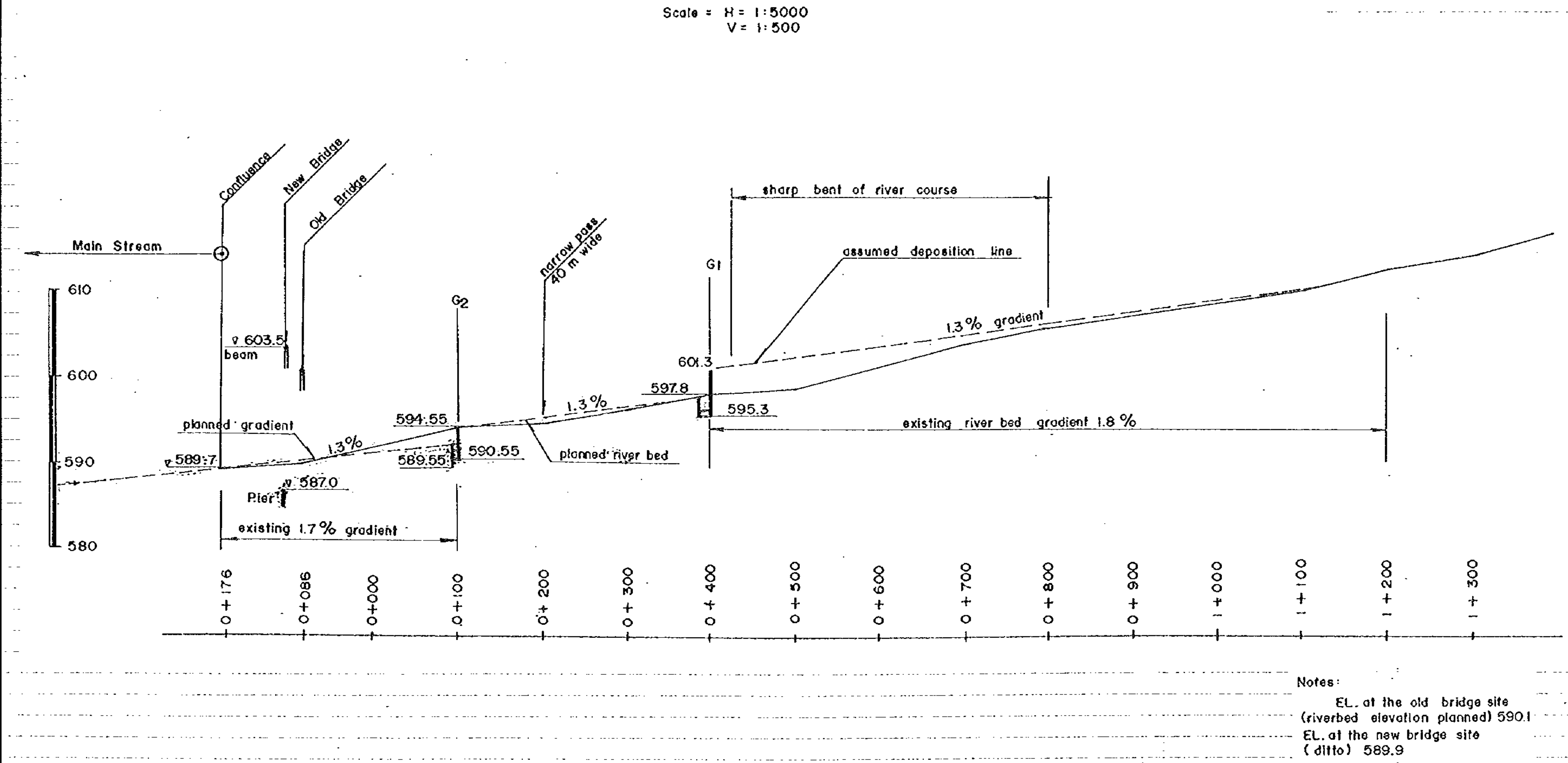

Fig. 6.6.1
Longitudinal Channel Profile on Upstream of Mahadevbesi Bridge

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
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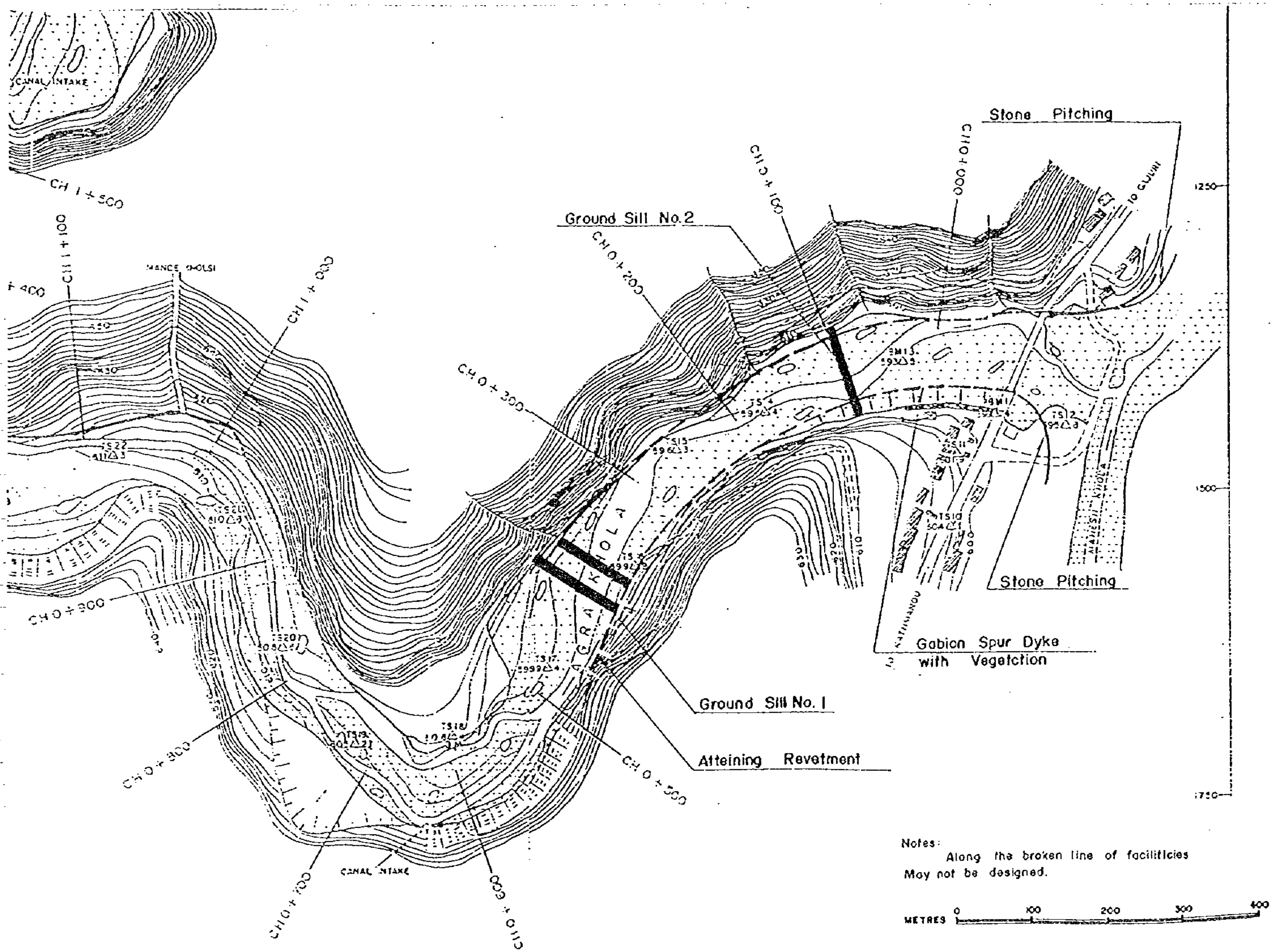

Fig. 6.7.1
Proposed Structure to Channel Stabilisation at Mahadevbesi Bridge

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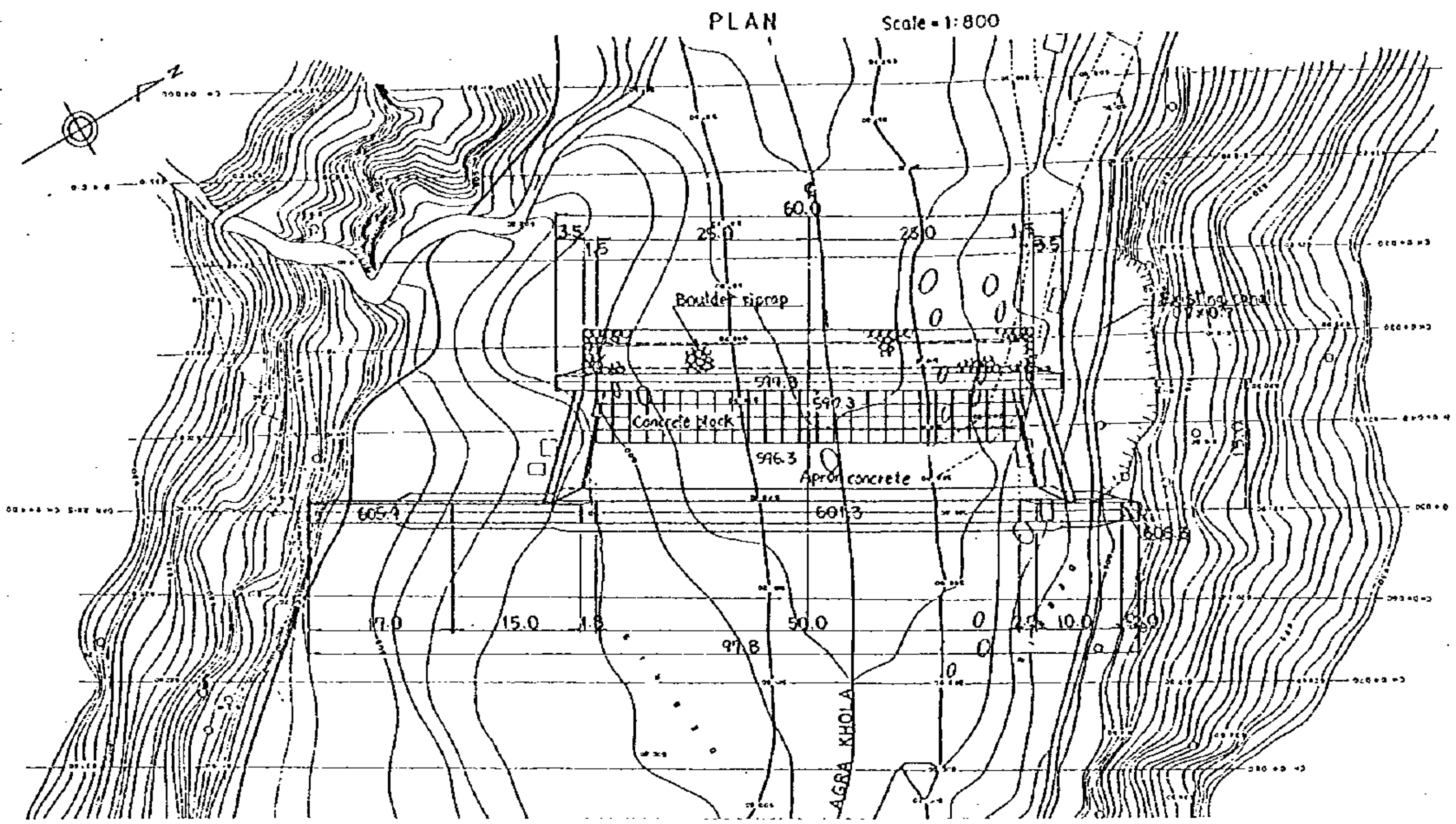

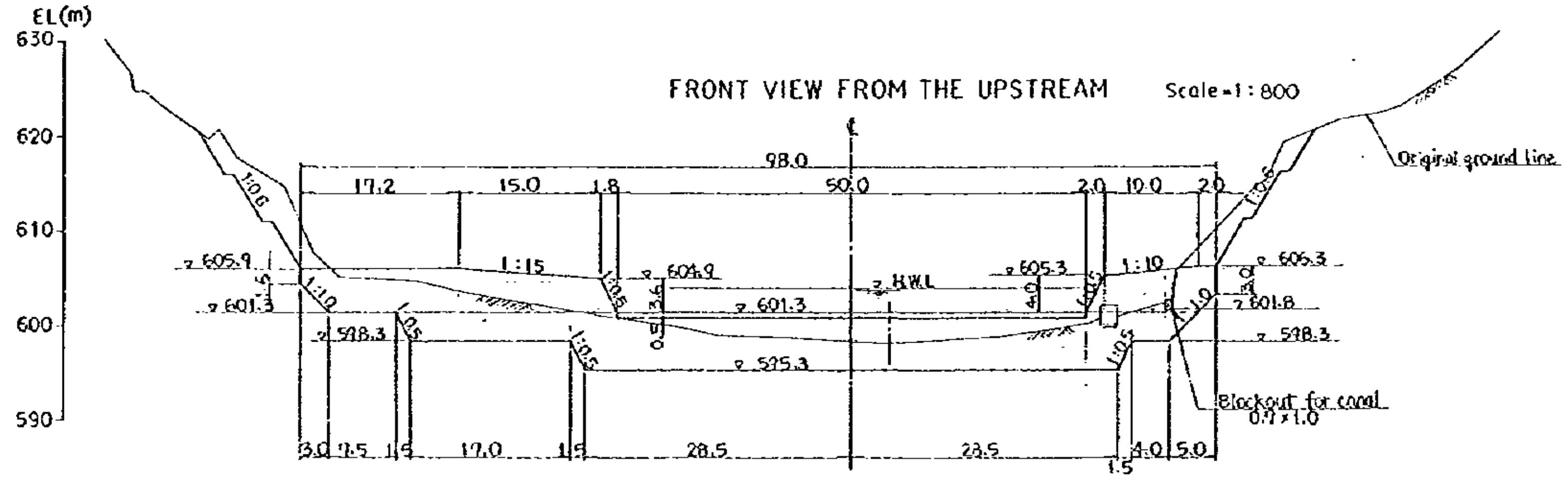

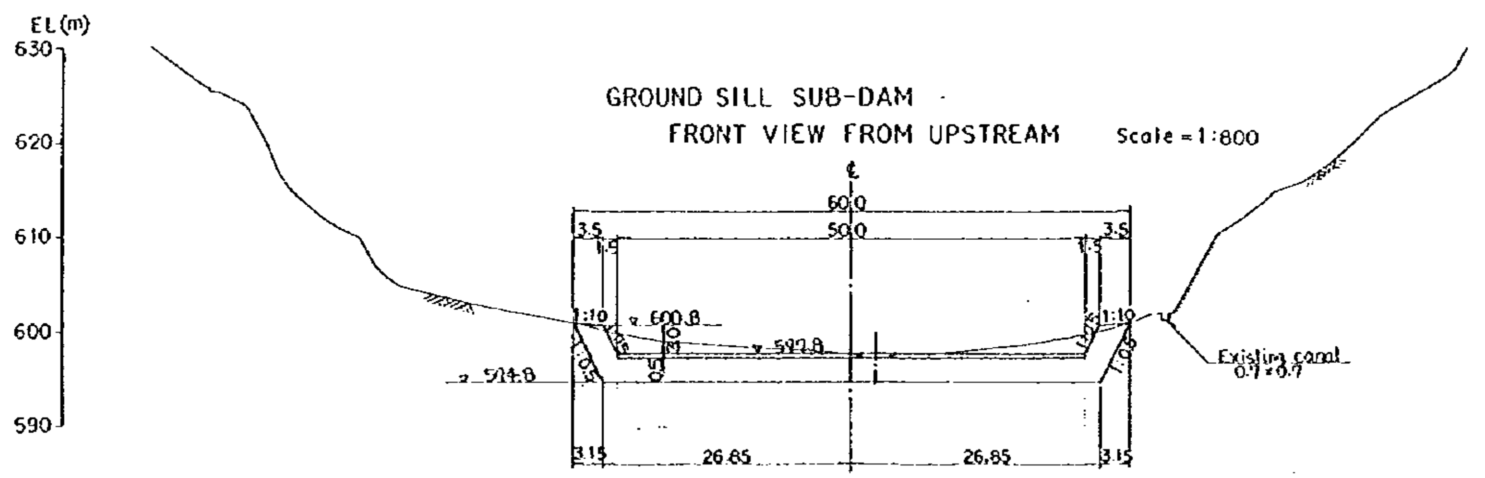

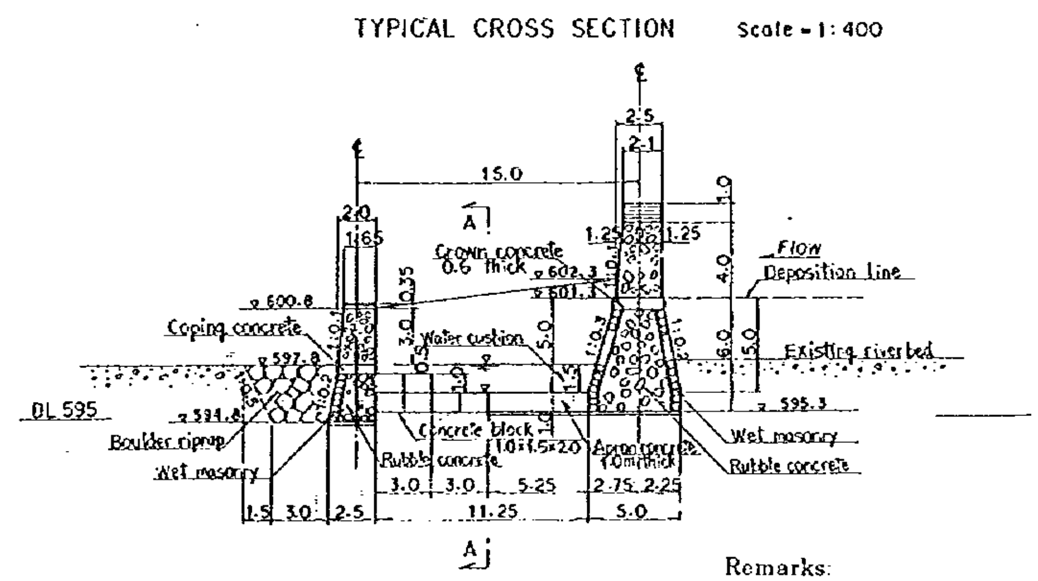

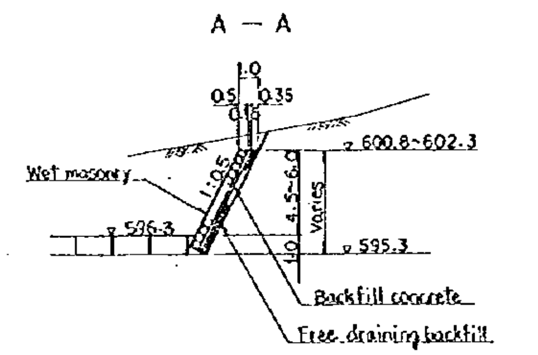

Remarks:
This work is to be carried out with ICB basis.

Fig. 6.7.2
Groundsill No.1 in Mahadevbesi IDPP

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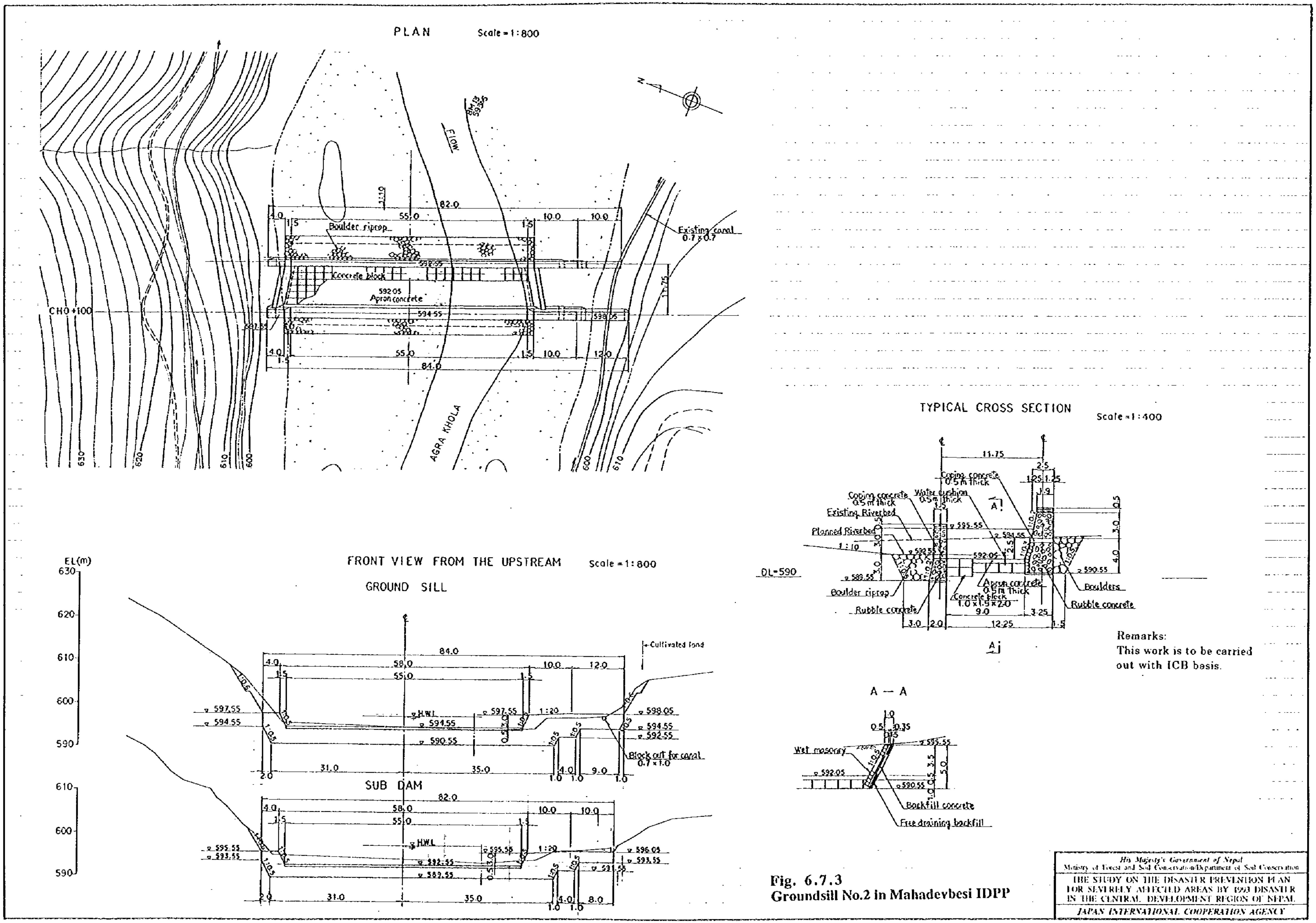

Remarks:
This work is to be carried out with ICB basis.

Fig. 6.7.3
Groundsill No.2 in Mahadevbesi IDPP

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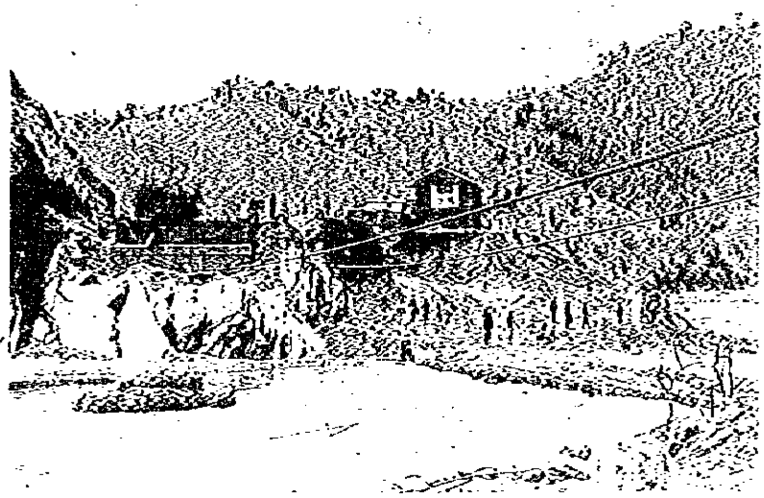
Mahadevbesi Bridge

Three out of four spans were washed away. Erosion on the other side of Mahesh Khola implies the severity of debris flow of Agra River.

Prithivi Highway was seriously damaged between Naubise and Mugling (L = 84 km): Three major bridges of Mahadevbesi, Belkhu and Malekhu were destroyed; Road was heavily eroded by flood of Trishuli river at many locations; Major landslides took place to block the traffic in Jogimara.



Temporary cable crossing at Mahadevbesi

Photo 6.1 Mahadevbesi Bridge (1)

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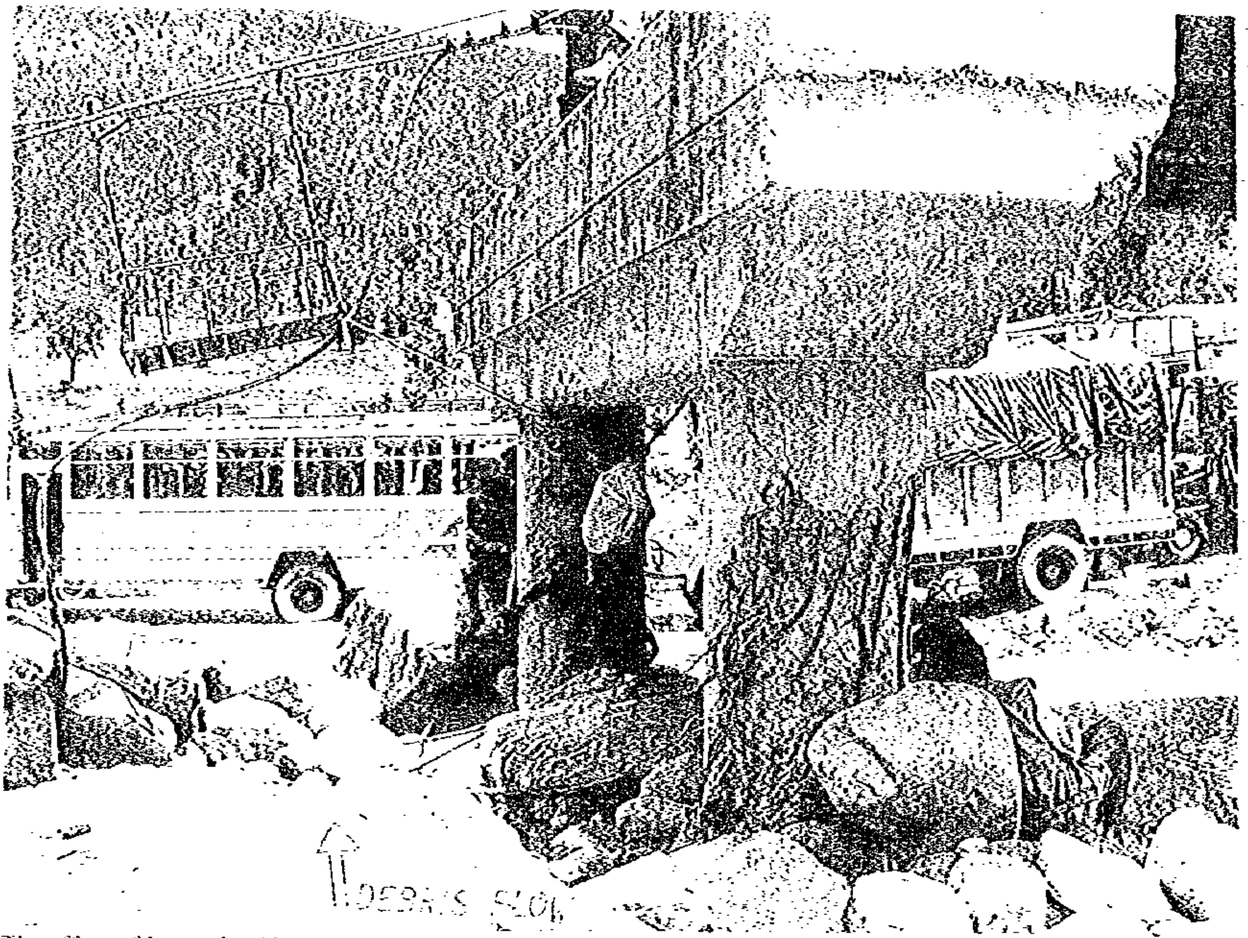

The effect of large sized boulders to twin cylindrical pier of Mahadevbesi Bridge

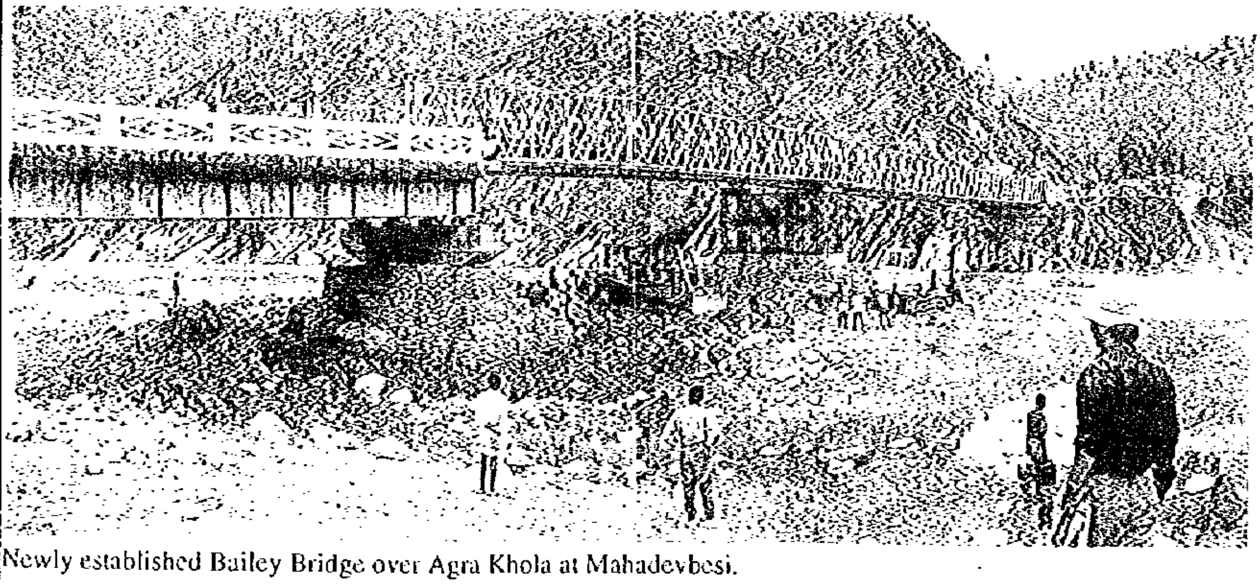
Newly established Bailey Bridge over Agra Khola at Mahadevbesi.

Photo 6.2
Mahadevbesi Bridge (2)

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CHAPTER 7

INFRASTRUCTURE DISASTER PREVENTION PLAN FOR KULEKHANI RESERVOIR

7. INFRASTRUCTURE DISASTER PREVENTION PLAN FOR KULEKHANI RESERVOIR

7.1 General

The Kulekhani hydropower system is located in Makwanpur district, Central Region of Nepal, about 30 km south-west of Kathmandu City as shown in Figure 7.1.1.

The Project consists 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 hight rockfill dam. The watershed area of the Kulekhani reservoir is 126 km^2.

Serious flood damage was observed after the commencement of operation of the Kulekhani hydropower stations in 1984 and 1986. In September 1984, during the construction period of the No.2 power station, a heavy storm occurred for 3 days recording 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 damage 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 the 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 occurred in July 1993 and caused the following severe damage:

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

Due to the above damage, the operation of both the No.1 and No.2 power stations was forced to stop for 5 months from July to December 1993. Urgent rehabilitation measures were conducted as additional works by the NEA under the Kulekhani Disaster Prevention Project.

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

1) Construction of a sloping intake structure for the No.1 power station to avoid clogging of the reservoir intake by sediment accumulation,
2) Construction of an embedded intake and a regulating headpond for the No.2 power station to escape further debris flow of the Mandu Khola,

3) Construction of check dams on the Palung and Darkot Khola to mitigate sediment inflow into the Kulekhani reservoir.

The construction stage commenced in November 1996, and it will be completed in early 1998.

7.2 The Basin Characteristics

7.2.1 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 the Palung Khola which flows from the west to the east through the centre of the watershed, and many tributaries which flow from the north, the south, and the west and merge with the Palung Khola. The elevation varies from 1,534 m at the dam crest to 2,621 m at the peak of the Simbanjang of Mahabarat Range which is located on the southern boundary of the watershed.

Figure 7.2.1 shows the slope map of the watershed, which is extracted from the "Master Plan Study on Sediment Control for Kulekhani Watershed", November 1994, NEA (hereinafter referred to as "the NEA master plan"). The map was prepared based on the topographic map on 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./ cm^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 wide flat lands extend throughout the middle part of the watershed mainly around Palung, Tistung, and Chitlang. These areas are well cultivated and densely populated. The gradients of the tributaries become gentle in the flat valley and they flow into the Kulekhani Reservoir. Such topographic characteristics may contribute to regulate the delivery of sediment discharge to the reservoir.

7.2.2 Geology

Figure 7.2.2 shows the geological map of the Kulekhani watershed. The geological structure of the Kulekhani watershed is divided into Phulchauki Group and Bhimphedi Group. Phulchauki Group consists of Kulekhani Formation, 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-grained biotic schist and micacenous quartzites. Rock slides observed around Phedigaon are 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 an 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.

The 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 of the Palung mainstream has a steep gradient of mountain slope. During 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 the 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 from piedmont to ridge. Debris flows occurred in the Phedigaon area during the July 1993 disaster. Apparent changes of landforms have not been recognised in other parts of the schist zone. Considering the deep weathering layer in the schist zone, it is assumed that many of fine materials have been transported downstream and deposited in the reservoir.

7.2.3 Land use

The present land use condition is shown in Figure 7.2.3 and summarised below:

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 occupies about 44% of the entire watershed, while the sloping agricultural land 34%. The above two categories are the major land use pattern (in total they account for 78% of the entire watershed).

According to the land use map, the landslide area is 0.2% of the watershed according to an estimate 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 corresponds to 5.4% of the entire watershed. Major landslides are observed in the southern part of the watershed which is covered with forest in the granite mountain.

7.3 Assessment of Damage due to the 1993 Disaster

On July 19 and 20, 1993, an unprecedented storm and flood hit Nepal including the Kulekhani Project area. Rainfall of 540 mm per day was observed on July 19 at Tistung, 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 records of the reservoir water levels. 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 issue of sedimentation in the Kulekhani reservoir was at first revealed by the Department of Soil Conservation (DOSC) based on the results of echo-sounding survey in the reservoir. The DOSC reported that a volume of 7.71 million m^3 of sediment 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 in more or less than 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 taken immediately.

The Nepal Electricity Authority (NEA) carried out the 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. The sediment yield by respective tributary was estimated as shown in Figure 7.3.1, and the location of slope failures in the watershed is shown in Figure 7.3.2.

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

Figure 7.3.3 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 at El.1,471 m was only 11.7 m.

7.4 Sedimentation Trend in the Kulekhani Reservoir

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

Figure 7.3.3 also shows the trend of sedimentation within the reservoir. The sediment profile in the reservoir is estimated based on the results of the echo-sounding surveys carried out by the DOSC in March and December 1993, and by the DOSC and NEA jointly in October 1994 and November 1995. The reservoir profile in 1971 was assumed from the reservoir plan on a 1:10,000 scale.

The location of survey lines by echo-sounder is shown in Figure 7.4.1. There are 35 survey lines within the reservoir including major tributaries such as the Darkot, Chitlang and Bisingkhel Khola. Table 7.4.1 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 Sedimentation within the 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 NEA.

Based on the above estimated figures, 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 that the estimated accumulated sediment volume from 1981 to March 1993 covering 12 monsoon seasons was 10.3 million m^3, which is equivalent to 0.858 million m^3/year of sediment deposition. In other words, the sediment denundation rate was 6.89 mm / km^2 / year without any severe event like the 1993 rainstorm.

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

7.5 Approaches to Overall Plan Formulation

7.5.1 Current Major Issues

As described in Chapter 5 of Annex-1, there are three major issues in the Kulekhani watershed as shown below:

1) Sustainable operation of the Kulekhani hydropower plants is not guaranteed due to the marginal storage volume below the intake structures of the power facilities in the Kulekhani reservoir.
2) The regulating capacity of the Kulekhani reservoir is rapidly decreasing and the power generation capacity to meet the peak load in the dry season

cannot be expected after 2010, taking into account the observed sediment deposition in the reservoir.

3) The basinwide watershed management activities are not supported by the people in the watershed due to less impact of the activities on the rural development.

The first issue is rather serious, and it will require urgent countermeasures to continue the power generation activities of both the Kulekhani No.1 and No.2 power stations. The remaining storage below the intake is only about 3 million m^3, which is much smaller than the sediment volume deposited by the July 1993 disaster. It means that the dead storage will be filled at once with sediment by the next disaster, and no more power generation activities will be possible after that.

The second issue is not an urgent one because it would happen around 15 years later. The minimum required storage to guarantee 4-hour peaking operation through out the year is estimated at 48 million m^3 while the current effective storage is about 63 million m^3. However, the economic loss caused by the decrease of effective storage due to accumulation of sedimentation will be quite big. Sufficiently feasible countermeasures should be found out and immediate actions shall be taken accordingly.

The third issue is rather complicated. The people in the watershed as well as electricity users in the nation will not easily understand the importance of the watershed management activities, therefore the effect of such activities is generally invisible and unquantified. Under such conditions, it would be difficult to allocate sufficient budget to execute the watershed management activities. To encourage the watershed management activities, therefore, it would be required to establish a dense monitoring system to quantify the effect of watershed management activities.

7.5.2 Problem Analysis

Problem analysis is carried out according to the theory of Project Cycle Management Approach (PCM) in the Study.

PCM approach is broadly applied for project planning, implementation, and evaluation. In the latter half of the 1960s, the United States Agency for International Development (USAID) first introduced the theory of PCM, which is the logical framework for project planning, based on the objectives, output, activities and input. By applying the PCM approach the plan formulation for the project can be logically explained.

In the 1970s, many international agencies, such as the UNDP, UNICEF, GTZ, NORAD, JICA and so on, adopted the PCM approach for project planning.

Figure 7.5.1 shows the problem tree of the Kulekhani watershed. Two core problems have been defined by the Study Team, and the indirect causes and immediate effects of have been assessed. The direct causes of the core problems are indicated in the lower part of the figure and the immediate effects in the upper part.

Based on the above major issues, the core problems in the Kulekhani watershed are identified as follows:

1) Decrease of life of the Kulekhani hydropower plants,
2) People in the watershed give priority to basin development rather than basin conservation.

By repeating the above assessment, the relation between the causes and the effects of the problems are developed as shown in Figure 7.5.1.

According to the developed problem trees, there are three major flows of problems, and the three root causes of the problem flows are the following:

1) Marginal capacity of dead storage of the Kulekhani reservoir,
2) No direct benefit by providing sediment control measures, and
3) No clear policy in watershed management activities.

As shown in Figure 7.5.1, various problems are developed from the root causes of problems, and finally come to the core problems. The immediate effects of the core problems would be "Less trustfulness of the electricity users and the people in the watershed toward the Government" if no countermeasures to solve the core problems are taken timely.

7.5.3 Objectives Analysis

Objectives of the overall disaster prevention plan for the Kulekhani reservoir must be to solve the two core problems mentioned above. And it would be required to solve the root causes to create the core problems as shown in Figure 7.5.1.

The objective tree is developed according to the PCM procedures, and it is prepared based on the problem tree as shown in Figure 7.5.2. According to the theory, the objective tree is provided to assess the effects when the problems included in the problem tree are solved. Then, the problems will be replaced with the affirmative sentences in each column in the problem tree. After this process, the relationship between "immediate cause" and "immediate effect" indicated in the objective tree will be changed to "mean - objective" relations.

The means are entered in the lower part of the tree in Figure 7.5.2, and the objectives are in the upper part at the ends of arrows. The two main objectives of the project are defined referring to the two core problems, as summarised below:

1) To sustain the life of the Kulekhani hydropower plants,
2) To carry out watershed management with the people's participation.

When the project is successfully implemented and satisfies the above two core objectives, it is expected that it also satisfies the demands of both the electricity users and the people in the watershed.

7.5.4 Approaches to the Overall Disaster Prevention Plan

Based on the objectives analysis mentioned in sub-section 7.5.3, three major approaches are found as shown in Figure 7.5.3. These are:

1) Sloping intake approach
   The main objective of constructing a sloping intake is to prevent its clogging due to sedimentation. Since the location of the intake in the reservoir is at El.1471 m and the sediment level has reached El. 1460 m,

preventive measures against sediment inflow into the reservoir are essentially required. The countermeasures which have been proposed by the NEA and are currently under implementation wile financial support from the OECF, are to construct a side wall along the slope over the existing intake structures, and to install stoplogs on the front side according to the progress of sediment deposition. These structures, will make it possible to raise the intake water level, then sediment is prevented from entering the waterway of the hydropower structures.

2) Sand resources development approach

The sand resources development approach is quite simple: To excavate the sand from the effective storage of the reservoir, and to transport and sell the excavated sand in Kathmandu market. Some excavation equipment and improvement of transportation route would be required to realise the idea. The main objective of the sand resources development approach is to sustain the function of the Kulekhani reservoir of which main role is to guarantee peak power operation in the dry season. For this purpose, an effective storage of at least 48 million m^3 will be required. On the other hand, the existing effective storage is about 63 million m^3. In the 1993 disaster, it is reported that the total erosion volume in the basin was about 22 million m^3, while the sediment deposit volume in the reservoir was 6.8 million m^3. Considering the remarkable amount of the remaining sediment along the river course as well as on the slope, sediment inflow into the reservoir will continue, and the accumulation will affect the function of the reservoir gradually. Taking earlier countermeasures must be a more economical solution.

3) Integrated watershed management approach

Integrated watershed management is a very complicated approach and it has various objectives which are difficult to be defined clearly. In the case of the Kulekhani watershed, however, clear objectives can be identified; they are to mitigate sediment yield in the watershed, and to encourage the local people to participate in the watershed management activities. In this aspect, the DOSC has already carried out integrated watershed management activities with the maximum effort to induce the people's participation. To satisfy both objectives, the integrated watershed management approach will include the following activities:

a) Assessment of needs of the community in the watershed,
b) Hazard assessment and mapping, and multipurpose gully control works,
c) Agricultural research and cash crop production,
d) Rural infrastructures such as road, irrigation, school, health post, water supply, communications and so on,
e) Dissemination of community forestry program,
f) Demonstration farm for horticulture, herbs and valuable trees with improved contour farming,
g) Monitoring system for the activities of local people, and the effects of the schemes, and
h) Benefit allocation system from electricity users to the local people in the watershed through the watershed management activities.

As indicated in Figure 7.5.3, the above three approaches are inevitably required to satisfy the two core objectives. To sustain the life of the Kulekhani hydropower plants, it is required to maintain the power intake and effective storage, and to mitigate sediment yield in the watershed. On the other hand, mitigation of sediment yield would not be succesful unless the people's needs in the watershed are taken into account. To mitigate sediment yield, it is required to provide gully control works, to carry out appropriate forest management as well as to apply proper contour farming technics. However, it is required that people become interested in participation in watershed management activities to promote such sediment mitigation activities. To induce people's participation, rural development aspects should be taken into account in the integrated watershed management approach.

Accordingly, to achieve the core objectives mentioned above, three different approaches would be inevitably required. The details of each respective approach are explained in sub-sections 6.2 through 6.4 in Annex-2.

7.6 Priority IDPP for the Kulekhani Reservoir

Among the three different approaches, the priority schemes under the IDPP for the Kulekhani reservoir are assessed. Prior to the comparative studies, the criteria for selecting the priority schemes are proposed as follows:

(1) Cost affordability,
(2) Effect on the urgent matter of clogging of the power intake,
(3) Effect on the mitigation of sediment deposition in the reservoir,
(4) Effect on the mitigation of sediment yield in the basin,
(5) Impact on the local people,
(6) Economic viability,
(7) Financial viability,
(8) Environmental impact.

The above selected eight (8) criteria are assessed for the respective approach by the Study Team and the results are as follows:

No.	Criteria	Sloping Intake Approach	Sand Resources Development Approach	Integrated Watershed Management Approach
1	Cost affordability	C	B	A
2	Effect on the urgent matter of clogging of intake	A	C	C
3	Effect on the mitigation of sediment deposition in the reservoir	C	A	B
4	Effect on the mitigation of sediment yield in the basin	C	C	A
5	Impact on the local people	C	B	A
6	Economic viability	A	A	B
7	Financial viability	B	A	C
8	Environmental impact	B	C	A
9	Overall Evaluation	14	16	18

Note : A : high or positive, B:medium or none, C: low or negative.

If the overall evaluation is made by the simple procedures of scoring i.e. giving 3 points to A, 2 points to B and 1 point to C, the integrated watershed management approach would be the most effective measure for the various issues in the Kulekhani reservoir. This seems to be the best solution from the long term viewpoint, and the Study Team recommend that the DOSC the continue of the existing watershed management activities for the Kulekhani watershed through the CDPP approach. However, it would not be effective to cope with the urgent problem of intake clogging (criteria 2), and also has less financial viability (criteria 7). Particularly, "criteria 2" is the most urgent issues concerning the Kekhani reservoir, and some other countermeasures must be provided immediately.

Taking into consideration the above urgency, the NEA has decided to implement the sloping intake approach, even it is costly and has no impact on the local people.

Although both the integrated watershed management and sloping intake approaches have been already been implemented, no actions have veen taken for realising the sand resources development approach. This approach would have a high effect of sustaining the peak operation of the Kulekhani power plants, which is the most important role of the Kulekhani hydropower project. In addition, it is expected to be highly viable from the economic as well as financial viewpoints. Accordingly, it is recommended to go forward to realise the sand resources development approach.

Finally, the Study Team would like to recommend to select the sand resources development approach as the priority scheme for the IDPP taking into consideration the current progress of the other two approaches. The general layout of the sand resources development approach is shown in Figure 7.6.1.

Table 7.4.1 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

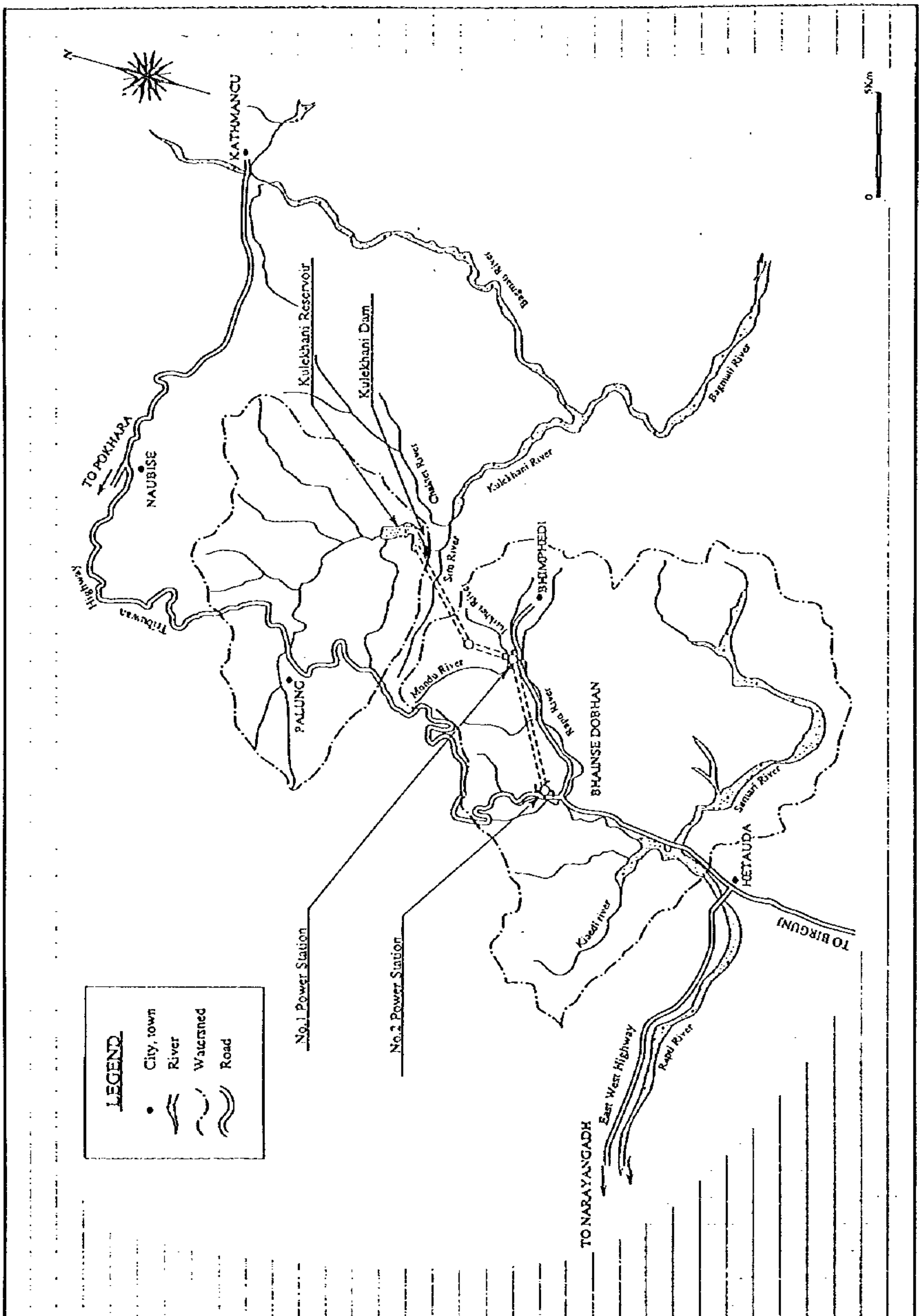

Fig. 7.1.1
Location Map of Kulekhani Hydropower Project

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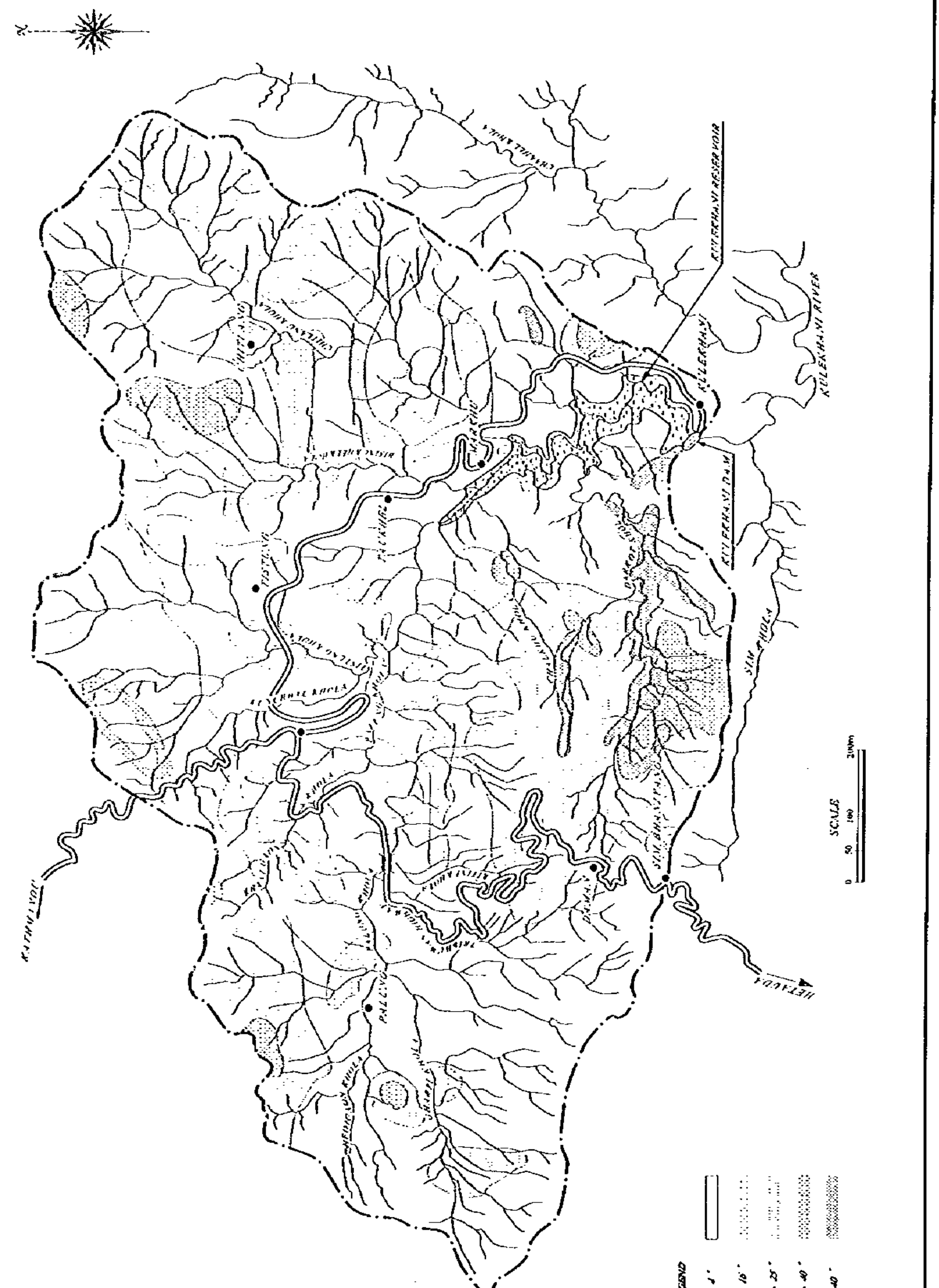

Fig. 7.2.1
Slope Map of the Kulekhani Watershed

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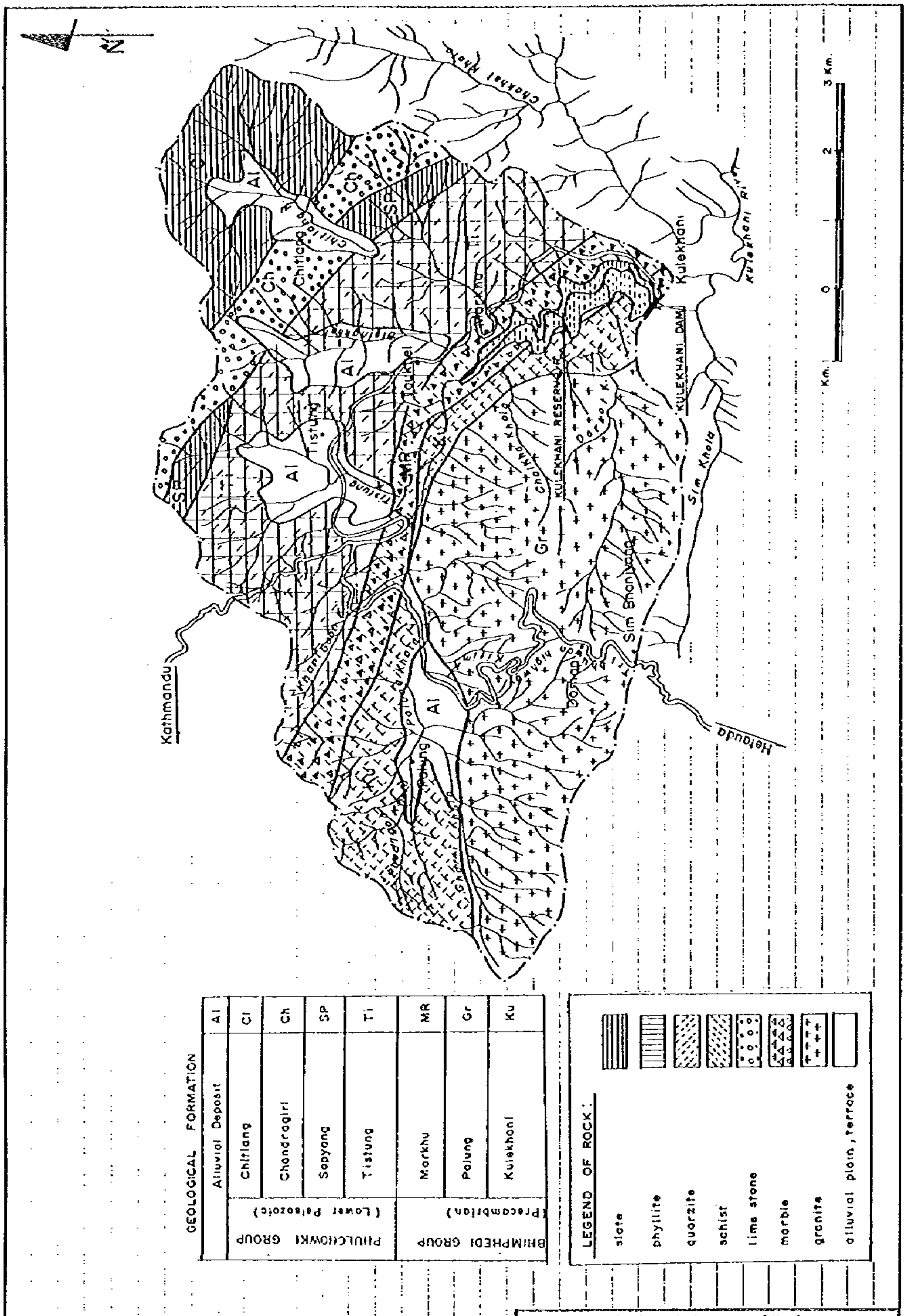

Fig. 7.2.2
Geological Map of Kulekhani Watershed

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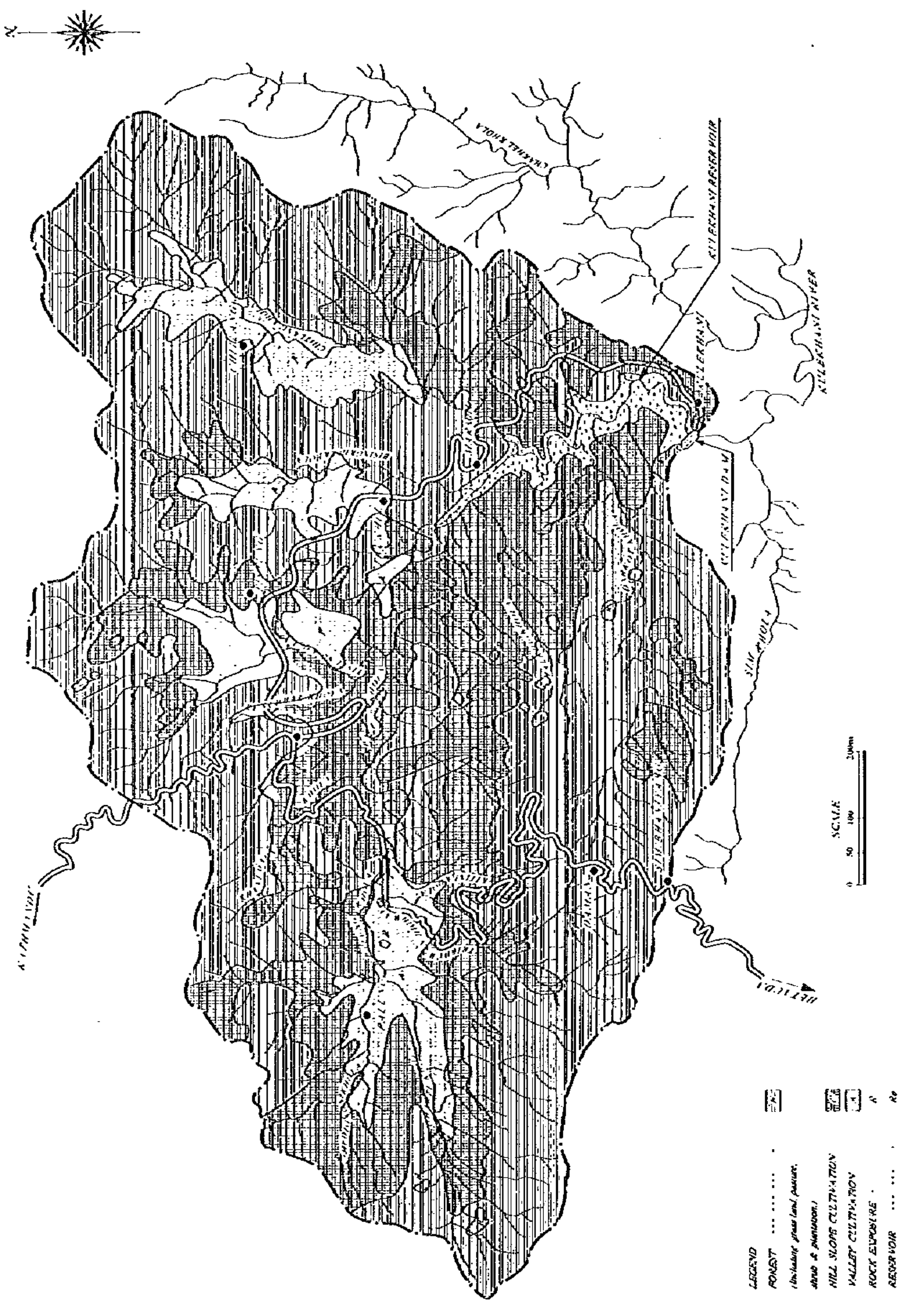

Fig. 7.2.3
Updated Land Use Map

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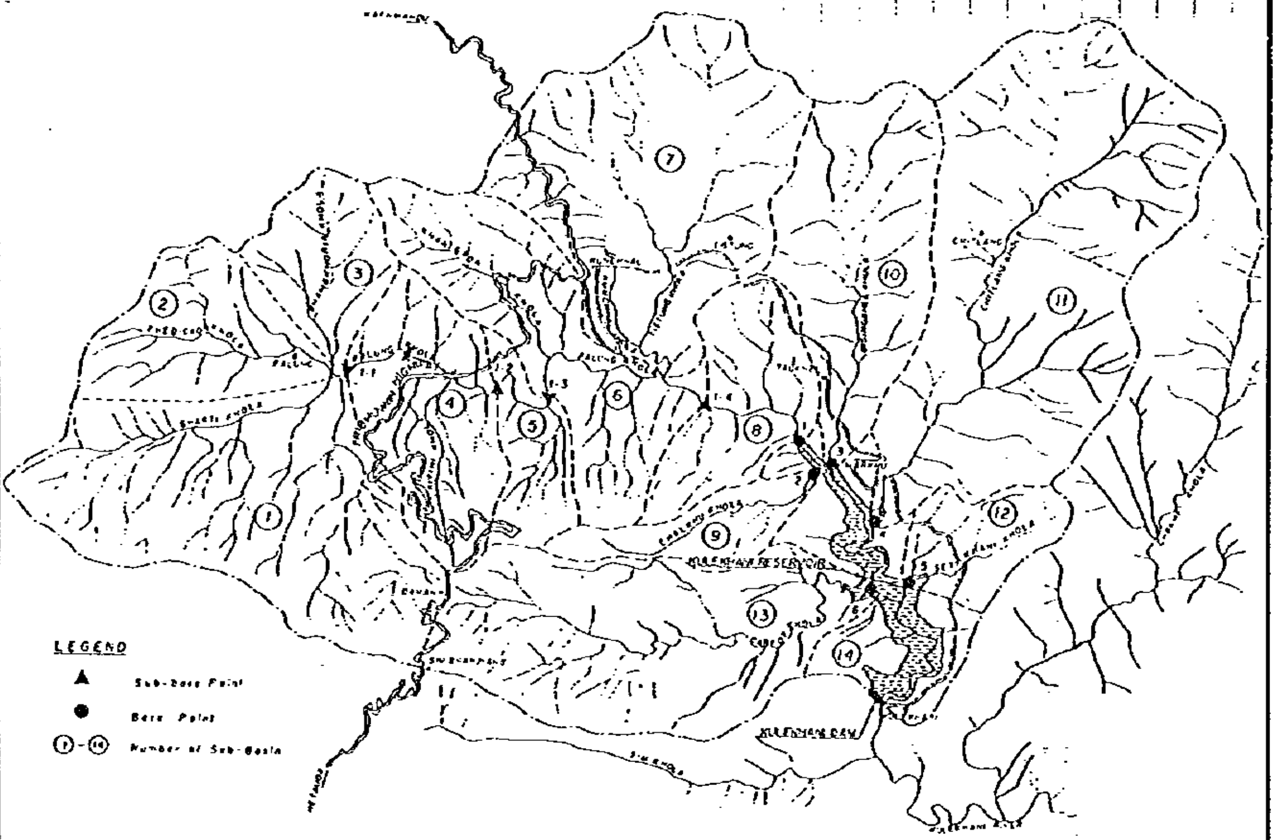

Sub Basin	AREA Catchment Area (km2)	AREA Accumulated Area (km2)	1993 Collapse Failures (1000m3)	1993 River bank Erosion (1000m3)	1993 Riverbed Erosion (1000m3)	1993 Sediment Erosion (1000m3)
1	16.4	-	4,191.8	26.0	497.3	4,715.1
2	5.6	-	1,020.7	58.0	387.5	1,466.2
3	3.9	-	382.0	6.0	36.4	424.4
4	7.0	33.0	1,098.0	0.0	438.3	1,536.2
5	3.0	36.0	757.6	0.0	29.6	787.2
6	9.0	61.0	2,041.2	61.2	239.0	2,341.4
7	16.0	-	1,293.6	43.5	18.3	1,355.3
8	5.0	66.0	624.6	12.0	72.9	709.5
9	2.4	-	596.2	0.0	239.0	835.2
10	40.5	-	756.0	33.2	48.3	837.5
11	23.0	-	1,656.0	82.1	91.1	1,829.3
12	3.1	-	223.2	16.8	9.5	249.5
13	14.0	-	3,477.6	24.0	1,272.5	4,774.1
14	7.0	-	336.0	0.0	87.5	423.5
Total	126.0	126.0	18,454.4	362.8	3,467.1	22,284.3

List of Sub-basin of Kulekhani Watershed

Sub-basin No.	Sub-basin Name
No.1	Garti Khola
No.2	Phedigaon Khola
No.3	Bangkoria Khola
No.4	Kitini Khola
No.5	Residual basin of the Mainstream(1)
No.6	Khanigaon Khola
No.7	Tistung Khola
No.8	Residual basin of the Mainstream(2)
No.9	Chalkhu Khola
No.10	Bisingkhel Khola
No.11	Chitlang Khola
No.12	Setikhani Khola
No.13	Darkot Khola
No.14	Residual basin of the Reservoir

Source Master Plan Study on Sediment Control for Kulekhani Watershed,Nov.1994,Nippon Koei

Fig. 7.3.1
Result of Sediment Yield Analysis for Kulekhani Watershed

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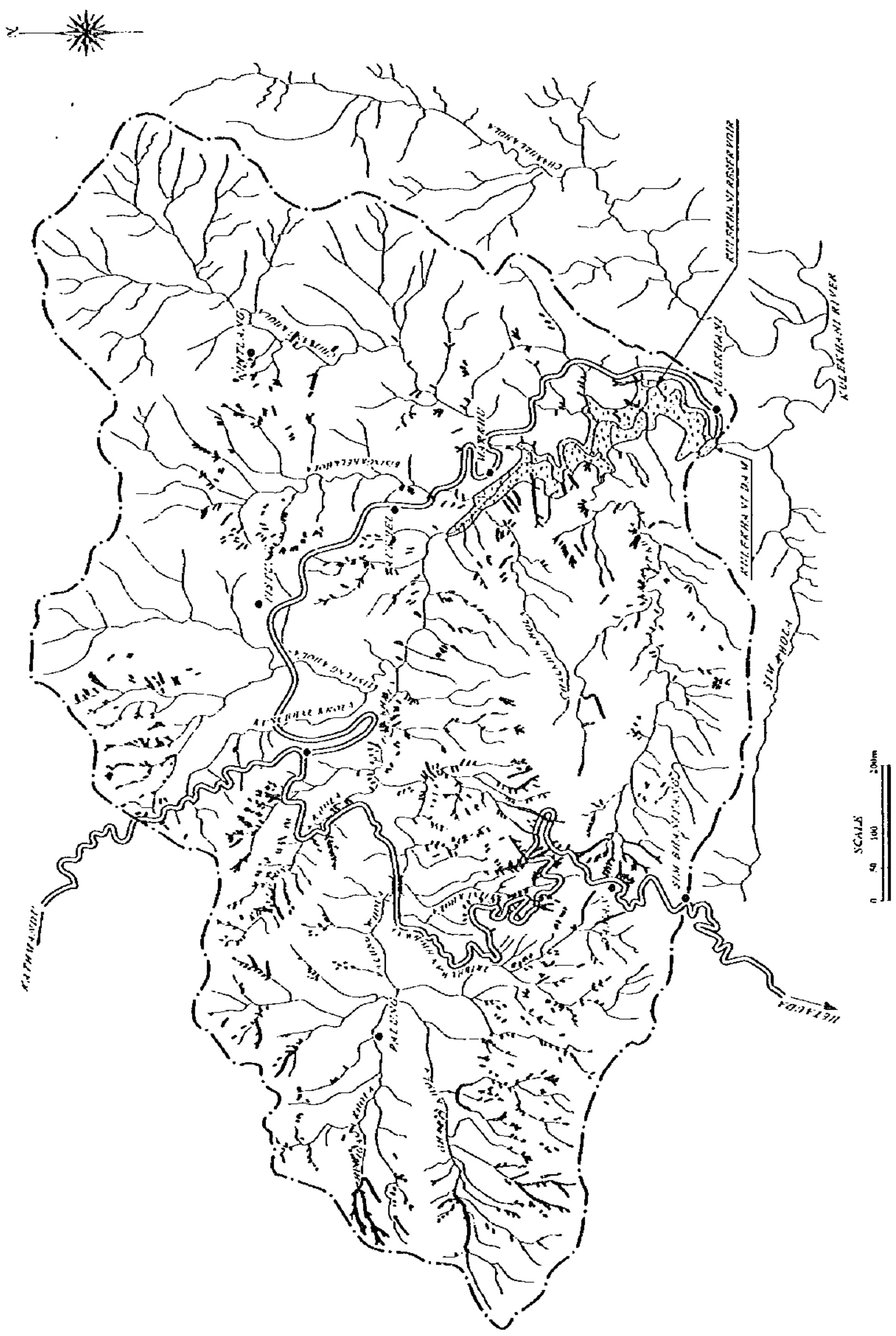

Fig. 7.3.2
Location Map of Slope Failure in Kulekhani Watershed (As of Sep. 1994)

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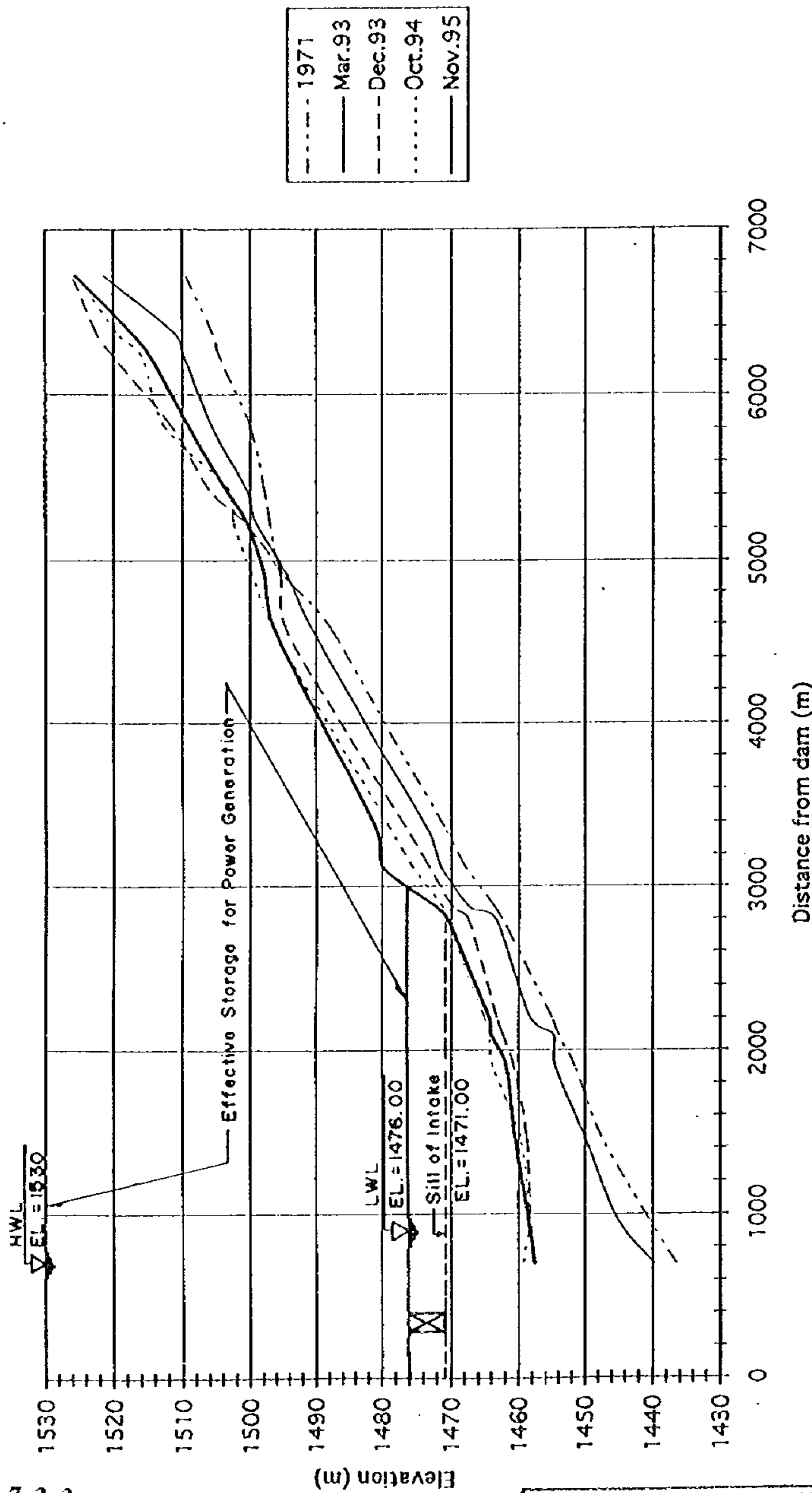

Fig. 7.3.3
Trend of Sediment Deposition in Kulekhani Reservoir
(At the lowest point of Reservoir)

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KULEKHANI RESERVOIR

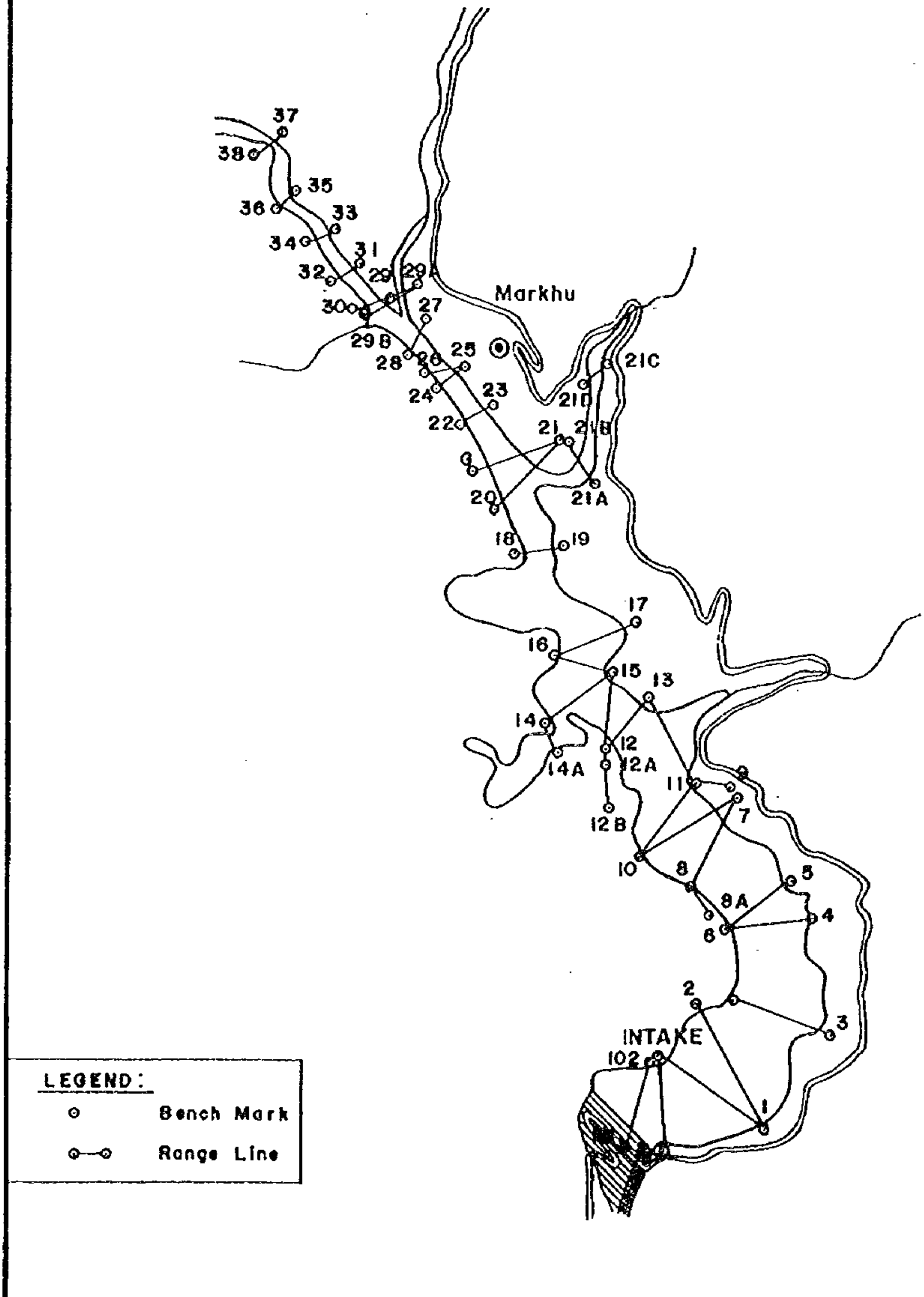

Fig. 7.4.1
Location Map for Echo-Sounding Line in Kulekhani Reservoir

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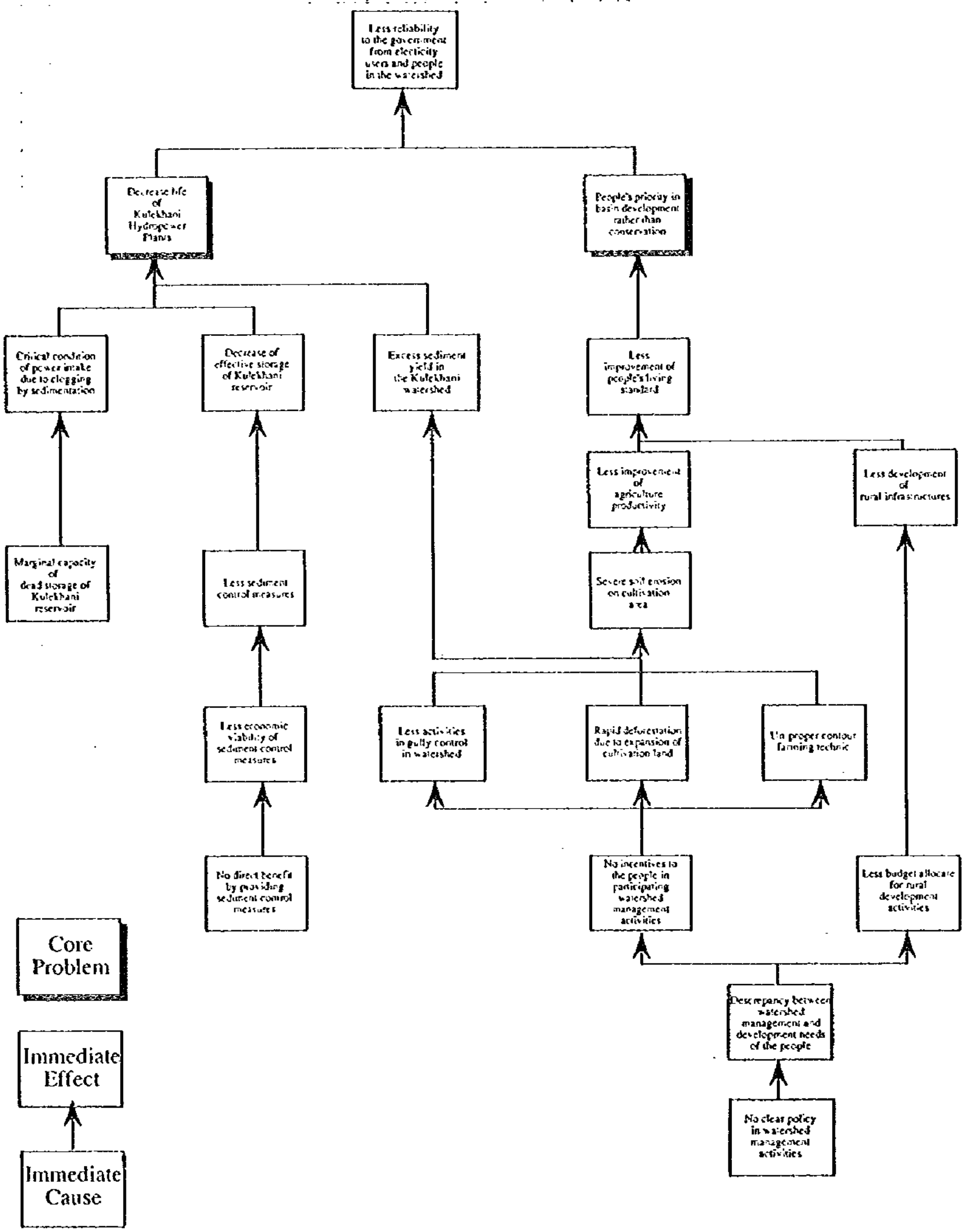

Fig. 7.5.1
Problem Tree for the IDPP for Kulekhani Watershed

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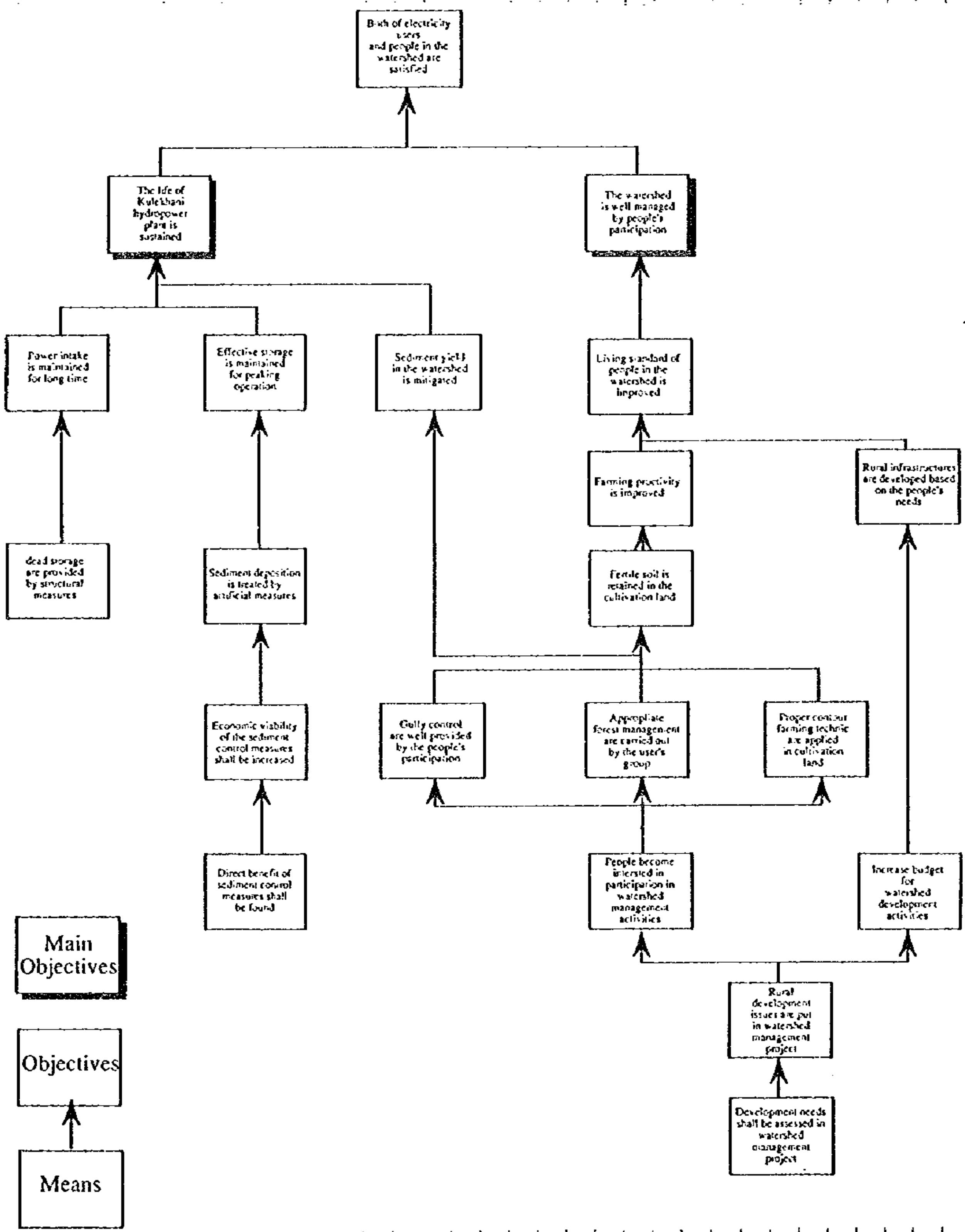

Fig. 7.5.2
Objectives Analysis for the IDPP for Kulekhani Watershed

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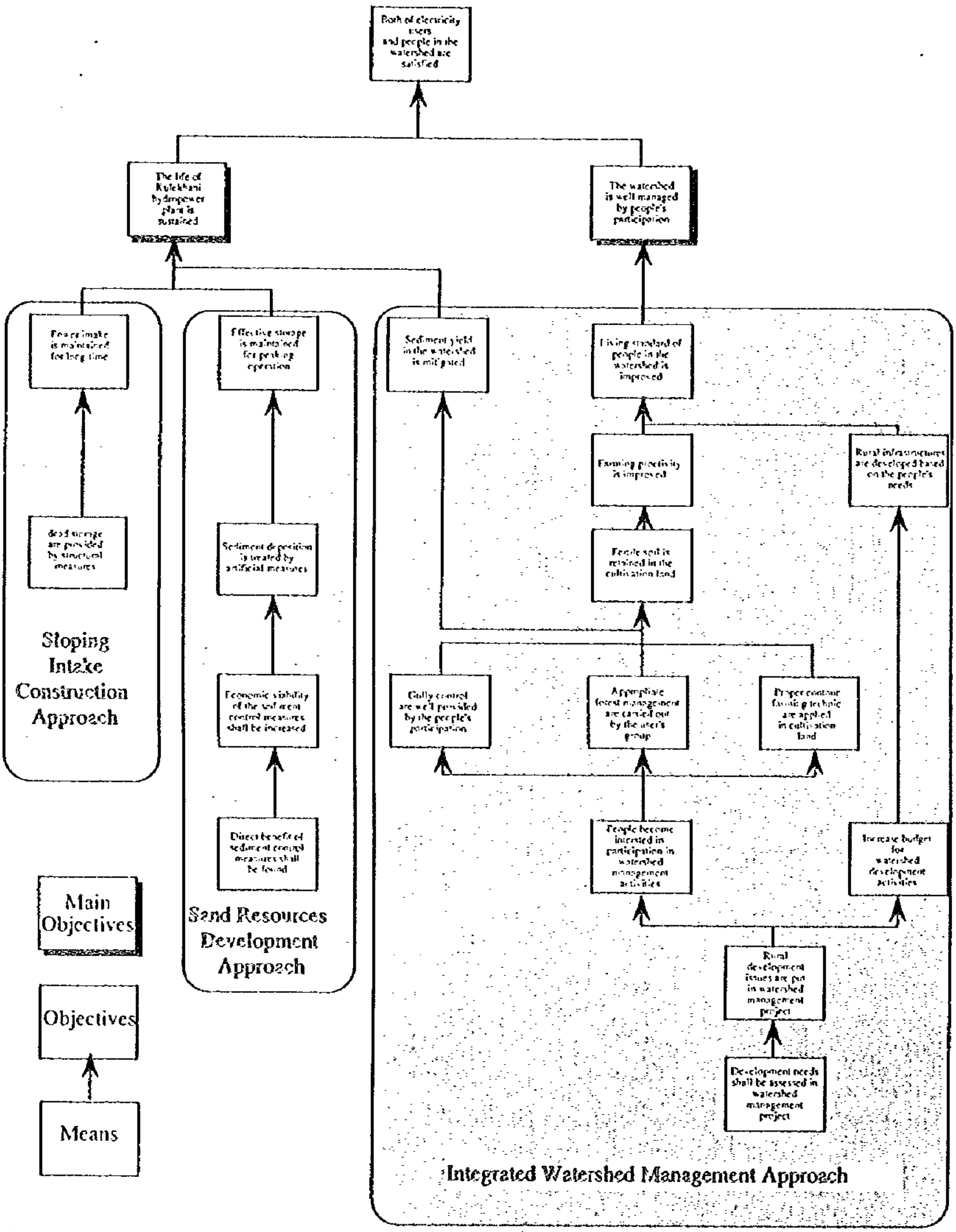

Fig. 7.5.3
Alternatives Analysis for the IDPP for Kulekhani Watershed

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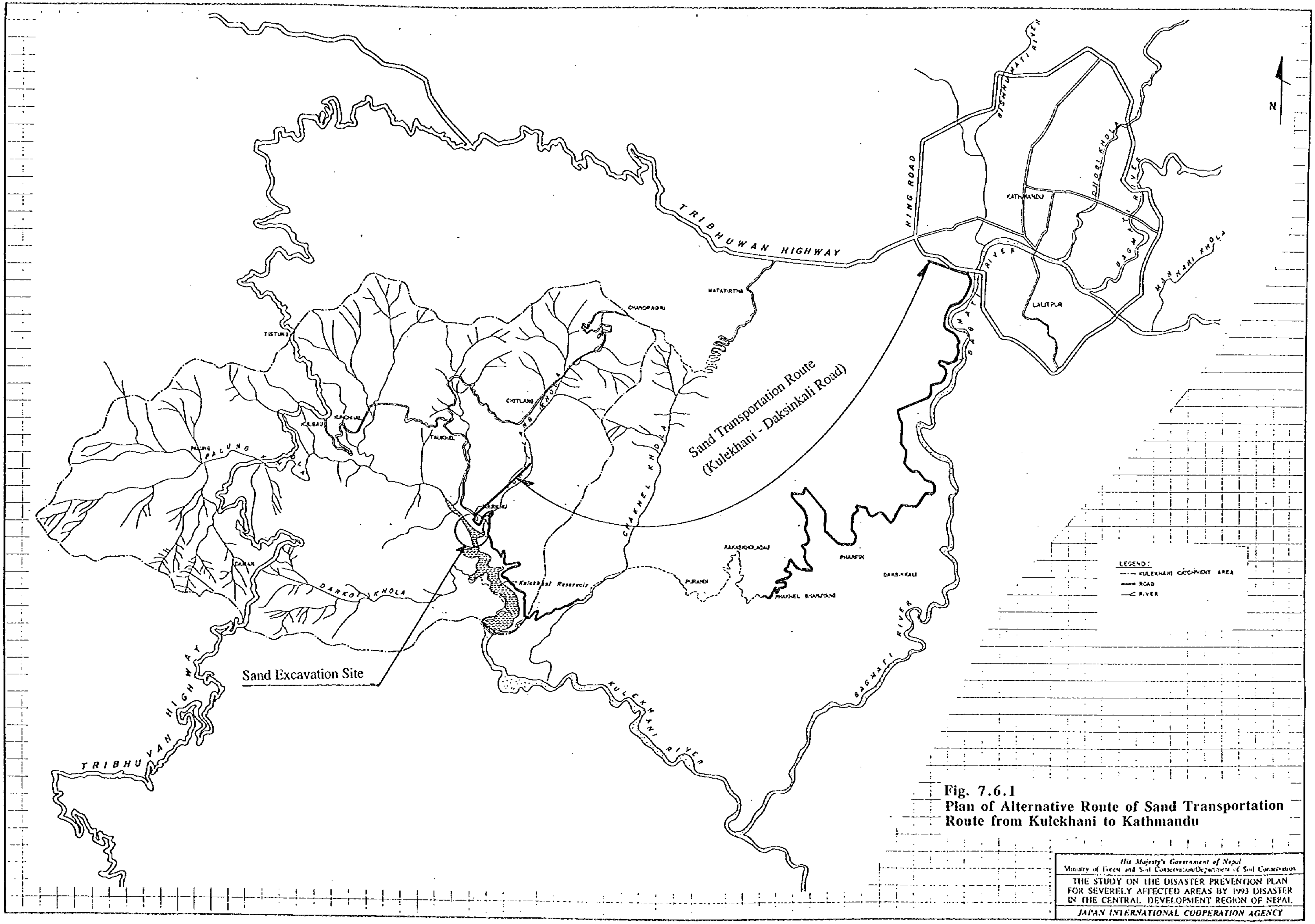

Fig. 7.6.1
Plan of Alternative Route of Sand Transportation Route from Kulekhani to Kathmandu

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