APPENDIX D

WATERSHED AND FLOOD PLAIN CONDITIONS

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CHAPTER I GEOLOGY

1.1 Regional Geology

Ilocos Norte lies on the northwestern part of Luzon, about 486 km from Manila. It is bounded by the provinces of Cagayan, Kalinga and Apayao on the east, by the provinces of Abra and Ilocos Sur on the south, and by the South China Sea on the north and west.

The province has an aggregate land area of approximately 3,399 km^2. The topography in the alluvial areas is flat to moderately sloping on the coastal plain and sand dune areas, and rises moderately to steeply toward the Central Cordillera Range which has an altitude of 2,352 m above sea level at Mt. Sicapoo.

The present landforms of Ilocos Norte are products of Tertiary and Quaternary orogeny and tectonism. The limited exposure of undifferentiated crystalline schists and quartzite of Barangay Suyo is the oldest rock known in the area and is considered to be a part of the Philippine basement of the Pre-Jurassic Age. Cretaceous-Paleocene rocks consisting of serpentinized peridotite intrusive, undifferentiated volcanic flows and highly indurated sediments are located in the western limb of the Central Cordillera. In contact with these rocks are moderately folded Miocene sedimentary rocks that are conformably overlain by flat-lying to gently dipping Plio-Pleistocene sediments. Batholithic masses of highly altered diorite discordantly intrude the Miocene and older rock sequences.

The geologic structures are of great significance to groundwater movement and occurrence. Large and prominent faults serve as recharge to deep and shallow aquifers, while folds generally indicate the flow direction of groundwater. Major gravity faults in Ilocos Norte are oriented parallel to the longitudinal direction of the Central Cordillera, while major and minor thrust faults predominate in the serpentinized peridotite and occurs also between the diorite intrusive and Cretaceous-Paleocene volcanic rocks. Numerous minor faults and lineaments that are vertical with some parallel were observed associated with the major faults.

Folding is well displayed in the Middle to Upper Miocene sediments which are intimately associated with faulting. These folds are almost oriented northeast to north-south.

1.2 Geological Classification in Laoag River Basin

The following stratigraphic sequence proposed by the Bureau of Mines is used to classify land formation in the Laoag River Basin. The first six categories are sedimentary rocks and the last five are igneous rocks. The geological map is presented in Fig. D.1.1.

(1) Recent Sand Dunes (Rsd)

Sand dunes, called La Paz Sand Dune, are well developed along the coastal area around the mouth of the Laoag River. They extend north to Pasuquin and south to Paoay, with a width of 1.5 to 2.5 km. Composed of loose, well sorted, fine grained sub-angular to subrounded sand, the thickness varies from 0 to 50 m.

(2) Recent Alluvium (R)

These are made up of recent river and coastal plain deposits, coral reefs, lacustrine and minor colluvial deposits. These deposits form a relatively flat topography, so most parts of the Recent Alluvium were developed into paddy fields. The recent river deposits are composed of gravel and sand with some silt and clay. Some deposits are predominantly of clean sand and random clustered lenses of unsorted clean gravel. Other deposits are predominantly sand with minor clay.

The Recent Alluvium extends widely along the course of the Laoag River in a stretch from the left bank of Bongo River to the mouth of Laoag River. In addition, it also extends in the valleys and plains of Guisit River and other tributaries.

Thickness of the Recent Alluvium varies from nil at the boundaries to less than 100 m in some places.

(3) Recent Alluvial Fan Deposits (Raf)

These deposits are concentrated along the western foot of the Central Cordillera between Nueva Era and Solsona. They are composed of loose sediments ranging from boulder to fine sand sizes. The thickness decreases from the apex to the base of each fan head. The thickness can be more than 25 m.

(4) Plio-Pleistocene Sediments (N3)

These are composed of fine to coarse-grained, sub-angular to sub-rounded, fairly sorted tuffaceous sandstone and are flat lying to gently dipping beds mostly to the east of the recent alluvium. They are slightly consolidated at depth, as the coarse-grained interbeds are less affected by pore reduction caused by overloading. Some hard calcareous interbeds of not more than 0.30 m thick are common.

Plio-Pleistocene Sediments are widely present in the northern part of Laoag City between San Nicolas and Batac, around Piddig and Banna, and form the terraces and hills. This base is called Laoag Formation in the Geology and Mineral Resources of the Philippines, issued by the Bureau of Mines and Geosciences, Ministry of Natural Resources (the former name of the Department of Environment and Natural Resources) in 1982.

(5) Middle to Upper Miocene Limestone (N2Ls)

This rock unit is white to buff when fresh, silty to sandy in many places; in others it is massive. Bedding are perceptible in some places and high relief is noted when the rock is faulted. The limestone is characterized by solution openings along vertical joints and bedding planes. Numerous sinkholes and joints on the surface serve as entry points for recharge from rainfall. Large and small springs occur at lower elevations and along contact with impermeable rocks with variable discharge.

This unit is called Pasuquin Limestone, and extends over the hills of Dingras and Banna, and the headwaters of the Labugaon and Solsona rivers in the Central Cordillera.

(6) Middle to Upper Miocene Sediments (N2)

This base is called Bojeador Formation in the Geology and Mineral Resources of the Philippines and the geological map in the scale of 1:50,000. These deposits are moderately compacted and cemented sequence of subangular to subrounded, fine to coarse grained, fairly sorted tuffaceous sandstone, siltstone and shale. They are moderately folded, and dips are from 20 to 35 degrees. Some portions are moderately to intensely sheared, and numerous small faults and joints are associated.

These deposits form the two hills; one running from north to south between San Nicolas and Dingras, and the other expanding to the eastern part of Sarrat.

(7) Plio-Pleistocene Volcanics (QV)

These rock units are quaternary volcanics, and are found in the narrow area of headwaters of the Papa River. These volcanics consist of non-active volcanic cones and quaternary volcanic flows of mostly andesitic to basaltic lavas associated with dacites and ryodacite, occurring mainly as lava flows on volcanic centers.

(8) Neogene Intrusive (NI)

This batholitic mass of hornblendo quartz diorite is highly weathered in many places, disintegrating into thick loose granular material. The weathered portions are highly porous and permeable. Recharge occurs on the surface by rainfall and by streams passing through the weathered portions. Only the weathered portions when thick can be classified as good aquifers.

This rock unit, which intruded for the period of Cretaceous, Paleogene and Meocene, extends over the middle to lower portions of the Madongan, Solsona, Labugaon and Cura watersheds.

(9) Lower Miocene Volcanics (VA)

This rock unit is composed of volcanic agglomerate which mainly consists of dense, hard, well cemented angular to subangular andestic pyroclastics and other volcanic fragments mostly of andestic composition embeded in a fine grained acid to groundmass lavas. This rock unit forms the hills around Nueva Era.

(10) Cretaceous-Paleogene Volcanic (Kpg)

This metarock unit constitutes the core of the central Cordillera which extends broadly over the watershed of each tributary of the Laoag River. These extrusives consist of slightly to moderately altered basalt-spilite, andesite-keratopyre, dacite and diabase which are locally intercalated with altered clastic sedimentary rocks. They are highly faulted and jointed with fracture zone in some places.

(11) Cretaceous-Paleogene Intrusive (UC)

This rock unit is composed of basic, ultrabasic and ultramafic minerals, mainly peridotite, dunite, pyroxinite and layered gabbro sometimes referred to as peridotite gabbro complex. This rock unit is almost serpentinized.

This rock unit is the oldest bed rock in the Laoag River Basin, and extends in the Mount Cavit hill along the right bank of the Laoag river mouth, and in the hillside of the left bank of Bongo River near Nueva Era.

CHAPTER II VEGETATION COVER IN THE WATERSHED

2.1 Present Condition

The present vegetation cover in the major watersheds has been investigated through photo interpretation using the aerial photos taken in April 1996. This investigation was carried out mainly for the sediment yield survey with the purpose of estimating the area of bush and shrub land. The present distribution of bush and shrub land in each major watershed is shown in Fig. D.2.1 and summarized below.

Present Bush and Shrub Cover in the Major Watersheds

Watershed	Catchment Area (km^2)	Bush and Shrub Area (km^2)	Bush and Shrub Coverage (%)
Cura	69.5	28.0	40.3
Labugaon	100.5	27.8	27.7
Solsona	79.0	24.0	30.4
Madongan	153.8	34.9	22.7
Papa	51.4	10.1	19.6
Bongo	57.0	8.6	15.1
Total	511.2	133.4	26.1

As presented above, bush and shrub coverage in the major watersheds is considerably high. The Cura, Labugaon and Solsona watersheds, which are located in the northern part of the basin, have relatively higher coverage. Furthermore, most of the bush and shrub land is located in the lower areas of each watershed. This fact means that the bush and shrub land may be man-made scars from commercial and fuel logging and slash-and-burn agriculture. Based on the interview survey with related agencies, the following activities accelerated the devastation of mountain slopes in the watershed.

(1) Logging for Drying Tobacco

Under Spanish rule, tobacco culture was introduced to the Ilocos Region in the early 17th century. Trees have been logged as firewood for drying tabacco. These activities, however, have minimal effects as the cultivated areas for tobacco are concentrated in the plains along the coast which are 20 km away from the Central Cordillera slopes.

(2) Commercial Logging

In the late 1970's, the private sector carried out enormous commercial logging in the major watersheds. These logs were conveyed to Dagupan in Pangasinan by trucks through Solsona and Dingras. In Dagupan, the logs were processed into lumber for the domestic market.

(3) Slash-and-Burn Agriculture by the Itneg

According to the history of Ilocos Norte, settlers began to migrate to the alluvial fan areas from the towns of Laoag, Dingras and San Nicolas in the early 18th century. Before the settlers arrived, the aborigines called Itneg occupied these areas. Due to population pressure by immigrants, the Itneg had to transmigrate to the mountain areas of the Cordillera Central. They made their living by hunting and slash-and-burn agriculture.

The effects to denudation by this method could not be determined due to lack of information about the activity. At present DENR is making efforts to discourage the Itnegs from slash-and-burn agriculture.

2.2 Reforestation Projects of DENR

The DENR is the government agency responsible for the sustainable development of the natural resources and ecosystems. One of the functions of DENR is forest management service based on the policy of forest resources development emphasizing maintenance consistent with sustainable use. The Provincial Environment and Natural Resources Office (PENRO) is set up in every province with the Community Environment and Natural Resources Office (CENRO) under it. They are likewise responsible in the implementation of environmental plans and programs in their respective areas of jurisdiction.

In the study area, the DENR is undertaking the following reforestation projects as well as watershed rehabilitation and management. These project areas are shown in Fig. D.2.2.

2.2.1 Communal Forest Project

This project is a community development project wherein a private individual/community can apply for a forest land parcel to utilize, protect, rehabilitate and develop in order to ensure the continuity of its productive condition. This project is located in three municipalities, Nueva Era, Dingras and Solsona with a total area of 12,812 ha.

Among the three municipalities, Nueva Era has the biggest forest area. Due to this fact, some groups/individuals in the municipalities of Badoc, Banna (Espiritu), Batac, Currimao, Laoag City, Pinili, Paoay including Solsona had applied for a parcel in Nueva Era to be developed.

2.2.2 Regular Reforestation Project

This project aims to maintain the existing forest land through (a) forest protection by foot patrol and directly suppress fire, if any; (b) replanting, cultivation, application of fertilizer, etc.; and (c) nursery for seedlings/saplings of suitable species, strip brushing, hole digging and staking.

This project covers an area of 9,064 ha in the municipalities of Marcos-Nueva Era, 580 ha in Solsona, and 1,173 ha in Sarrat.

2.2.3 Upland Contract Reforestation

Qualified families/communities (5 to 10 ha for families and 10 to 100 ha for communities) are awarded the lease of the upland forest for them to conserve and manage. They are provided with livelihood opportunities for a period of three years.

In 1989, 110 ha in the municipality of Nueva Era, 210 ha in Marcos and 150 ha in Solsona were funded by the ADB through this program. In that same year, 73 ha in Nueva Era and 12 ha in Marcos were funded by the OECF. In addition to the OECF project, 15 ha in Carasi were included.

In 1990, a project covering a total area of 713 ha in the seven municipalities of Nueva Era, Marcos, Solsona, Dingras, Sarrat, Piddig and Carasi and a regular Upland Contract Reforestation Project with a total area of 53 ha in the municipalities of Nueva Era, Solsona, Sarrat and Piddig were funded by the OECF.

In 1991, a total area of 255 ha in the municipalities of Marcos, Nueva Era, Dingras, Piddig, Solsona, Sarrat and Carasi was funded by the OECF. An area of 164 ha in Nueva Era and a regular Upland Contract Reforestation (UCR) with an area of 96 ha in the municipalities of

Marcos, Nueva Era, Dingras, Piddig, Solsona, Sarrat and Carasi were funded by the ADB. In 1992, a total area of 100 ha in the Municipality of Dingras was funded by the OECF.

The Upland Reforestation Project contract is renewable every three years. In case the lessee violates the contract/forestry law or losses interest in the project, the government (DENR) takes over the reforestation.

2.2.4 Integrated Social Forestry Projects

This project is for the benefit of upland dwellers/forest occupants to uplift their socio-economic condition through long-term stewardship contracts and offers livelihood opportunities through agro-forestry.

The lessee of the area is allowed to utilize the forest land for a period of 25 years renewable for a period not to exceed 25 years with corresponding contract obligations and in accordance with forestry laws.

The project has a total area of 2,331 ha in DENR-CENRO.

2.2.5 Industrial Tree Plantation

This program is granted to a qualified individual to develop and exploit forest land with a minimum area of 1,000 ha depending on the capacity of the lessee to develop or convert the area into productive condition for a period of 25 years, renewable for another period not exceeding 25 years, but with the corresponding obligation to adopt protection and conservation measures to ensure the continuity of the productive condition of the said area.

This project with a total area of 50 ha is located in the municipality of Sarrat. This project is monitored by the DENR every quarter of the year to maintain and protect the forest land.

2.2.6 Sectoral Adjustment Loan (SECAL)

This project, with a total area of 2,100 ha, was established in August of 1992. DENR-CENRO, with assistance from the regional/central office is the implementing agency. Nueva Era is one of the pilot sites. The project is funded by the World Bank and the Philippine Government. A total of P40,153,020 is appropriated for seven year operations (1992-1998).

The project is a community-based rural development program geared towards the protection, development and management of the watershed and land resources. This is specifically guided by the twin objectives of poverty alleviation and natural resources conservation. Specifically, it hopes to:

(1) develop and enhance the capacity of target communities for sustained development;

(2) generate livelihood and employment opportunities;

(3) rehabilitate the natural resources base of the project area;

(4) improve upland productivity;

(5) strengthen the technical and managerial capabilities of the DENR, local government units and other government organizations to deliver support to rural communities;

(6) enhance the national government and NGO partnership in resource management; and

(7) provide essential infrastructure and facilities.

2.2.7 OECF Loan II (The Philippine Forestry Development Project II, PFDPIN-II)

This project is the continuation of PFDPIN-I, which will take care of the southeastern part of the province covering the municipalities of Carasi, Dingras, Espiritu, Marcos, Nueva Era, Piddig, Sarrat and Solsona, the aggregate area of which is approximately 1,444 km^2 representing 21.2% of the provincial land area. The project embraces the catchment areas of the Laoag River watershed reserve which includes four major rivers; namely, the Solsona, Madongan, Papa and Bulug.

The project when implemented will not only save and rehabilitate the watershed but at the same time, serve as protection and maintenance of the already established plantation of PFDPIN-I which is adjacent to the area.

(1) Objectives of the Project

The project aims to develop and rehabilitate the watershed of the Laoag River through reforestation and the application of vegetative and structural measures and the appropriate scheme for effective soil and water conservation, eventually reducing soil erosion. Specifically, the project objectives are:

(a) To reforest 16,000 ha of critical area within the Laoag River watershed with fast growing and premium species and rattan;

(b) To intensify watershed protection and rehabilitation;

(c) To develop and implement an appropriate scheme for social forestry that will alleviate the living condition of the forest occupants and transform them as partners in developing the watershed; and

(d) To develop institutional capability in watershed planning and management.

(2) Proposed Project Components

(a) Reforestation

This major component of the project is to reforest 16,000 ha of critical areas with fast growing tree species. Such species include *Acacia, Curiculiformis, Cemelina Arborea, Eucalyptus sp., Cassia Siamea, Casuarina Equisetifolia, Gliricidia Sepium* and also three species of rattan. The rationale of planting the areas to fast growing species is to answer the urgent need to provide covers to prevent soil erosion and provide source of fuel wood, and additional income to residents in the surrounding communities through the contract reforestation program.

(b) Social Forestry

One of the basic concepts of development is the involvement of the people in the process. These are some peculiarities in the upland. Farm in such areas require some modification of their designs. The people in about 17,000 households living around the watershed are part and parcel of the watershed itself. This is to develop appropriate farming technologies for the people. Such changes or modifications of their farm designs will be undertaken through the concept of agro-forestry farm systems development. Training, establishment of demo farms and development of off-farm activities will be the main component of the social forestry program

2.2.8 Industrial Forest Management Agreement (IFMA)

With a total area of 1,050 ha, this project is located in the municipalities of Nueva Era, Pinili, Badoc and Marcos. It is also a 25-year lease contract, which is renewable, awarded to a qualified person to develop and utilize forest land to improve/enhance the socio-economic well-being of the people with an obligation to adopt all the protection and conservation measures for the continuous production capacity of the project area.

CHAPTER III SEDIMENT YIELD IN THE WATERSHED

3.1 Aerial-Photo Interpretation and Field Investigation

Sediment yield survey in the watershed was carried out based on the following procedure.

3.1.1 Aerial-Photo Interpretation

An aerial-photo was taken in April 1996 for this study. However, the main purpose of this aerial photo is the preparation of topographic map of the alluvial fan area. To cope with the needs of sediment yield survey, a supplemental aerial photo with a scale of 1:40,000 was taken covering the major watersheds of Cura, Labugaon, Solsona, Madongan, Papa and Bongo.

Likewise, aerial-photos with a scale of 1 : 8,000 covering the whole Laoag River basin, which was taken by NIA in September 1991, was interpreted to clarify the micro-topography in each watershed.

3.1.2 Geomorphologic Classification of Micro-topography

Micro-topography is related to sediment yield. The following are the micro-topography extracted from the aerial photos taken in 1991 as basic information on the sediment yield mechanism.

(1) Riverbed Deposits

An area of riverbed deposits is identified as the present riverbed with accumulated sediment and without vegetation cover. Sediment yield from the mountain slopes is temporarily stored in this area, and gradually transported downstream.

(2) River Course without Deposits

A segment of the river course on the exposed base rock is classified as river course without deposits. A narrow path or gorge is usually formed in this segment.

(3) Debris Flow Deposits/Scars

Debris flow deposits/scars are classified as riverbed on which debris flow avalanched and deposited sediment in the past. The following are typical patterns of micro-topography in this area:

(a) Scars of viscous fluid passing in the bends of the river course;

(b) Gully erosion in the riverbed deposits and apparent deposits in the downstream reach; and

(c) Sediment deposits, forming lobe- and tongue-shape along the river course.

In many cases, there are large-scale landslides in the mountain slopes upstream of these deposits/scars. These deposits are source materials of secondary erosion during medium to large scale floods since they are unconsolidated.

(4) Flood Terrace/Sand Bar Covered by Plants

These are sand bars covered by plants and terraces which have a slightly higher elevation than the riverbed. This micro-topography is made by enormous volume of sediment deposits in previous large floods and succeeding riverbed degradation.

These deposits are also unconsolidated; thus, they are easily affected by bank erosion. In some cases, a large flood can wash out this micro-topography.

(5) Colluvial Slope (Cone and Talus)

This micro-topography includes talus at the slope foot and alluvial cone at the downstream end of mountain torrent. The gradient of deposit varies to its grain size and moisture condition. Talus is made by slope failure or falling rocks, and its slope is steeper than the slope of alluvial cone. On the other hand, alluvial cone is made by debris flow deposits. Alluvial cone is similar to alluvial fan, but it is usually smaller and steeper than alluvial fan.

(6) River Terrace

River terrace is located along the river course and has a higher elevation than riverbed. Even large floods can hardly inundate a river terrace. Continuous channel degradation causes some differences of elevation between riverbed and the remaining plain. Finally, the remaining plain is formed into the river terrace with a significant difference of elevation from the riverbed.

(7) Large-scale Slope Failure

This micro-topography is relatively a large area in the basin. The following are major causes of large-scale slope failures:

(a) Slope failure in an area of potential landslide/creep;

(b) Slope failure of one of the big blocks in a landslide area; and

(c) Slope failure caused by sudden change of erosion base level due to river piracy.

In these areas, a considerable volume of sediment is yielded after collapse.

(8) Scars of Large-scale Slope Failure

Sliding cliffs are identified as scars of large-scale slope failure which occurred in previous times and is covered by vegetation. At the foot of the sliding area, a large volume of sediment deposits composed of shattered base rock and talus deposit are observed. They are one of the predominant source materials of sediment yield.

(9) Potential Landslide/Creep Area

These include an area of typical landslide topography and a potential area for large-scale slope failure. Typical landslide topography has a gentle slope area called landslide block, encompassed with a semicircle-shaped cliff. On the other hand, a potential area for large-scale slope failure has depressions spreading in a line along the ridge, and the step-shaped slope with swelling convex-shaped slope just below it. This type of deformation is created by slope sliding, toppling and creeping.

A potential landslide/creep area has the possibility to collapse in a large scale during heavy downpour or big earthquake. If a large-scale slope failure occurs, sediment yield is expected to reach 1 to 10 million m^3. The large-scale slope failure that recently occurred in the Bongo River Basin is classified as collapse of a potential area.

The interpreted micro-topography is presented in Fig. D.3.1. Simultaneous with this work, the extent of slope failure was also examined using both aerial-photos taken in 1991 and 1996. These slope failure areas are shown in Fig. D.3.2.

3.1.3 Investigation of Failure Depth and Area in Each Scale of Slope Failure

The scale of slope failure varies from about 100 m^2 to 50,000 m^2. In accordance with the scale, the depth of failure also changes. Field measurement was made for slope failures in various scales and these areas were adjusted in the photo images and converted to some representative scale.

The following scales of slope failure and failure depth were established to estimate the sediment yield:

Classification of Slope Failure	Representative Area	Depth of Slope Failure
Very Small	170 m^2	1 m
Small	1,000 m^2	2 m
Medium	more than 2,500 m^2 (direct measurement on the map)	5 m
Large (in Bongo Watershed)	50,000 m^2 (direct measurement on the map)	15 m

The sediment yield of small-scale slope failures were estimated by multiplying the representative area by the number of failures and failure depth for each classified scale.

3.2 Topography of Watershed

3.2.1 Conditions of Watershed

The major tributaries of the Laoag River originate from the Central Cordillera which is the largest mountain range running north and south in the northern part of Luzon Island. The watershed of Laoag River is located in the northern part of the Central Cordillera. Many ridges with an elevation of 1,000 to 1,500 m abound in this watershed. Mt. Sicapoo has the highest ridge with an elevation of 2,352 m. The mountains descend towards the west, then to the alluvial fans across the Solsona-Adams Fault.

The cascading surface waters of numerous tributaries along the steep mountain slopes result in deep gorges in the headwaters. In particular, the main streams of Madongan, Papa, Solsona and Labugaon have much erosive power due to steep slopes.

Valley development is much influenced by geological structures. In the area of metamorphic rocks, which constitute the core of Central Cordillera, there are many valley bends, waterfalls, nick-points and constrictions formed under the geological influences. On the other hand, diorite which is distributed in the Madongan to Cura watersheds tends to be weathered, resulting in the dense development of narrow valleys.

There are many gentle slope areas around the mountain ridges. This gentle slope surface was formed due to deformation of mountain body. A number of sharp drops, double ridges and crack-like lineaments exist in parallel with the mountain ridge. The large-scale landslides, which occurred in the headwaters of Bongo River in 1991 to 1996 is located in a crack-like lineament.

Numerous sliding and creeping terrains and scars of large-scale landslide are distributed in the watersheds. In the area where these micro-topographic components concentrate, large-scale landslides are also located and yield enormous sediments.

3.2.2 Cura Watershed

The Cura River originates from a ridge with an elevation of 1,770 m in the Central Cordillera, and has an area of 65.5 km^2. The topography is in the stage of maturity with steep slopes.

In the lower reaches of the watershed, there is not much indication of landsliding and creeping terrains, resulting in no scars at all. On the other hand, large-scale landslides and their scars are located in the headwaters [see Fig. D.3.1(1)].

The Cura River has a riverbed width of about 100 m at the downstream end, while in the upper reaches, the width is less than 30 m.

3.2.3 Labugaon Watershed

The Labugaon River originates from the western slope of Mt. Licud, which has an elevation of 1,844 m at the summit. Along the Central Cordillera, there are many gently relief surfaces mainly around Mt. Licud and Mt. Kilung, where the landsliding and creeping terrains are mostly developed. The watershed has an area of 100.5 km^2.

The topography is also in a stage of maturity with steep slopes. A number of landsliding and creeping terrains extend from the ridges bounding the Solsona watershed to the eastern ridges. Large-scale landslides mainly occurred in this area. On the other hand, along the right bank of the middle and lower reaches, where the Cura watershed bounds , not much landsliding and creeping terrains exist.

The Labugaon River has a riverbed width of about 100 m from the downstream to the upper stretch. Along the main river course, flood terraces are formed, 3-4 m high above the riverbed. Large-scale landslides prevail in the headwaters, and yield an enormous amount of sediment [see Fig. D.3.1(1)].

3.2.4 Solsona Watershed

The Solsona River originates from the northwestern slope of Mt. Sicapoo, and has a drainage area of 79.0 km^2. The topography is also in a stage of maturity with steep slopes. A small amount of riverbed deposits exist in the lower reaches. In a stretch of 3 km long from the downstream end, river terraces are formed on both sides and water flows at heights of 15 m below the terraces.

There are numerous landsliding and creeping terrains, and large-scale landslides in the headwaters, particularly, near the provincial boundary of the Solsona-Apayao Road. The road passes through sliding cliff and residual deposits of the scars of landslide. One of these scars is the largest landslide in the Laoag River Basin with a width of 1 km, a length of 2 km and a depth of more than 200 m. The volume of sediment yield may reach 400 million m^3.

A part of the sediment yield still remains forming a gentle slope in the valley. The surface water of the tributary has eroded this deposit to 100 m deep, then secondary large-scale slope failure occurred. The flood terraces originating from this landslide exist discontinuously along the river course. The difference of height between riverbed and terrace gradually reduces as the river moves toward the lower reaches. The river terraces just upstream of the Solsona diversion dam most likely originated from the same landslide. At that time, sediment transported from the sliding area filled up the valley, and formed a wide riverbed similar to the other rivers [see Fig. D.3.1(2)].

3.2.5 Madongan Watershed

The Madongan River originates from the southwestern slope of Mt. Sicapoo, and has a drainage area of 153.8 km^2. The topography is also in the stage of maturity. In the middle and upper watershed, the ridges have elevations of more than 1,000 m. In the ridges, ranges are formed with a height difference of 500 to 700 m between ridges and valleys. Furthermore, the middle and upper watershed has an average slope of 35° to 40° accruing to the steep topography of the Madongan watershed.

Landsliding and creeping terrains are spread over the watershed. In particular, landsliding and creeping terrains and large-scale landslides are concentrated in the headwaters of the left tributary in the middle reaches where the abandoned mine is located. A large-scale flood terrace is formed in the lower reaches of this tributary. There is no plant cover on the terrace at present. Thus, the terrace might have been formed by the recent events of the 1980's.

In the middle and lower reaches, the riverbed is formed with widths ranging from 100 m to 500 m. Flood terrace exists more than 5 m high above the riverbed, along the left bank 2 km upstream of the irrigation diversion dam. This fact indicates that more enormous volume of sediment was once accumulated in the Modongan River [see Fig. D.3.1(2)].

3.2.6 Papa Watershed

With a drainage area of 51.4 km^2, the Papa River originates from the ridge of the Ilocos Range with elevations of 1,100 m to 1,400 m. The topography is also in a stage of maturity with steep slopes. In the middle and lower reaches, the Papa River has a riverbed width of 250 m.

There is an abandoned road along the basin boundary in the south side, leading to the abandoned mine in the Madongan watershed. A large-scale landslide prevails along this road. Landsliding and creeping terrains concentrate in the southern half of the watershed [see Fig. D.3.1(3)].

3.2.7 Bongo Watershed

The Ilocos Range, which is the western part of Central Cordillera, runs from southwest to northeast. With a drainage area of 57.0 km^2, the Bongo River originates from the western slope of Mt. Cayudungan which has an elevation of 1,469 m. The topography of the watershed is also in a stage of maturity with steep slopes.

There are wide and gentle slopes along the south ridge of Mt. Dagot, which has an elevation of 1,240 m. Numerous landsliding and creeping terrains are located on these slopes. A large-scale landslide occurred in 1991 to 1996. There are many scars of large-scale landslide in the sub-basin of the tributaries originating from the slope of Mt. Dagot. In 1991, a wide and flat riverbed was formed due to much sediment deposits from these areas. For the period 1991 to 1996, however, this riverbed has been heavily scoured and the remaining bed was finally formed as flood terrace.

Wide gentle surfaces were formed in the western slope of Mt. Cayudungan due to previous large-scale landslide. These surfaces have been scoured, and the present terraces were formed [see Fig. D.3.1(3)].

3.3 Predominant Mechanism of Sediment Yield

Through aerial-photo interpretation, seven types of slope failure can be classified according to causes and the difference in original micro-topography. Surface slope failure can be pointed out as the predominant type from the number of occurrence. Large-scale landslide, however, is the most serious sediment yielding mechanism because of the enormous volume of sediment yield.

(1) Failure on the Landsliding and Creeping Terrain

The existing slope failures classified into this type have an area ranging from 5,000 m^2 to 50,000 m^2. The largest one is located in the headwaters of Bongo River. In Solsona and Madongan watersheds, the old scars of this failure type were identified. These areas have an area of more than 700,000 m^2 and the volume of sediment yield can be estimated at more than 10 million m^3.

(2) Secondary Slided-slope Failure

After sliding, a considerable volume of slided rocks and soils remain, forming a block at the slided slope end. Even if the slided slope is covered by vegetation, the eroding rate of the remaining block is still high because of crushed materials. Heavy rains easily erode those materials away.

This type of secondary failure can be found in the headwaters of the Labugaon and Solsona rivers.

(3) Weathered Rock Failure

This type of failure is frequently found on the steep slopes located in the headwaters of each watershed. The scale of failure is relatively large, and the slided depth may be a few meters to 5 m. The slope slides involve surface soils and weathered rocks. The scars form a single line or dendro-branch shapes.

(4) Surface Slope Failure

This type is a typical failure in the middle and lower portions of the watershed. Most areas with surface slope failure are located in the bush and shrub land. The scale is relatively small and the depth is about 1 m. The slided area forms a circle, shell and horseshoe shaped, and the slipped face is clearly identified on the site.

(5) Failure on the Valley

Along the mountain torrent, failure of weathered rock occurs by bank scouring. The depth of failure ranges from less than 1 m to more than 5 m.

(6) Failure along the Road

Slope failures frequently occur at the shoulders, the cut slope and the fill slope along the road. This type of failure occurs in small scale only by the cause of road construction. However, it may trigger the large-scale slope failure if the road crosses the large landsliding terrain.

(7) Gully Erosion

Gully is rarely developed in the watersheds excluding the areas along the road. In the Cura and Madongan watersheds, gullies are well developed due to insufficient drainage works.

3.4 Major Cause of Slope Failure and Landslide

3.4.1 Vegetation Cover

The bush and shrub lands, which are traces of logging and slash-and-burn agriculture, distribute in the lower part of the watershed as shown in Fig. D.2.1. On the other hand, a virgin forest of which main species are pine trees covers over the upper part.

In the bush and shrub lands, a small-scale slope failure is the predominant type of failure. A large-scale failure can be rarely seen in this area. Thus, the vegetation cover is deemed not to be a direct cause of the slope failure, although the forest can improve the hydrological situation with canopy interception and increase of infiltration during a heavy downpour.

3.4.2 Geology

In the watershed the geological features are divided into three formations, 1) Middle to Upper Miocene Sediment, 2) Cretaceous-Paleogene Metarocks and 3) Neogene Intrusive, as shown in Fig. D.1.1. Distribution of slope failures indicates the clear deference among these geological formations, as follows;

(1) Middle to Upper Miocene Limestone

This formation extends over the uppermost headwaters of the Labugaon and Solsona watersheds. In the Labugaon watershed, the large-scale landslide terrain concentrates into this formation. Further, the scar of the largest slope failure described in the Clause of 3.2.4 is also located in this area. This formation distributes in the highest part of the basin with an elevation of more than 1,500 m.

(2) Cretaceous-Paleogene Metarock

This formation mainly covers the upper part of the watersheds of Cura, Labugaon and Madongan rivers. Meanwhile, it mostly covers the Papa and Bongo watersheds. Most of the existing large-scale slope failures fall into this area in the whole watershed.

(3) Neogene Intrusive

In this formation most of the existing slope failures identified are small scale. There are scarcely large-scale slope failures exist in this area.

The Madongan watershed is an appropriate example indicating the clear deference between Cretaceous-Paleogene Metarock and Neogene Intrusive. The former mainly extends over the southern part of the watershed, while the latter extends over the northern part. Although each part has the similar altitude, the large-scale slope failures and landslide terrain concentrate in the southern part, Cretaceous-Paleogene Metarock area.

3.4.3 Major Cause

The following are the summary on major cause of the large-scale slope failure and landslide terrain including other factors of topography and altitude.

(1) The large-scale slope failure and landslide terrain mainly distribute in the geological formation of Middle to Upper Miocene Limestone and Cretaceous-Paleogene Metarocks.

(2) The large-scale landslide terrain and its failed scar concentrate at the valley heads along the ridges. In particular, the larger ones are mainly located at an altitude of more than 1,000 m.

(3) The large-scale slope failures mainly concentrate at the valley heads or steep slopes which are located at an altitude of more than 1,000 m.

3.5 Sediment Yield

3.5.1 Sediment Yield Mechanism

The interpreted areas of slope failure are summarized in the following table. As shown, the area was reduced from 1991 to 1996. Others in the table mean the small watersheds of Madongon and Lading rivers.

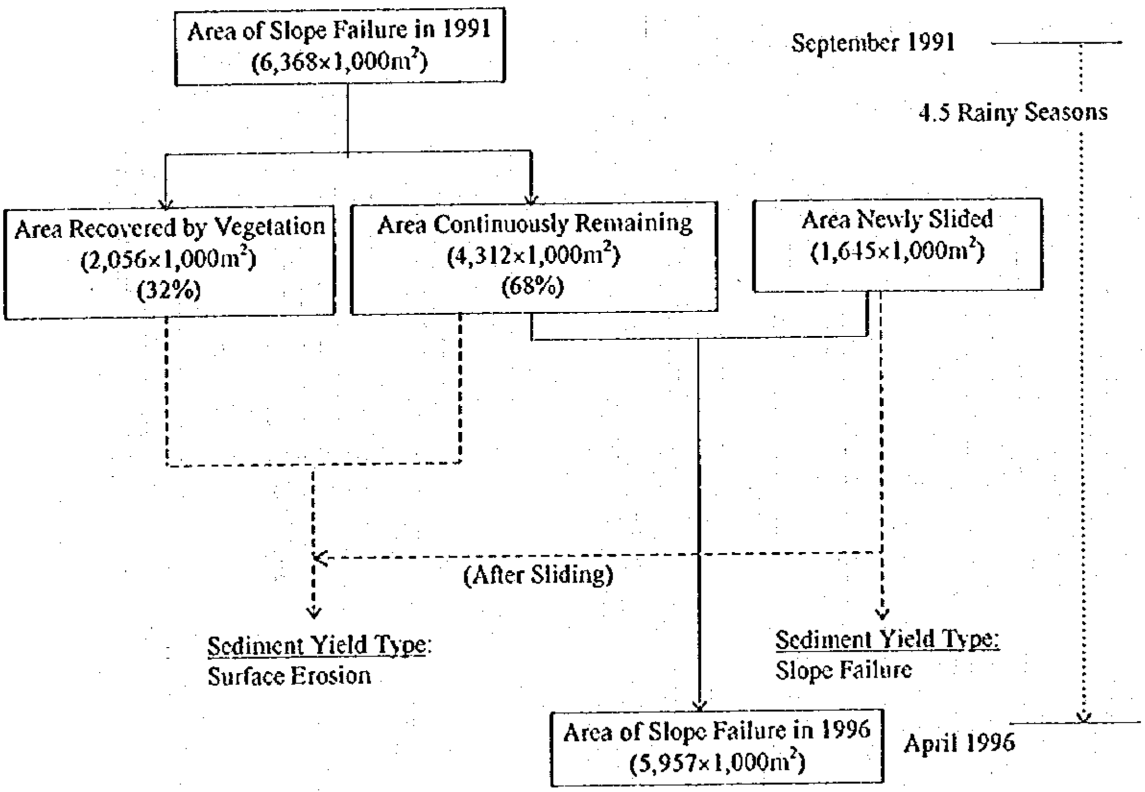
River	Catchment Area (km^2)	In September 1991 Number	In September 1991 Area (1000 m^2)	In April 1996 Number	In April 1996 Area (1000 m^2)
Cura	69.5	148	938 (1.35%)	1,383	799 (1.15%)
Labugaon	100.5	1,826	1,720 (1.71%)	1,758	1,513 (1.51%)
Solsona	79.0	1,100	1,021 (1.29%)	1,189	1,007 (1.27%)
Madongan	153.8	2,447	1,617 (1.05%)	2,651	1,490 (0.97%)
Papa	51.4	812	505 (0.98%)	831	500 (0.97%)
Bongo	57.0	790	423 (0.74%)	775	497 (0.87%)
Others	18.4	186	144 (0.78%)	314	151 (0.82%)
Total	529.8	7,309	6,368 (1.20%)	8,901	5,957 (1.12%)

Note: The percentage in parentheses is the sharing ratio of slope failure area in the watershed.

In order to clarify the change of slope failure areas, each area is compared in detail using both aerial-photos of 1991 and 1996. The results are shown in the following table.

River	Catchment Area (km^2)	Area of Slope Failure (1000 m^2) In Sept. 1991	Vegetation Recovery from 1991 to 1996	Continuously Remaining from 1991 to 1996	Newly Slided from 1991 to 1996	In Apr. 1996
Cura	69.5	938	359	579	220	799
Labugaon	100.5	1,720	453	1,267	246	1,513
Solsona	79.0	1,021	315	706	301	1,007
Madongan	153.8	1,617	657	960	530	1,490
Papa	51.4	505	126	379	121	500
Bongo	57.0	423	102	321	176	497
Others	18.6	144	44	100	51	152
Total	529.8	6,368	2,056	4,312	1,645	5,957

The mechanism of sediment yield can be derived from the interpretation results as illustrated. In the figure, the numbers show the total area of slope failure in the above table.



Once slope failure occurs, loose sediment is suddenly yielded in an enormous volume. After that, the bared slope will be eroded by raindrops until such time when the area is covered by vegetation.

3.5.2 Sediment Yield

Sediment yield for the year 1991 to 1996 is estimated by distinguishing slope failure from surface erosion.

(1) Slope Failure

Sediment yield is calculated by multiplying the area and the depth of slope failure as described in Section 3.1.

(2) Surface Erosion

Surface erosion rate in devastated areas has been frequently measured in the experimental basins in Japan. Those rates range approximately from 10 mm/year to 100 mm/year. In this study, the average erosion rate of 50 mm/year is adopted to calculate sediment yield by surface erosion. Sediment yield is calculated by the following equation.

Sediment Yield = [(Area recovered by vegetation + Area newly slided)/2 + Area continuously remaining] × Erosion rate × 4.5 years

Calculation results are shown in the following table.

River	Catchment Area (km^2)	Sediment Yield from 1991 to 1996 Slope Failure ($1000\ m^3$)	Surface Erosion ($1000\ m^3$)	Total ($1000\ m^3$)	Annual Sediment Yield per Catchment ($m^3/year/km^2$)
Cura	69.5	465	196	661	2,110
Labugaon	100.5	543	363	906	2,000
Solsona	79.0	674	228	902	2,540
Madongan	153.8	1,122	350	1,472	2,130
Papa	51.4	260	114	374	1,620
Bongo	57.0	1,015(265)	104	1,119(369)	4,360(1,440)
Others	18.6	75	34	109	1,300
Total	529.8	4,154(3,404)	1,389	5,543(4,793)	2,320(2,010)

Note: ( ) : excluding the large-scale land slide in the Bongo watershed

A large amount of 1-day to 3-day rainfall, which may have much relation to sediment yield mechanism, was not observed at the Laoag Station of PAGASA for the period 1992 to 1995.

A large-scale landslide occurred in the Bongo watershed in this period. The volume of sediment caused by the landslide reached 750,000 m^3 which is equivalent to 2,920 $m^3/year/km^2$. In accordance with the micro-topography interpretation, a number of landslide and creep areas were extracted as shown in Fig. D.2.3. Large-scale landslides have some possibility to occur in the future.

Flood terraces were also formed along the river course upstream of the mouth of mountains in the watersheds. These terraces might be deposits from previous catastrophic events such as large-scale landslide and the succeeding debris flow. In order to protect the residents in the alluvial fan, sediment control structures around the mountain mouth are indispensable.

3.5.3 Riverbed Deposits

Riverbed deposits are also secondary sources of sediment yield. The area of riverbed deposits was examined by aerial-photo interpretation. A river stretch which has similar depth and width of deposits was selected. Then the volume of riverbed deposits was estimated by multiplying the average width, the average depth and the length of river stretch. The average depth of riverbed deposits was determined by referring to the data of boring test at the irrigation diversion dams.

Dam	Maximum Depth	Average Depth
Labugaon Dam	9.0 m	6.7 m
Solsona Dam	3.5 m	2.8 m
Madongan Dam	16.7 m	9.7 m
Papa Dam	6.0 m	4.0 m
Bongo Dam	more than 18.5 m	6.2 m

The estimated volume of riverbed deposits is shown in the following table.

River	Catchment Area [A] (km^2)	Volume of Deposits [V] (1000 m^3)	Specific Volume [V/A] (m^3/km^2)
Cura	69.5	2,854	41,100
Labugaon	100.5	5,694	56,700
Solsona	79.0	1,448	18,300
Madongan	153.8	12,125	78,800
Papa	51.4	2,395	46,600
Bongo	57.0	1,926	33,800
Total	511.2	26,442	51,700

Comparing with the annual sediment yield, the volume of riverbed deposits is evaluated to have the following equivalent number of years. An enormous volume of deposits has accumulated in the Madongan, Papa and Labugaon river channels.

River	Equivalent Year of Annual Sediment Yield
Cura River	19 years
Labugaon River	28 years
Solsona River	7 years
Madongan River	37 years
Papa River	29 years
Bongo River	23 years

CHAPTER IV FLOODPLAIN TOPOGRAPHY

4.1 General

The macro-scale topography in the Laoag River Basin is illustrated in Figure D.4.1 and its components are described below.

(1) Headwaters

The Laoag River combines many tributaries draining from the Central Cordillera Mountains and finally empties into the South China Sea. The topography of the basin is heavily affected by the geological movement of the faults and folds running from north to south.

Ridges with an elevation of more than 2,000 m abound in the Central Cordillera and are classified as in a stage of maturity. The western skirts of the mountains are divided by the Solsona-Adams Fault, which is the northernmost part of the Bangui Fault crossing Northern Luzon from north to south.

(2) Solsona Basin

The Solsona-Adams Fault runs from north-northeast to south-southwest in the Laoag River Basin. The Solsona Basin is located on the west of this fault. The wide alluvial fan complex expands over this basin, and is formed by enormous sediment coming from the Central Cordillera Mountains.

The Solsona Basin is bounded on the west by the hills which run from north to south between San Nicolas and Dingras with an altitude of around 300 m. These hills are composed of tertiary sedimentary rocks, and heavily affected by the folding movement. Furthermore, the western fringe and a part of eastern fringe of the hills are divided by the faults. These hills are bounded on both east and west sides by the faults, and are relatively elevated in comparison with the outside areas, forming a so-called horst mountain.

The Solsona Basin is bounded on the north by the Boyong River Fault which runs through the Guisit River Basin from northwest to southeast separating the hills/mountains of the Guisit River Basin from the Cordillera Central Mountains. Further, the southern portion of the Solsona Basin is divided by the Ilocos Range which is a part of the Cordillera Central Mountains.

The Solsona Basin is, consequently, regarded as a fault basin with relative subsidence in terms of geomorphology.

(3) Flood Plain

Hills with elevation of about 100 m extend in the west of the horst mountain. The hills are composed of sedimentary rocks in the Pliocene to the Pleistocene. Furthermore, a coastal plain develops west of the hills. It consists of sand dunes and swampy areas between them.

After joining the tributaries running on the alluvial fan complex, the Laoag River flows down through the narrow path located between Dingras and San Nicolas. The river course breaks a path through the horst mountain as a transverse valley. In this stretch, the flood plain is not well developed.

After passing the narrow path of the horst mountain, the Laoag River flows down forming the wide flood plain, and finally empties into the South China Sea. Regarding meander, the old channel can be identified in the east of Laoag City proper. This implicitly indicates that the main stream or the distributary of the Laoag River flowed down along the present Daorao creek channel in times past. The Laoag River has gradually incised its present channel and, as a result, the flood plain is transformed into a terrace-like topography.

4.2 Geomorphologic Classification of Micro-topography

After the literature and field survey, the micro-topographic components in the alluvium are finally classified through aerial-photo interpretation by using photos with scale of 1:20,000 taken in 1996. This geomorphological map is presented in Fig. D.4.2. Each micro-topography is explained below.

(1) Alluvial Fan

Alluvial fan is classified into two categories, namely major tributaries and others, in terms of the scale of alluvial fan and its watershed.

(a) Major Tributaries

The alluvial fan complex is mainly formed by sediment supplied from six major tributaries, Cura, Labugaon, Solsona, Madongan, Papa and Bongo. The Solsona, Madongan and Papa rivers form a wide spreading alluvial fan, while the other rivers form a long- and narrow-shaped fans, being restricted by the surrounding topography of terraces and hills.

Among the former tributaries, the fan of the Solsona River has a slightly different shape. Along the Solsona River, the fan is developed from the apex to the confluence with the Cuyep-Cuyep River on the left bank, and to Solsona town proper on the right bank. On the right bank, fan development by the Cura/Labugaon River is predominant downstream of the Solsona town proper. In further downstream area, the Solsona fan appears again around Barangay Bagbago and Lumbad.

The Cura and Labugaon rivers form individual alluvial fans in a stretch of 1 to 1.5 km downstream from each fan apex, while one fan is formed by both rivers in the lower reaches. This Cura/Labugaon fan is bounded on the north side by the hills, and on the south by the Solsona fan.

The Bongo River forms an alluvial fan, being restricted by terraces on the both sides. The lower reaches of the Cabulalaan River can be regarded as an old channel of the Bongo River.

In the alluvial fan complex, the following micro-topography are interpreted:

i) Old channels;
ii) Gully eroding fan surface; and
iii) Natural levee

There is a high possibility that flood waters overbank the main channel and rush down through an old channel. Furthermore, if the flood water contains much sediment and deposits it in the channel, the flood water will spread over the alluvial fan. Thus, any place in the alluvial fan has some possibility to be inundated by floods.

(b) Others

Many small tributaries form small- to mid-scale alluvial fans just downstream of the mouth of their mountain valleys. In particular, the Cuyep-cuyep and

Cabulalaan rivers form mid-scale fans between large-scale fans formed by major tributaries, Solsona and Madongan, Papa and Bongo, respectively. These fans have steeper slopes compared to the large-scale fans.

(2) Valley Plain

Valley plain is classified into two categories; namely, fan-like plain and valley plain. Their difference originates from the surrounding topography.

(a) Fan-like Plain

If hills or plateaus expand along the downstream reach of the mouth of a mountain valley, alluvium with fan-shape cannot be fully developed in this reach. Fan-like plain has, transversely, their highest elevation at the center of a valley and has sediment deposits with large grain size. These are typical characteristics of the alluvial fan.

The typical fan-like plain can be seen in the Guisit River Basin.

(b) Valley Plain

Valley plain is formed along the river course where hills and plateaus further restrict the development of fan-shaped topography. Typical cross-section of the valley plain has a flat or concave shape.

During large floods, flood water tends to flow down on the whole cross-section of valley plain. Micro-topography of natural levee and old channel can be seen in the valley plain, so that flood water also tends to flow down through the old channel during mid-scale floods.

(3) Flood Plain

Flood plain was developed mainly on the left bank in a stretch from the confluence of the Papa and the Bongo rivers to the bend in Sarrat and on both sides of the lower reaches of the Laoag River. Flood plain is elevated a few meters from the present riverbed resulting in terrace-like topography.

Flood plain has flat topography in general. However, in detail it consists of a relatively higher portion near the riverbank and gradually reducing its elevation as it set apart from the bank. The former high portion is called natural levee, and the towns proper of Dingras, San Nicolas and Laoag are located in such portion. Old river channels can be observed also in the flood plain. One of the well developed old channels can be identified in the downstream portion of San Nicolas.

(4) River Terrace

Major river terraces are located along the right bank of the Cura River and along the upper Bongo River. These terraces can be regarded as diluvial terrace, because of the difference in height of the present riverbed and the gully developed on its surface. Other small terraces are found in the Cabulalaan River, in Sarrat town proper and in the convex bank of the Sarrat bend.

River terrace along the right bank of the Cura River has a step-like structure. The lowest terrace is situated about 10 m above the alluvial fan surface. Flat surface expands widely with a gully slightly developing on the surface. Near the hills it is covered by colluvial deposits. The highest terrace is about 40 m above the alluvial fan surface.

On the contrary, river terrace along the upper Bongo River is situated 20 to 30 m above the present riverbed. This terrace is an elevated fan which was originally formed by the Bongo River, and since then had been dissected. Both town proper of Nueva Era and Banna are located on such terrace.

(5) Sand Dune

Sand dune is classified into two categories; namely, stabilized dune and unstabilized dune.

(a) Stabilized Dune

Along the coastal line, stabilized dune expands 1.5 to 2 km wide and is utilized as farmland. There are some rows of marshland between the dune and is utilized as paddy fields.

(b) Unstabilized Dune

With the Laoag river mouth as the center, unstabilized dune extends 1 to 1.5 km wide between the coastal line and the stabilized dune. Although aforestation is being pursued by DENR, this dune remains very unstable.

(6) Natural Levee

Natural levees are not well developed along the Laoag River course and on the alluvial fan complex. The towns of Laoag, San Nicolas, Sarrat and Solsona are situated in this limited area. In the left bank downstream of San Nicolas, most villages are concentrated on natural levee areas.

(7) Old River Channel

Old river channel is a former river course in the alluvium and has relatively lower elevation compared with the surrounding areas. Thus, overbanking floodwaters tend to rush down through the old channel and dike breach occurs at the divergent point to the old channel.

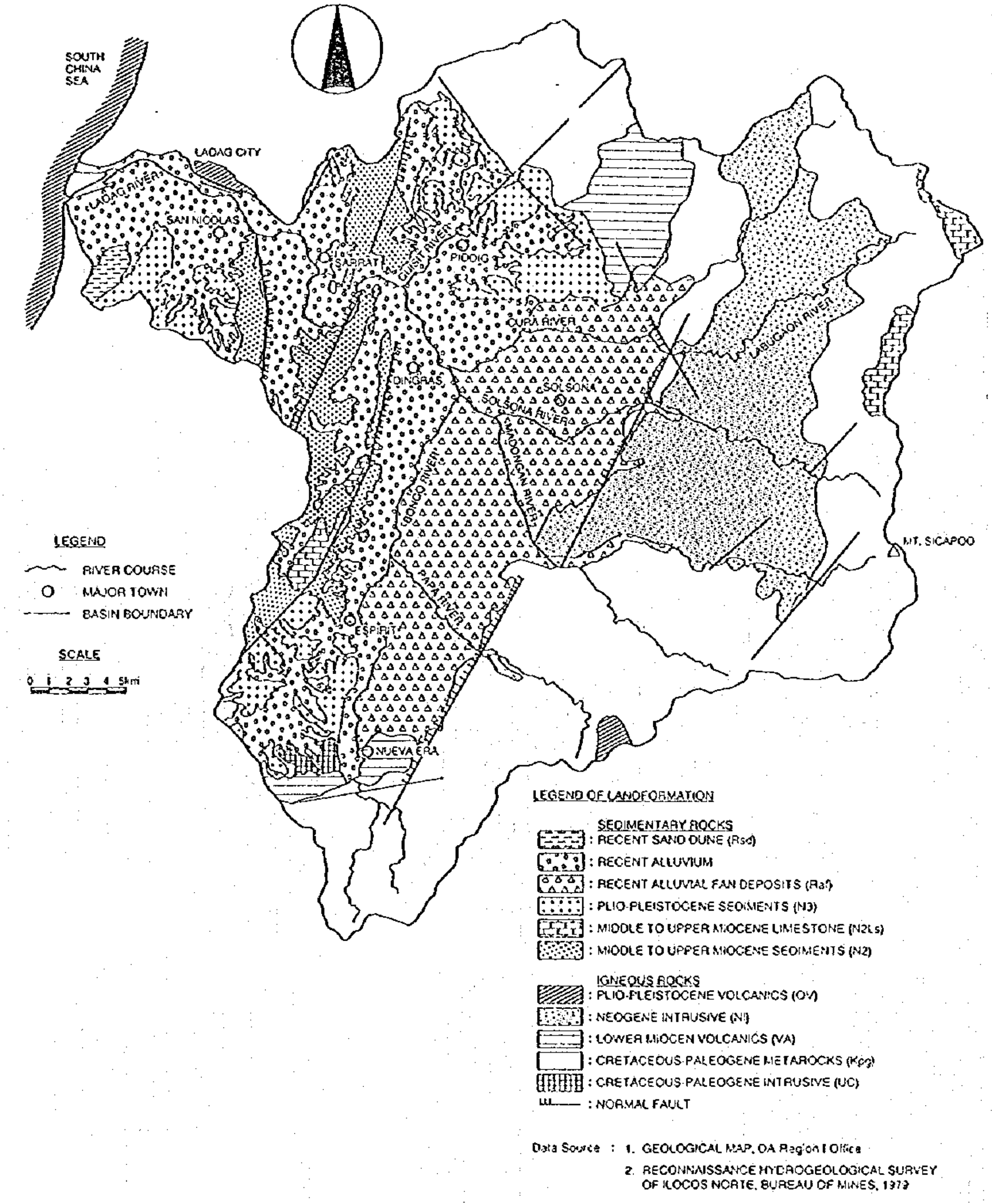
There are numerous old river channels in the alluvial fan complex, particularly in the fan of Madongan River. Papa and Solsona rivers have few former main streams in their fans. On the contrary, no former main stream can be identified in the Cura, Labugaon and Bongo rivers though many old channels exist there.

In the flood plain in the lower reaches, old river channels can be clearly identified in the left bank downstream of San Nicolas. In particular, there is a large one which runs through Barangay Aramiw and Mangato East. Further, another large old channel runs in the east of Laoag City proper. This channel connects with Daorao creek which is an independent river system beside the Laoag River system. It indicates that the main stream or some parts of the Laoag River flowed down the northern part of Laoag City in times past.

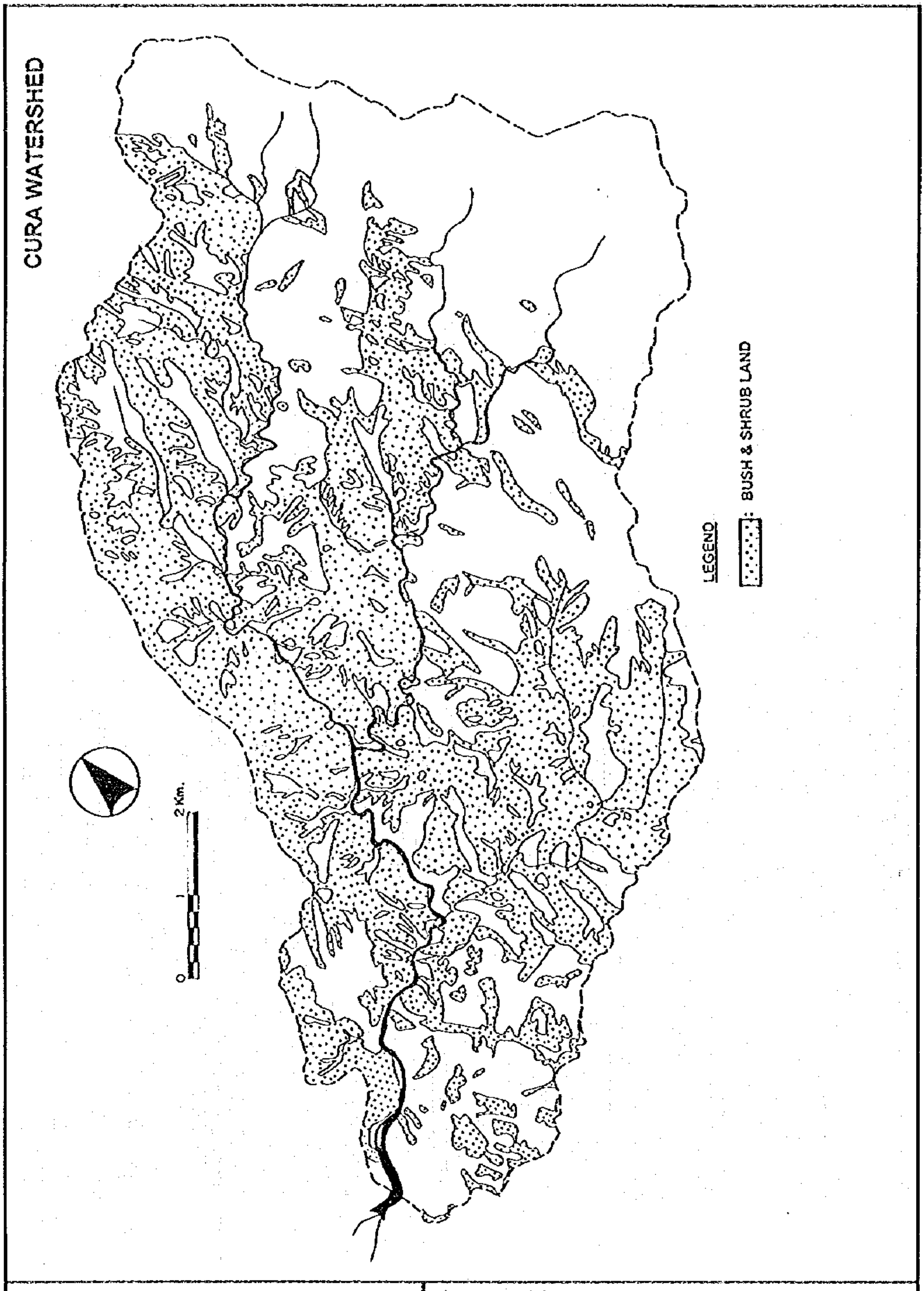
(8) Riverbed and Sand Bar/High-water Bank

The present river channel is composed of the riverbed and sand bar/high-water bank. The difference in elevation between riverbed and high-water bank ranges from 2 to 5 m. Usually high-water bank is submerged by small-scale flood of about 2-year recurrence.

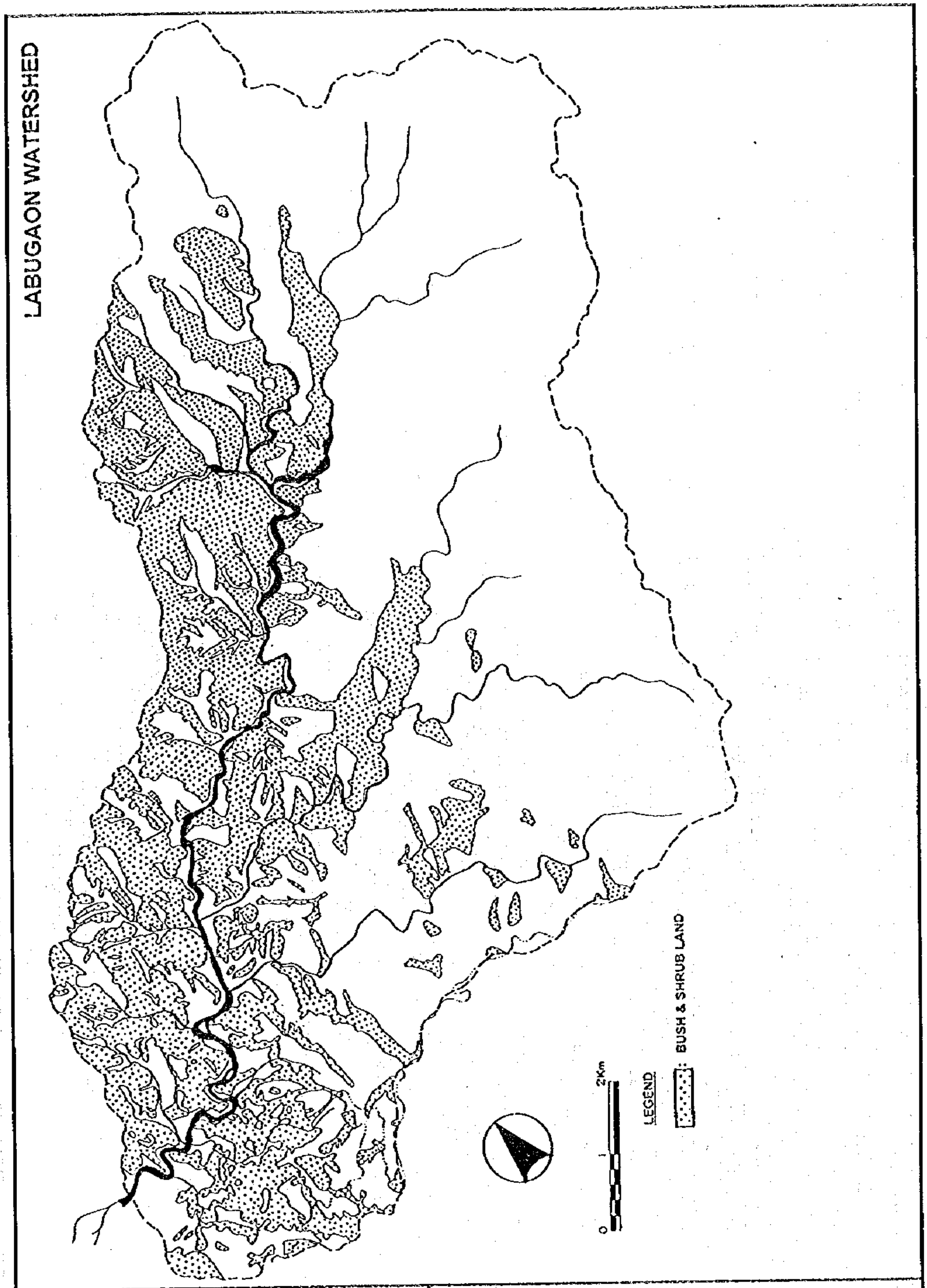
FIGURES



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.1.1 Geological Map in Laoag River Basin



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.2.1 (1) Bush and Shrub land in Cura Watershed

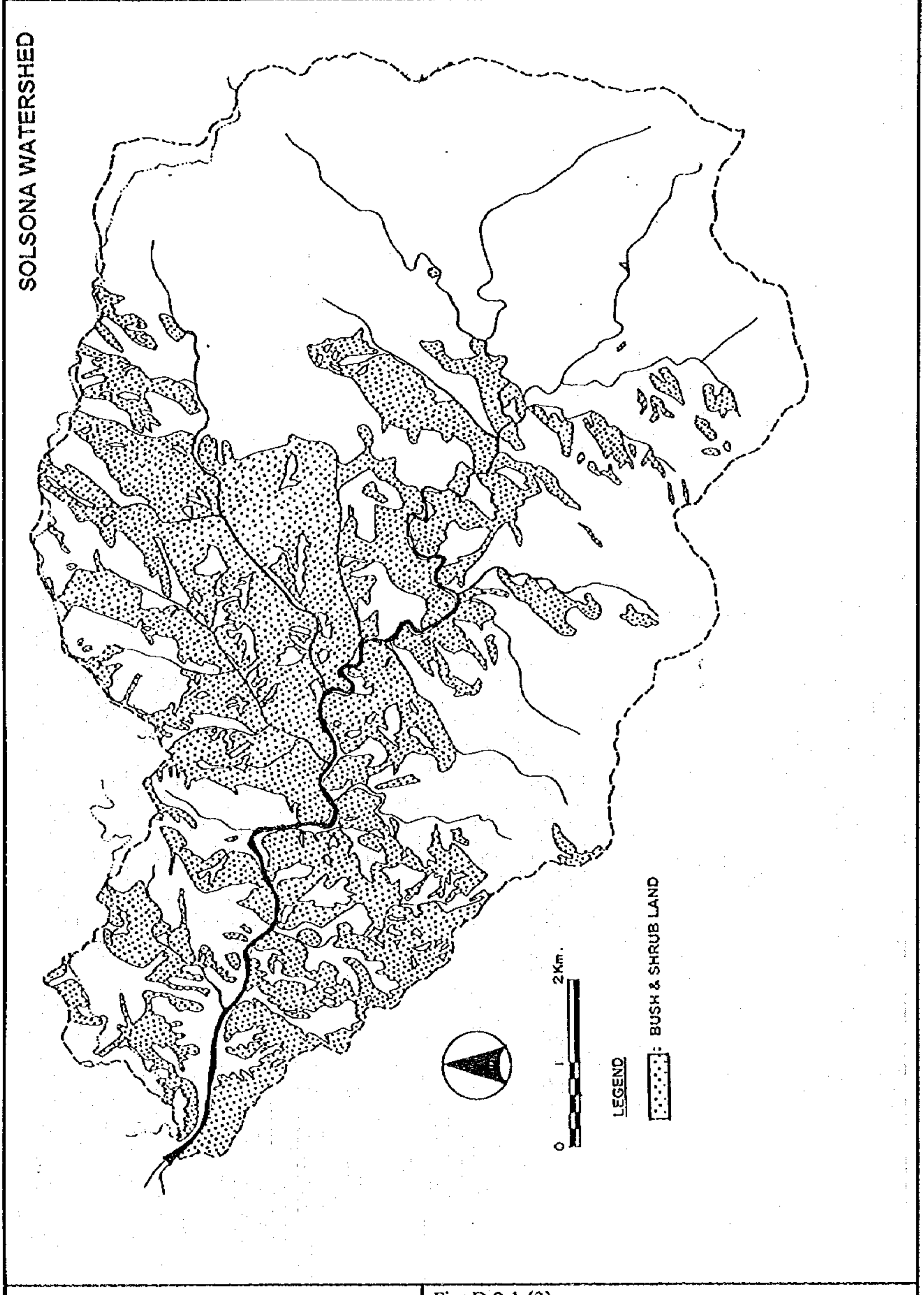


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

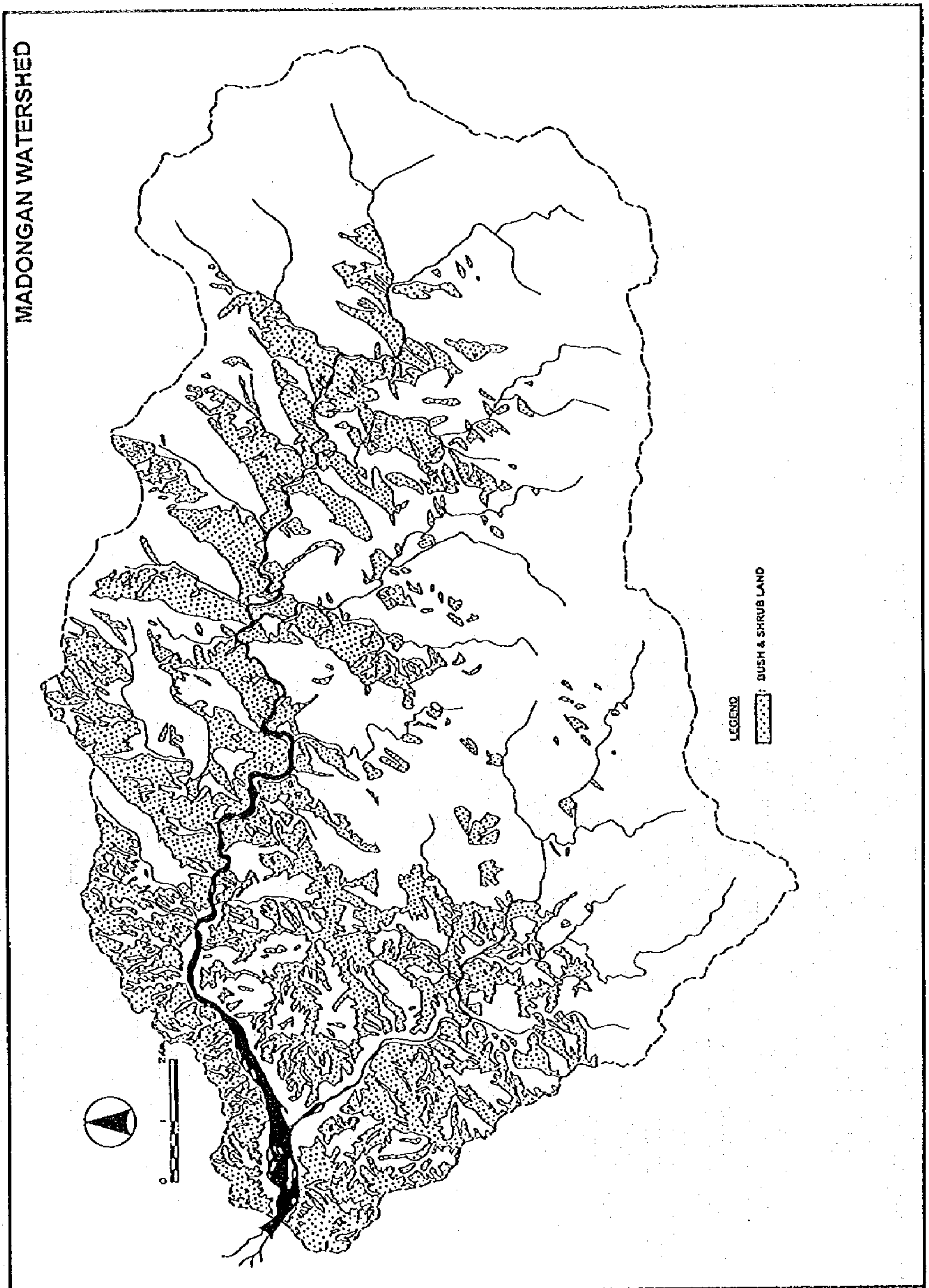
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. D.2.1 (2)

Bush and Shrub land in Labugaon Watershed



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.2.1 (3) Bush and Shrub land in Solsona Watershed

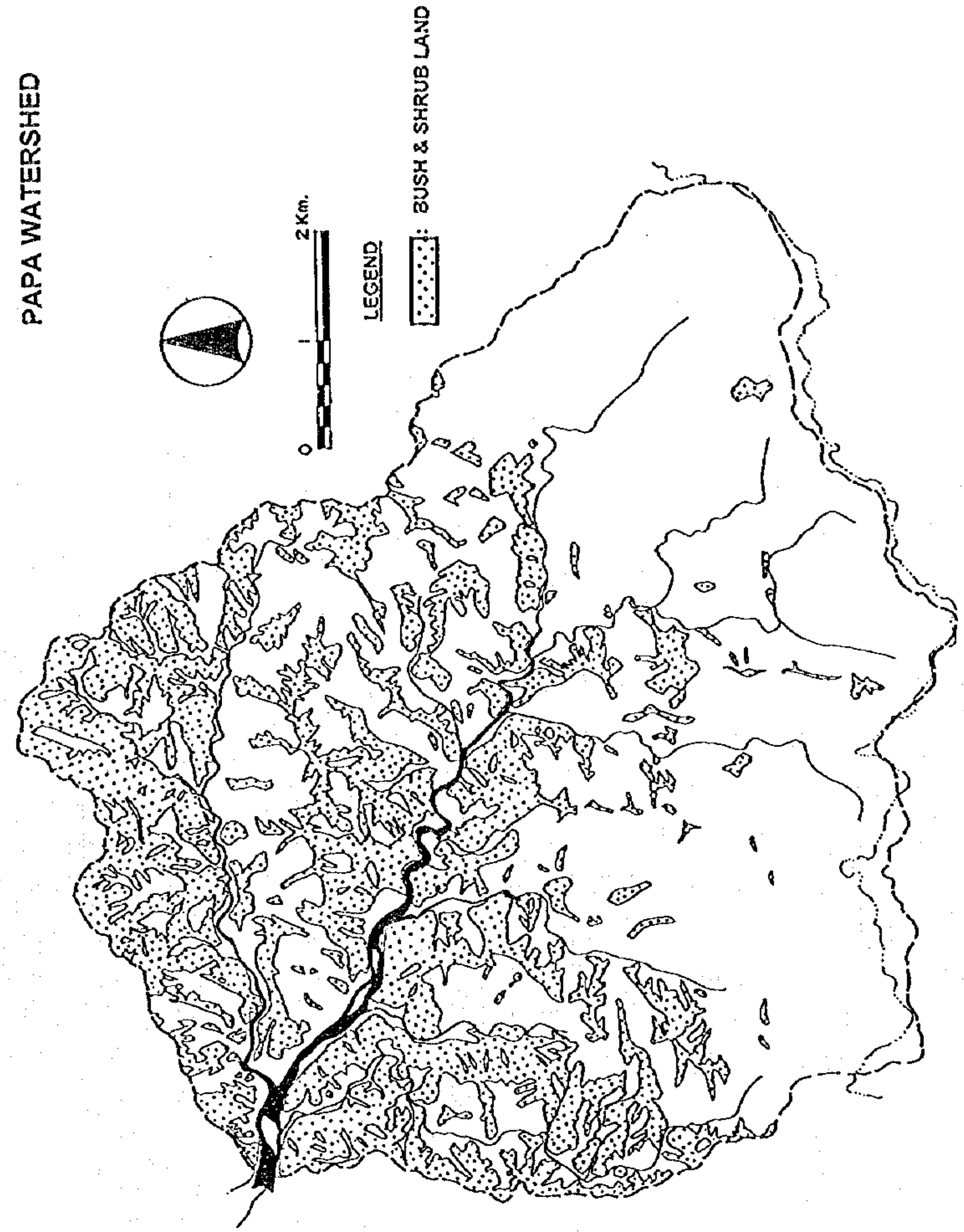


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

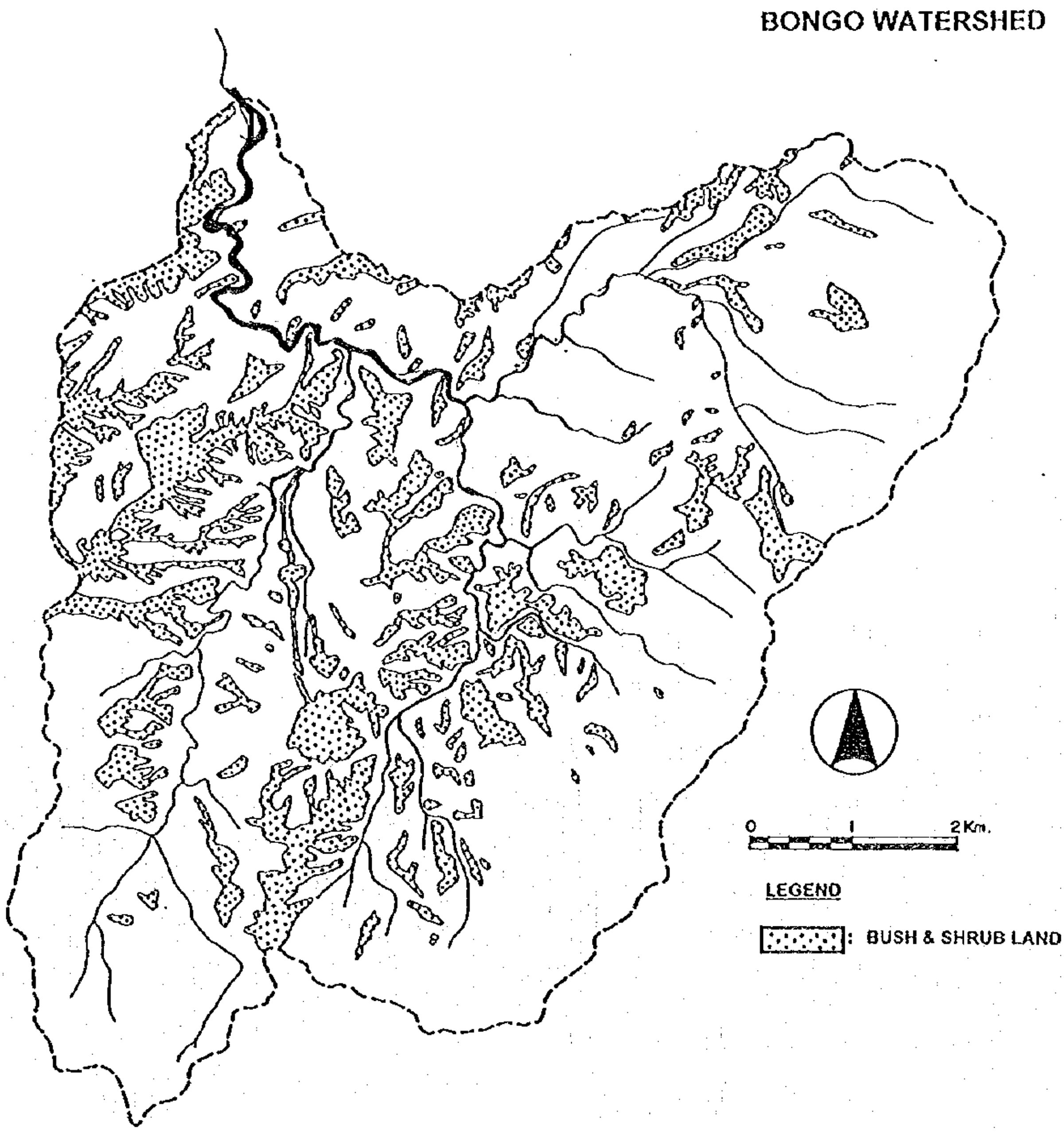
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. D.2.1 (4)

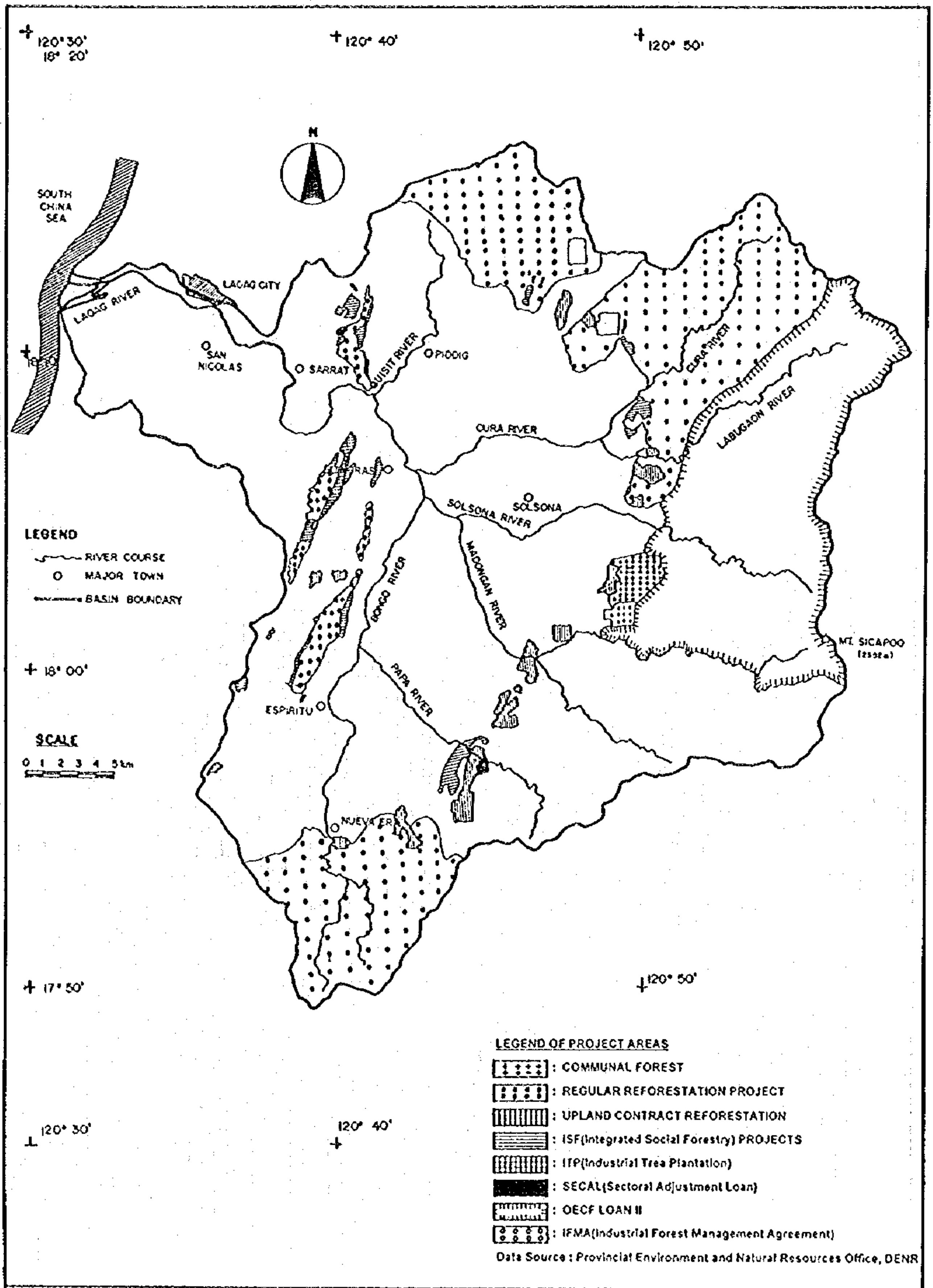
Bush and Shrub land in Madongan Watershed



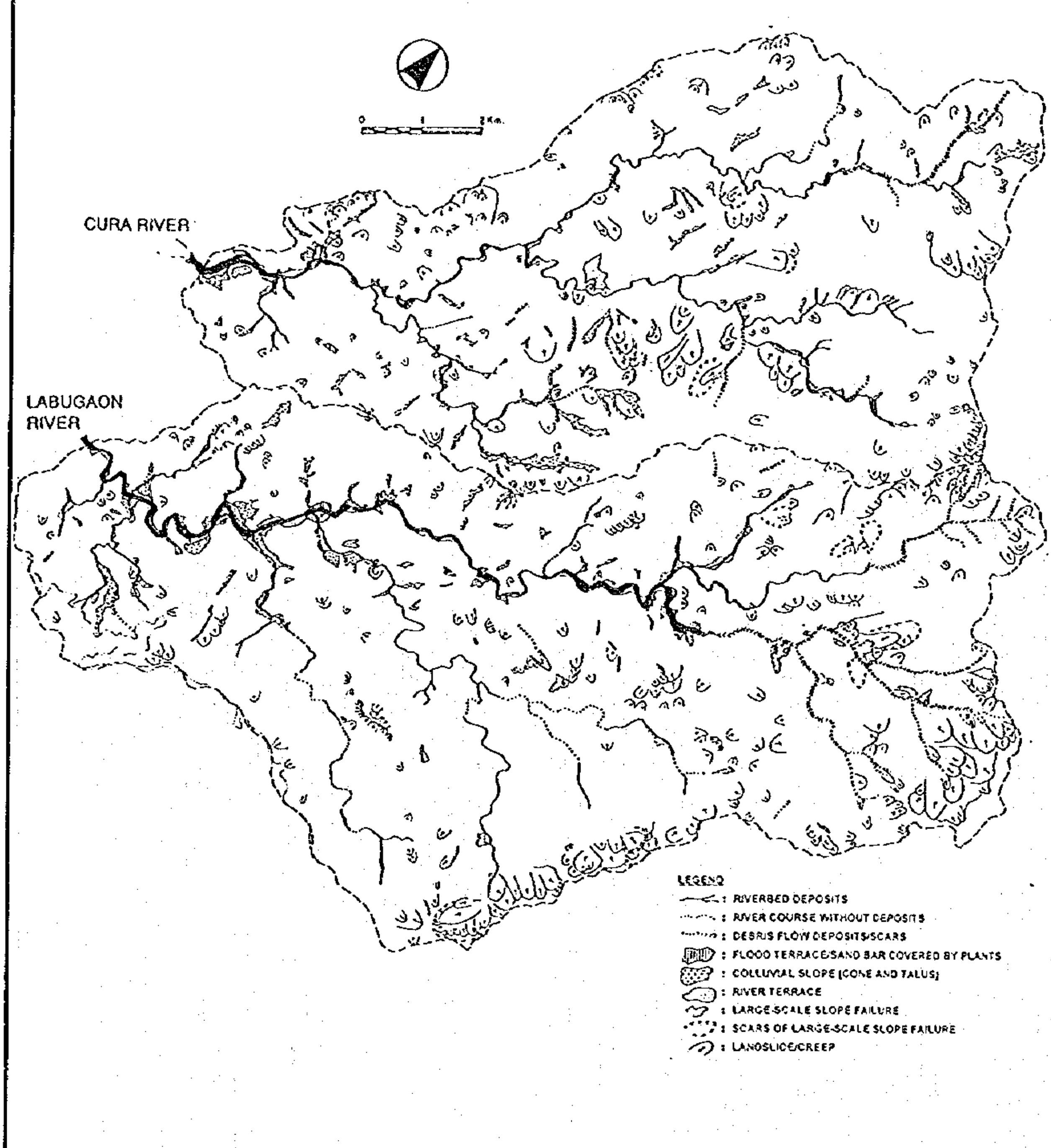
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.2.1 (5) Bush and Shrub land in Papa Watershed



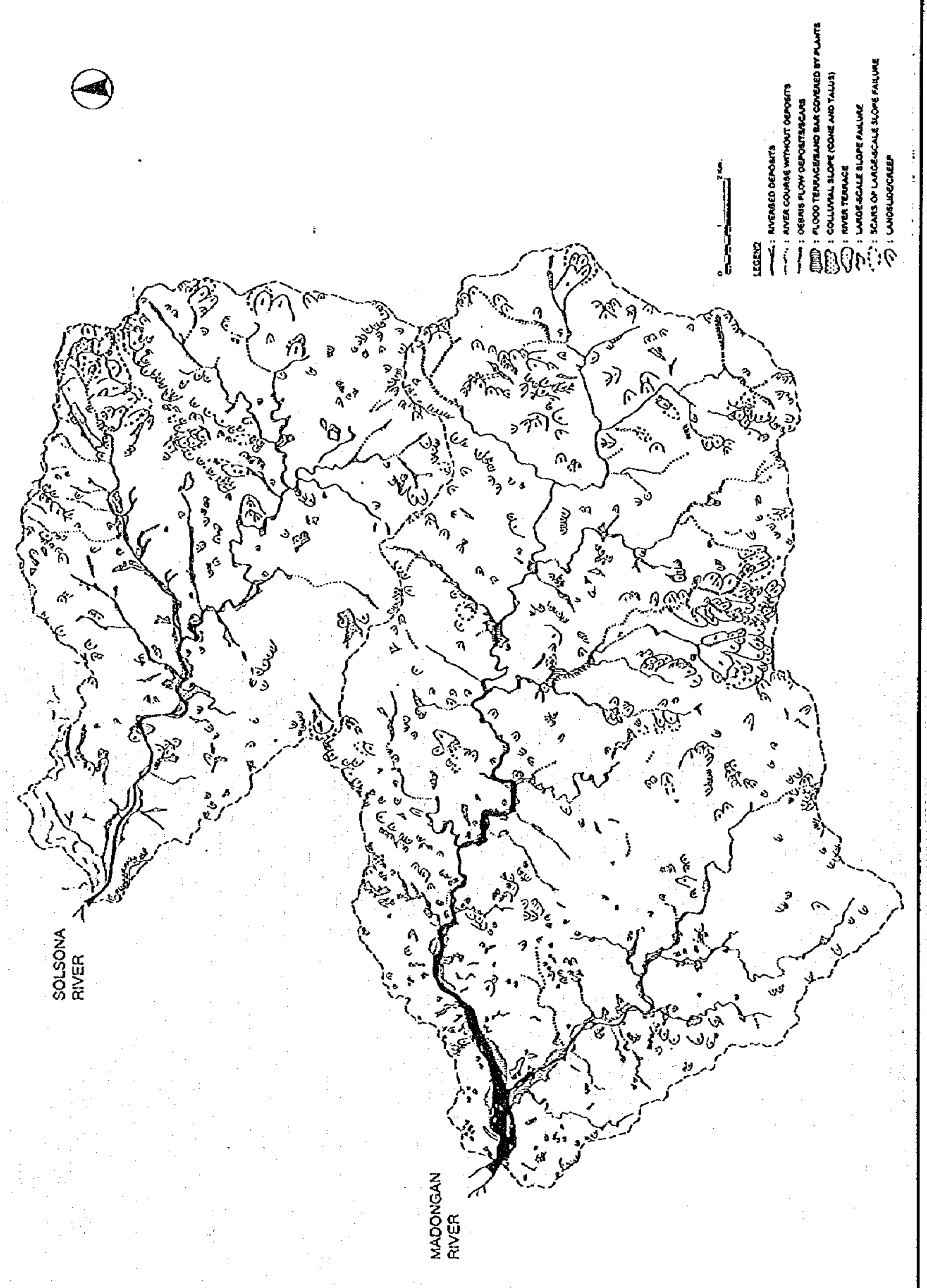
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.2.1 (6)
JAPAN INTERNATIONAL COOPERATION AGENCY	Bush and Shrub land in Bongo Watershed



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.2.2
JAPAN INTERNATIONAL COOPERATION AGENCY	Reforestation Project Area



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.3.1 (1) Micro-topography Related to Sediment Yield in Cura and Labugaon Watersheds

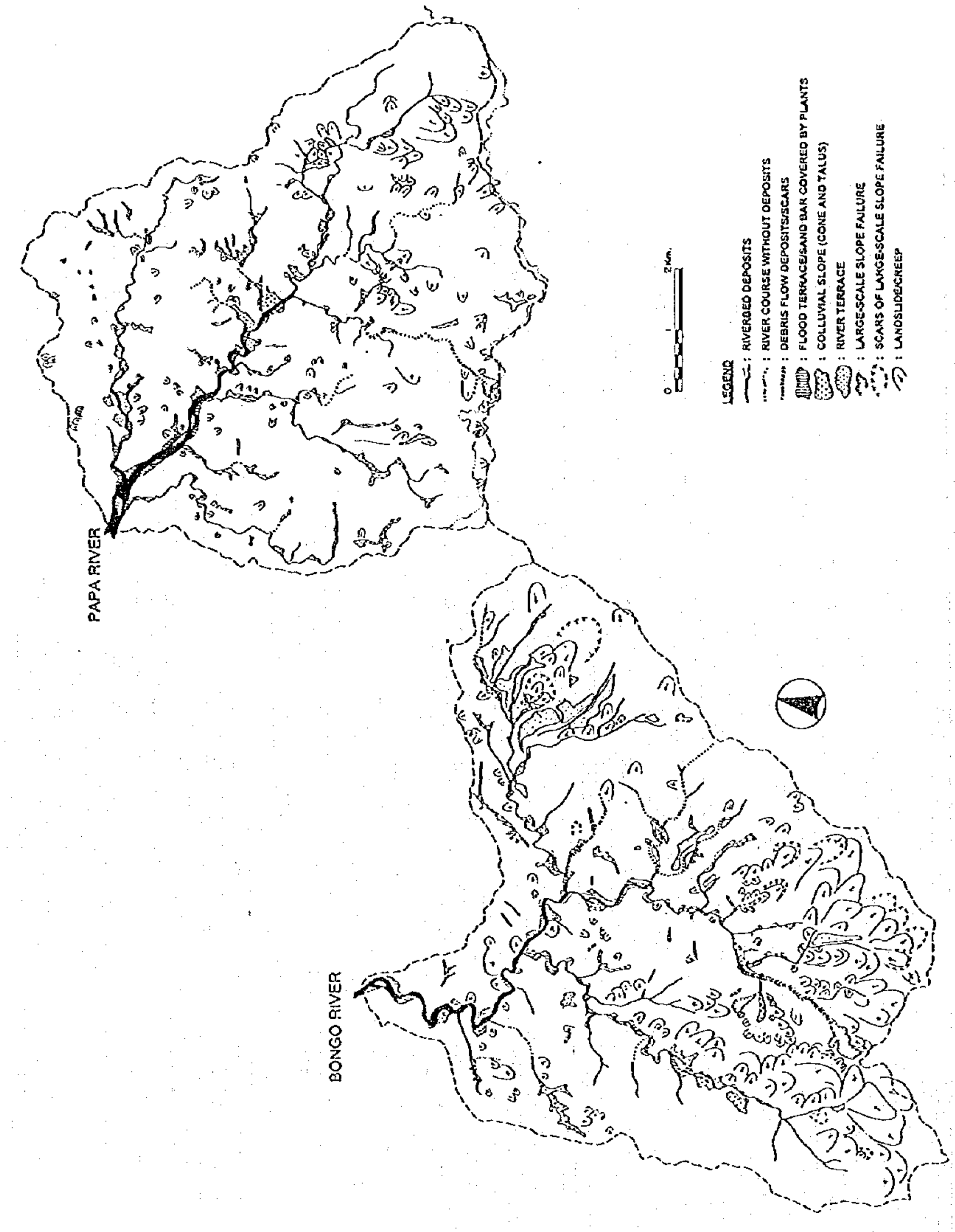


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

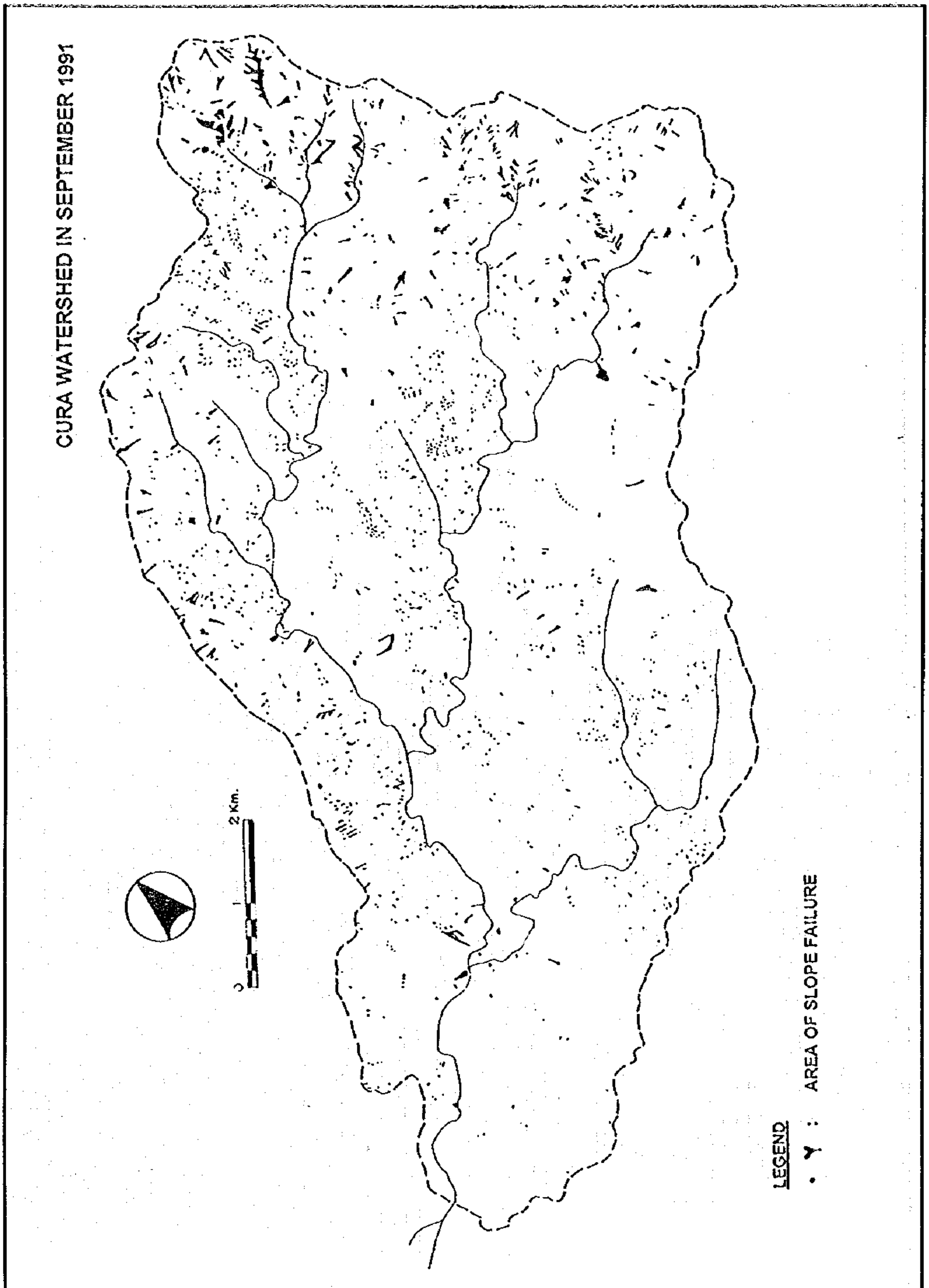
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. D.3.1 (2)

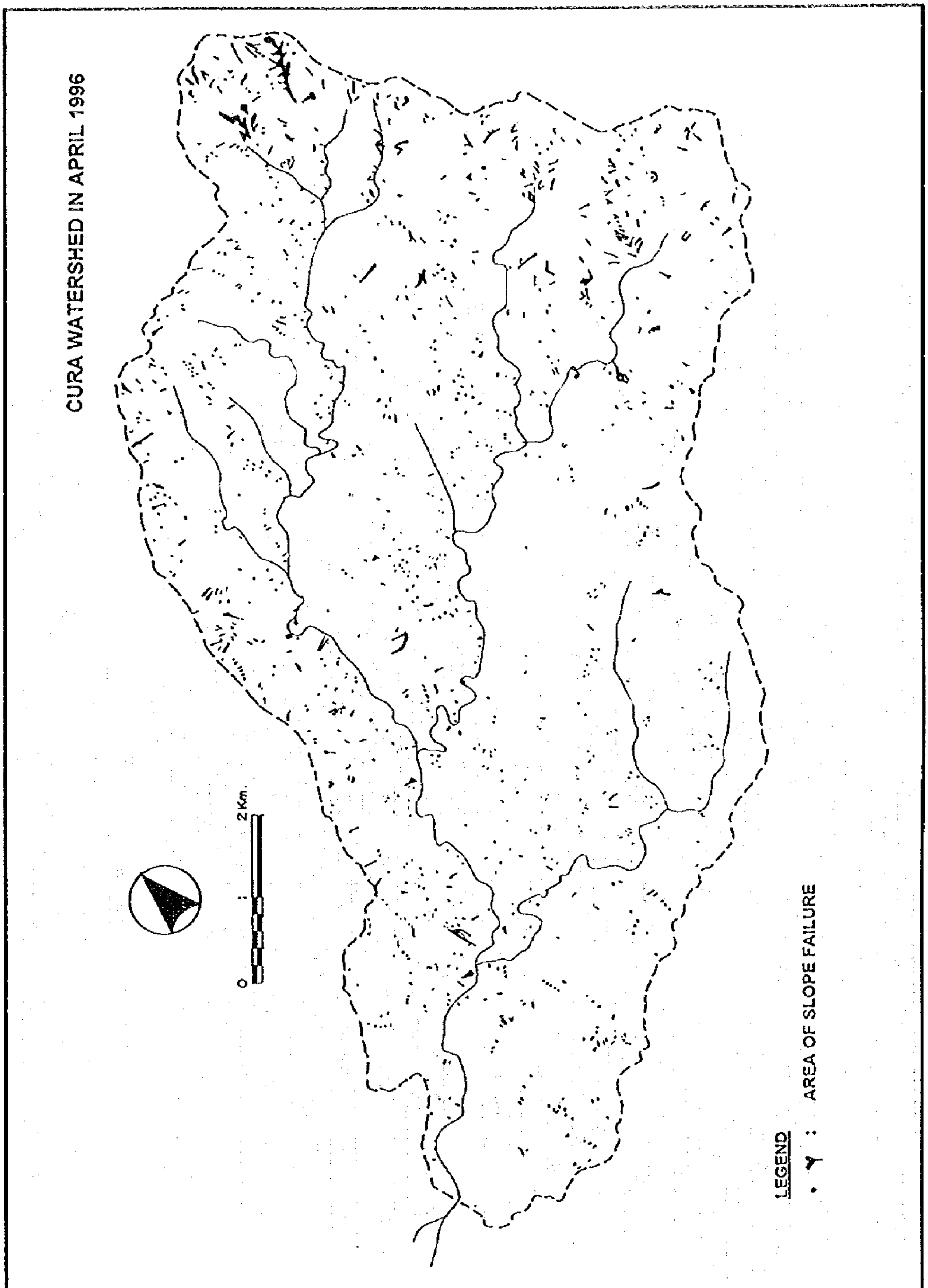
Micro-topography Related to Sediment Yield in Solsona and Madongan Watersheds



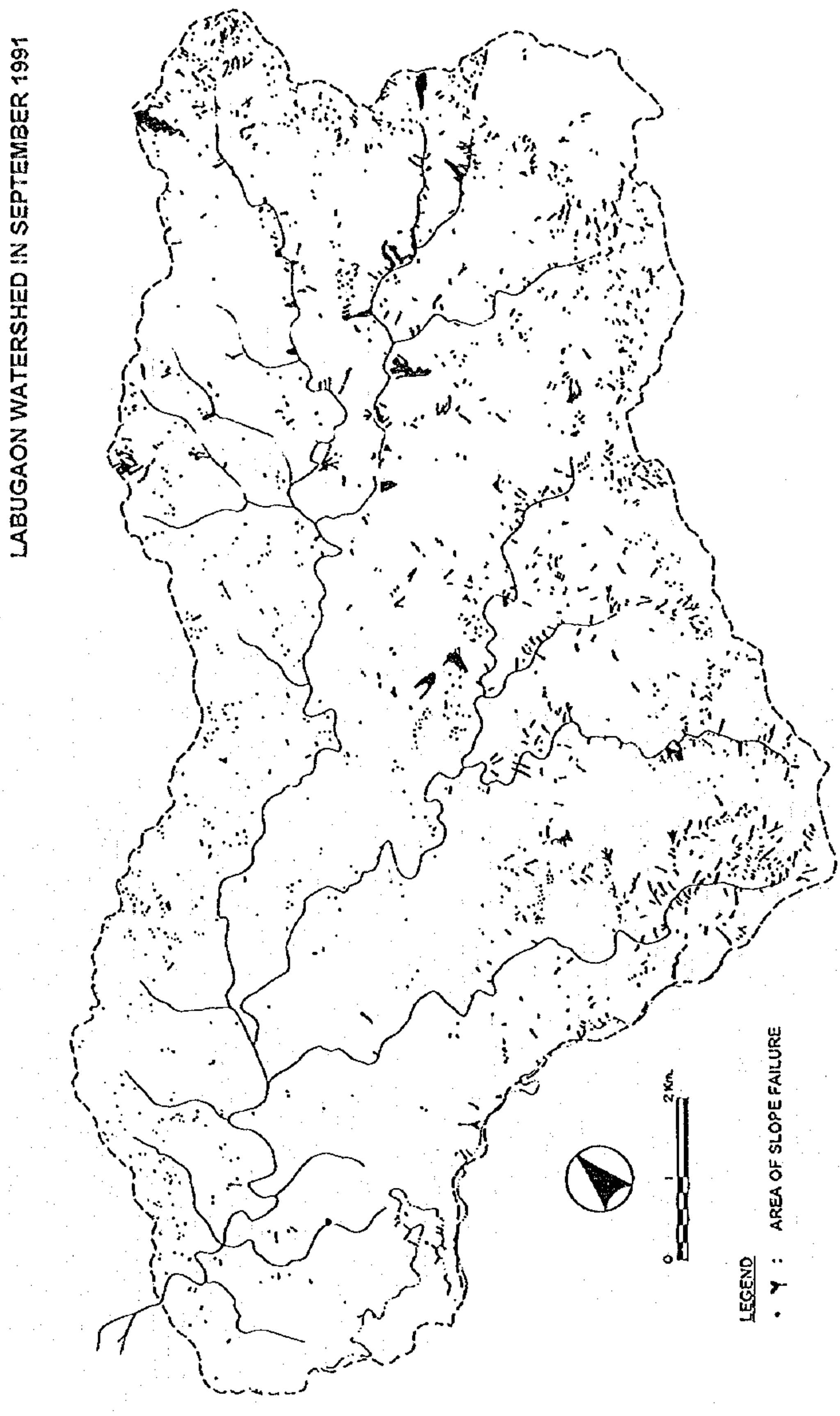
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.1 (3)
JAPAN INTERNATIONAL COOPERATION AGENCY	Micro-topography Related to Sediment Yield in Papa and Bongo Watersheds



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.3.2 (1) Area of Slope Failure in Cura Watershed, 1991



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (2)
JAPAN INTERNATIONAL COOPERATION AGENCY	Area of Slope Failure in Cura Watershed, 1996

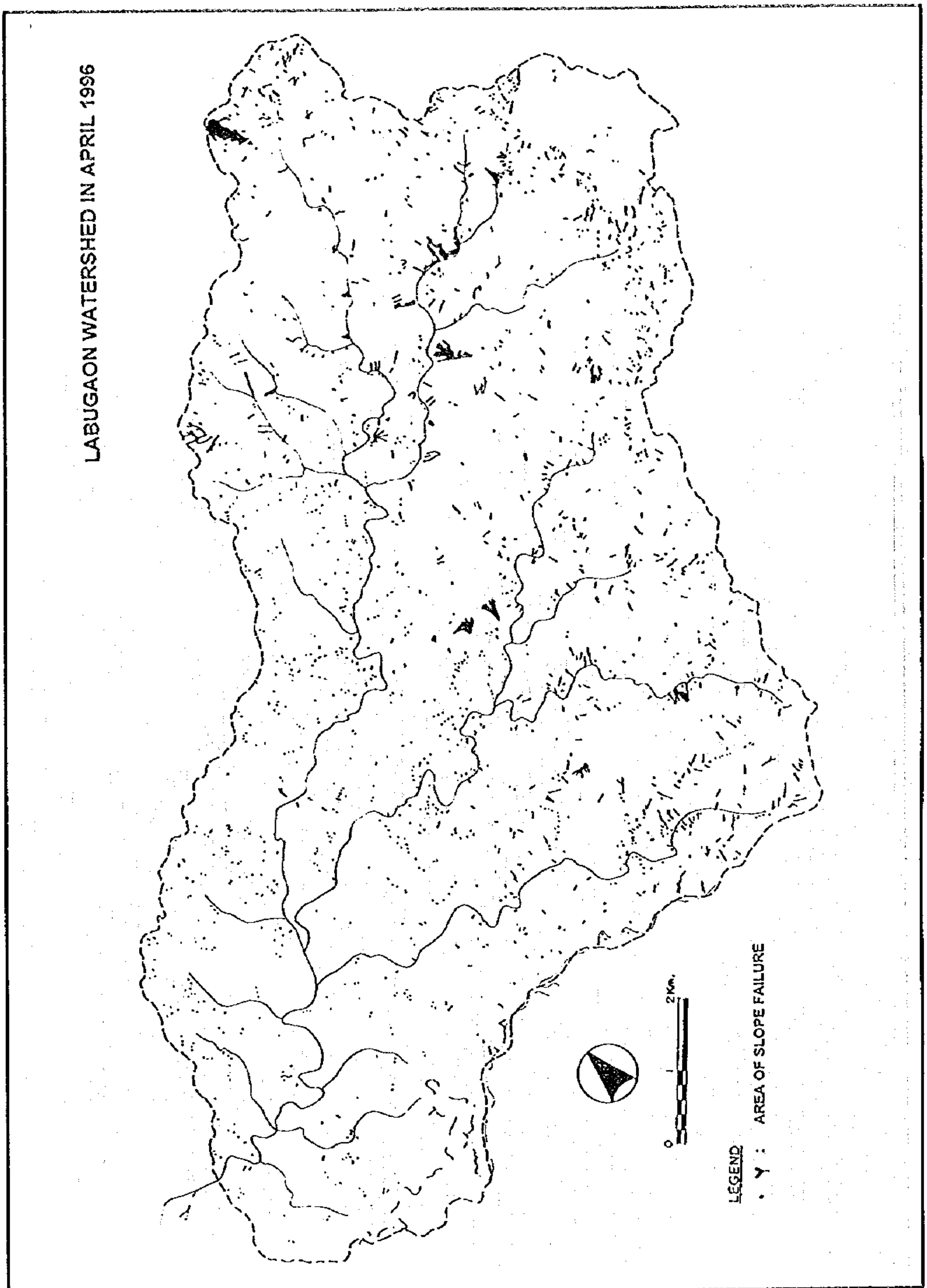


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

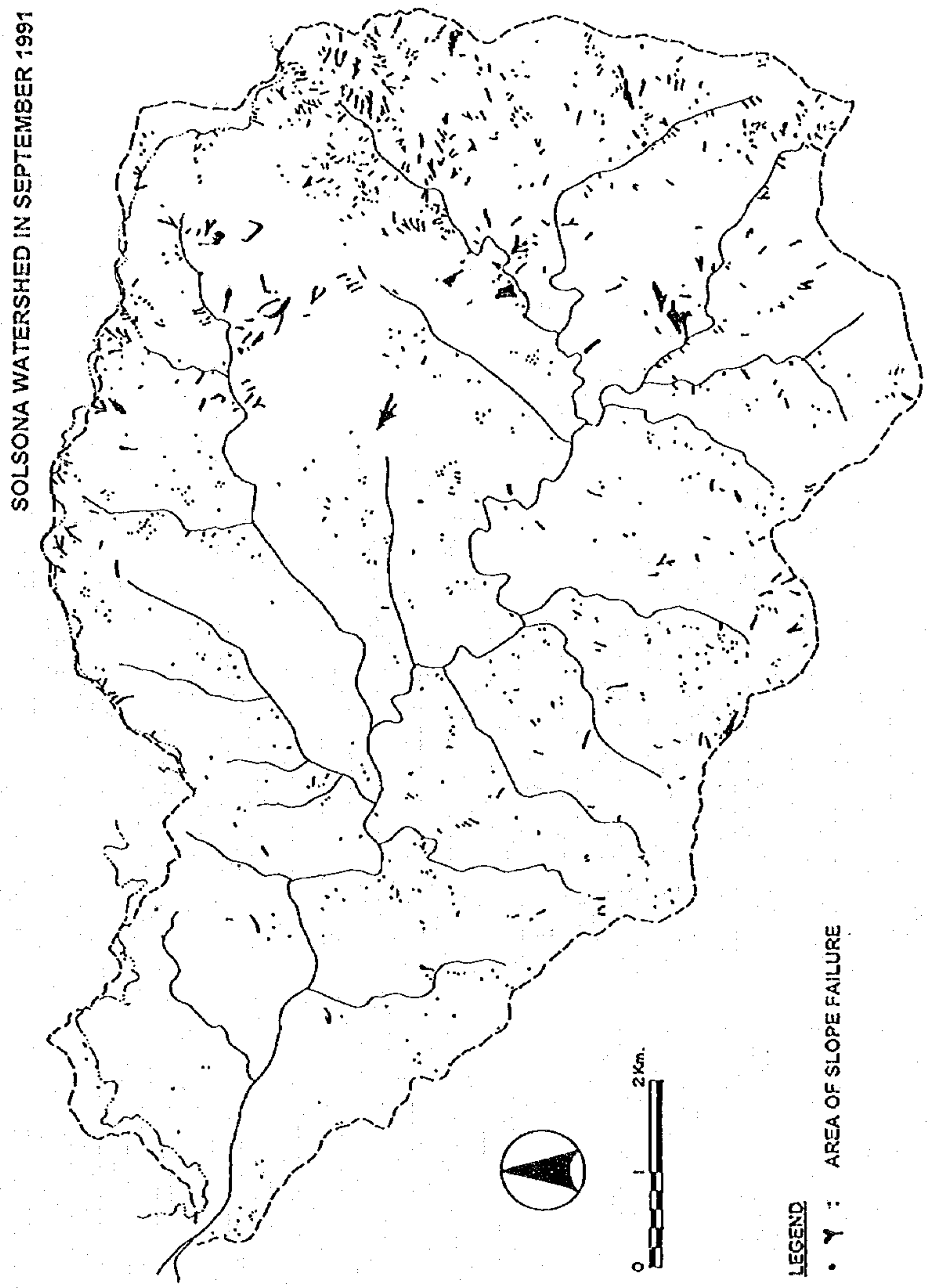
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. D.3.2 (3)

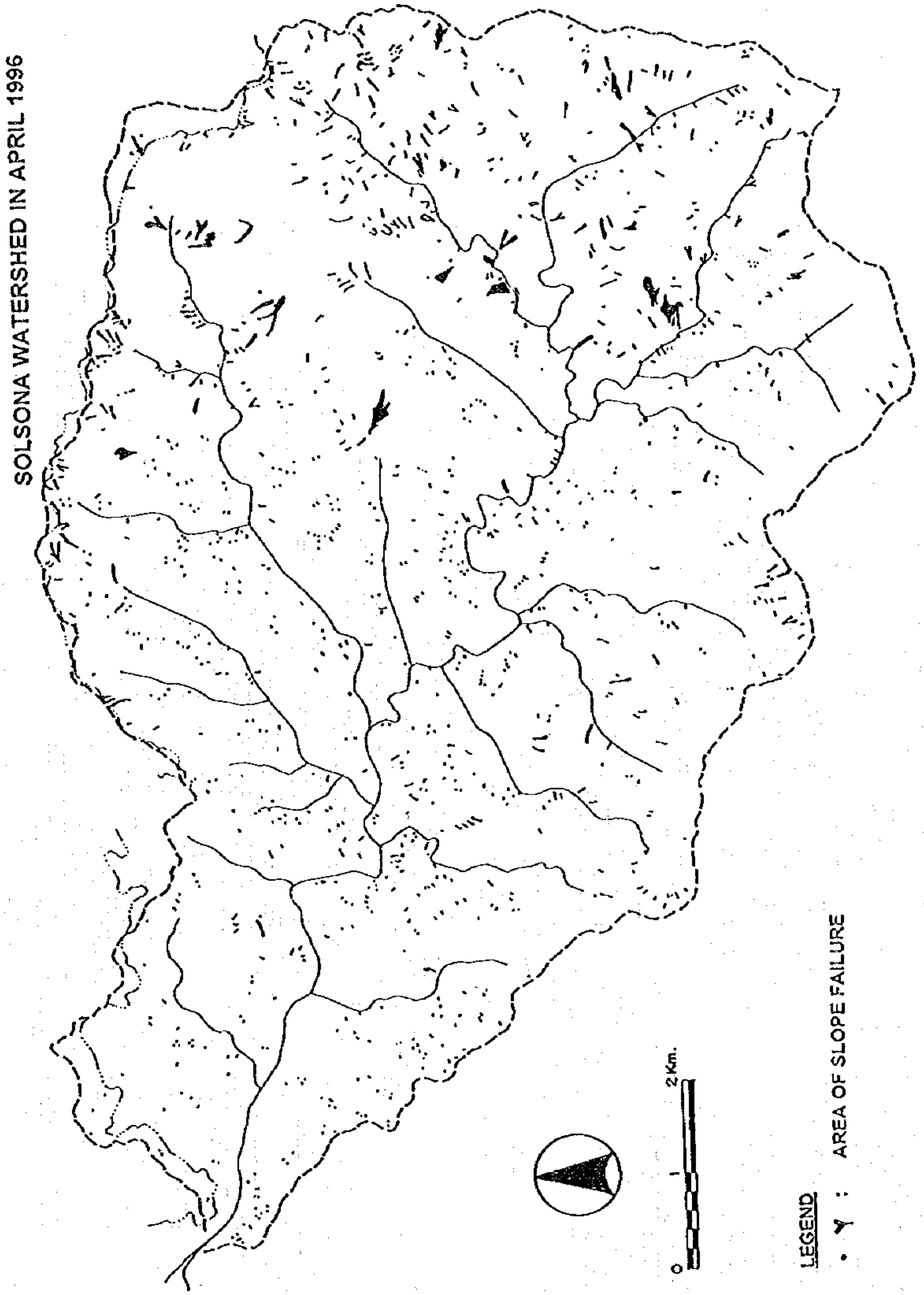
Area of Slope Failure in Labugaon Watershed, 1991



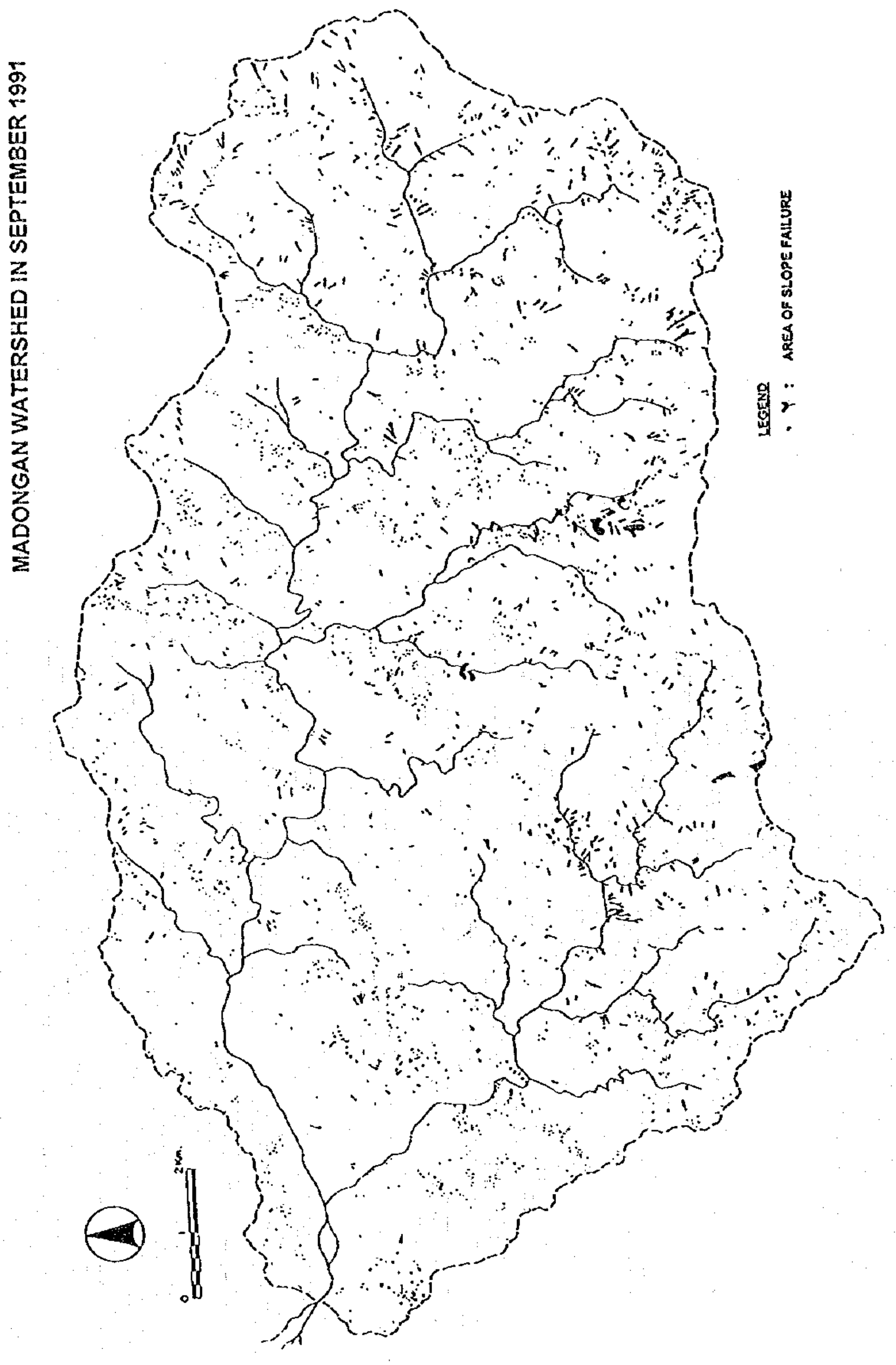
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (4) Area of Slope Failure in Labugaon Watershed, 1996
JAPAN INTERNATIONAL COOPERATION AGENCY	



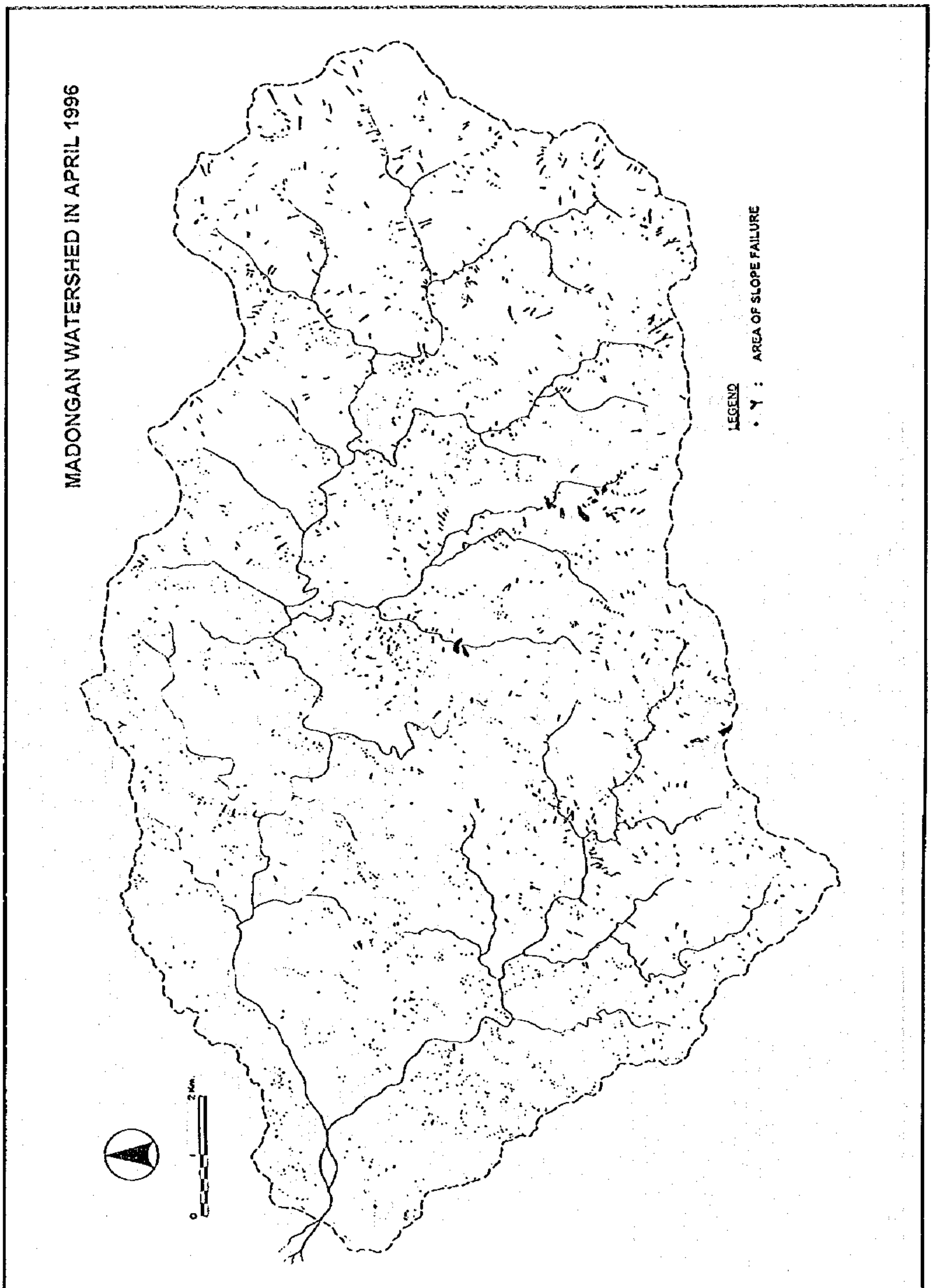
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.3.2 (5) Area of Slope Failure in Solsona Watershed, 1991



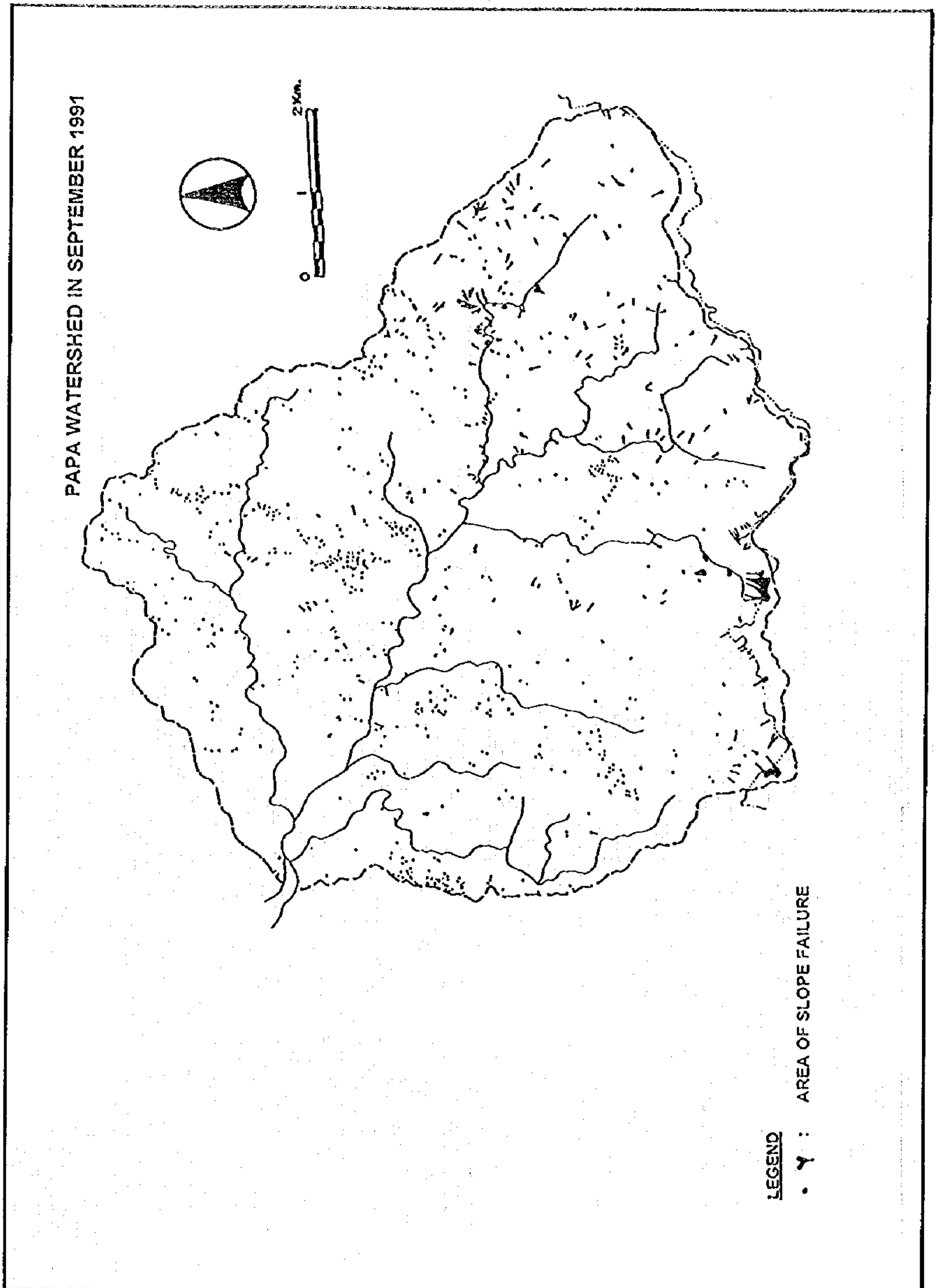
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (6)
JAPAN INTERNATIONAL COOPERATION AGENCY	Area of Slope Failure in Solsona Watershed, 1996



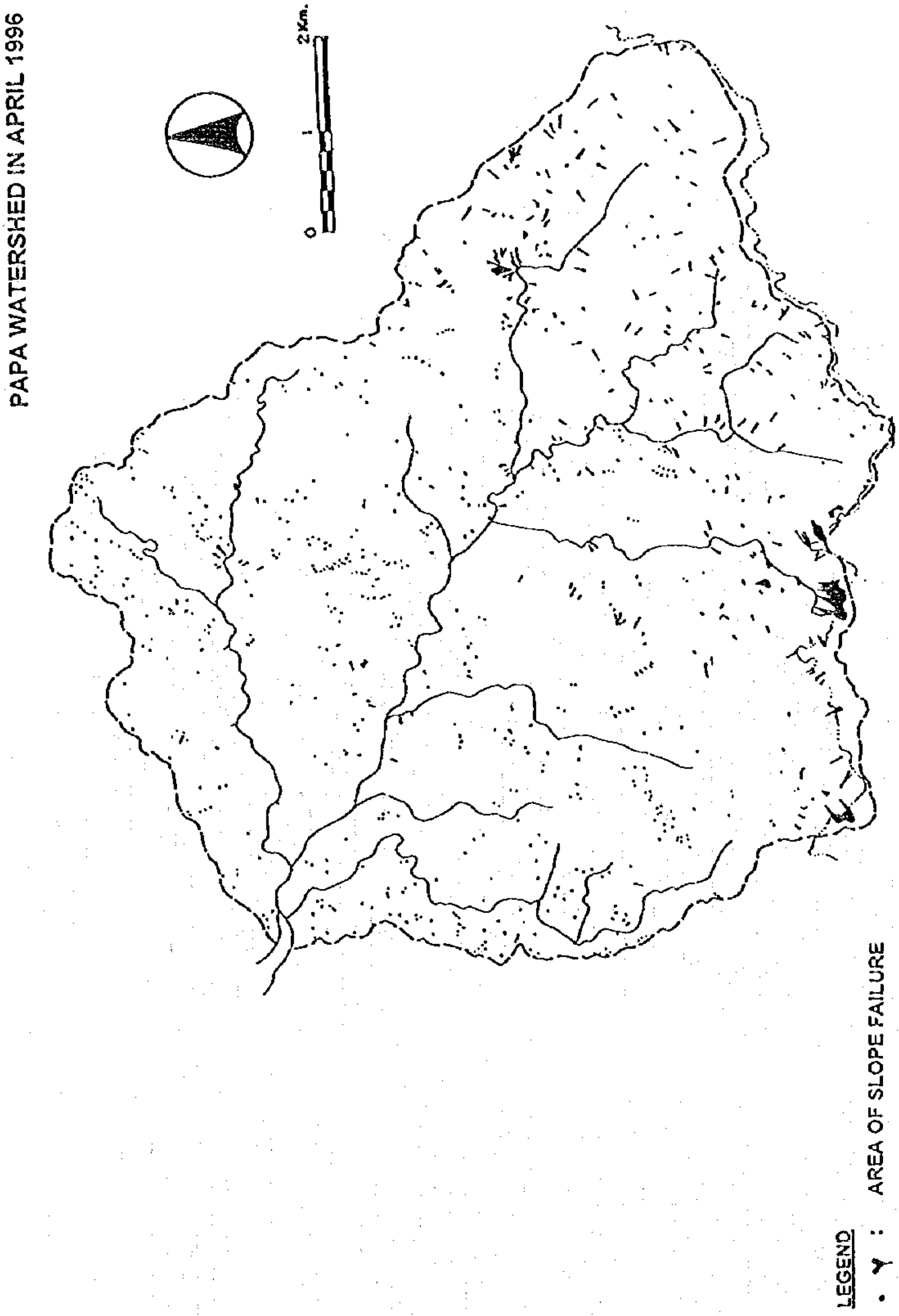
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (7)
JAPAN INTERNATIONAL COOPERATION AGENCY	Area of Slope Failure in Madongan Watershed, 1991



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (8)
JAPAN INTERNATIONAL COOPERATION AGENCY	Area of Slope Failure in Madongan Watershed, 1996

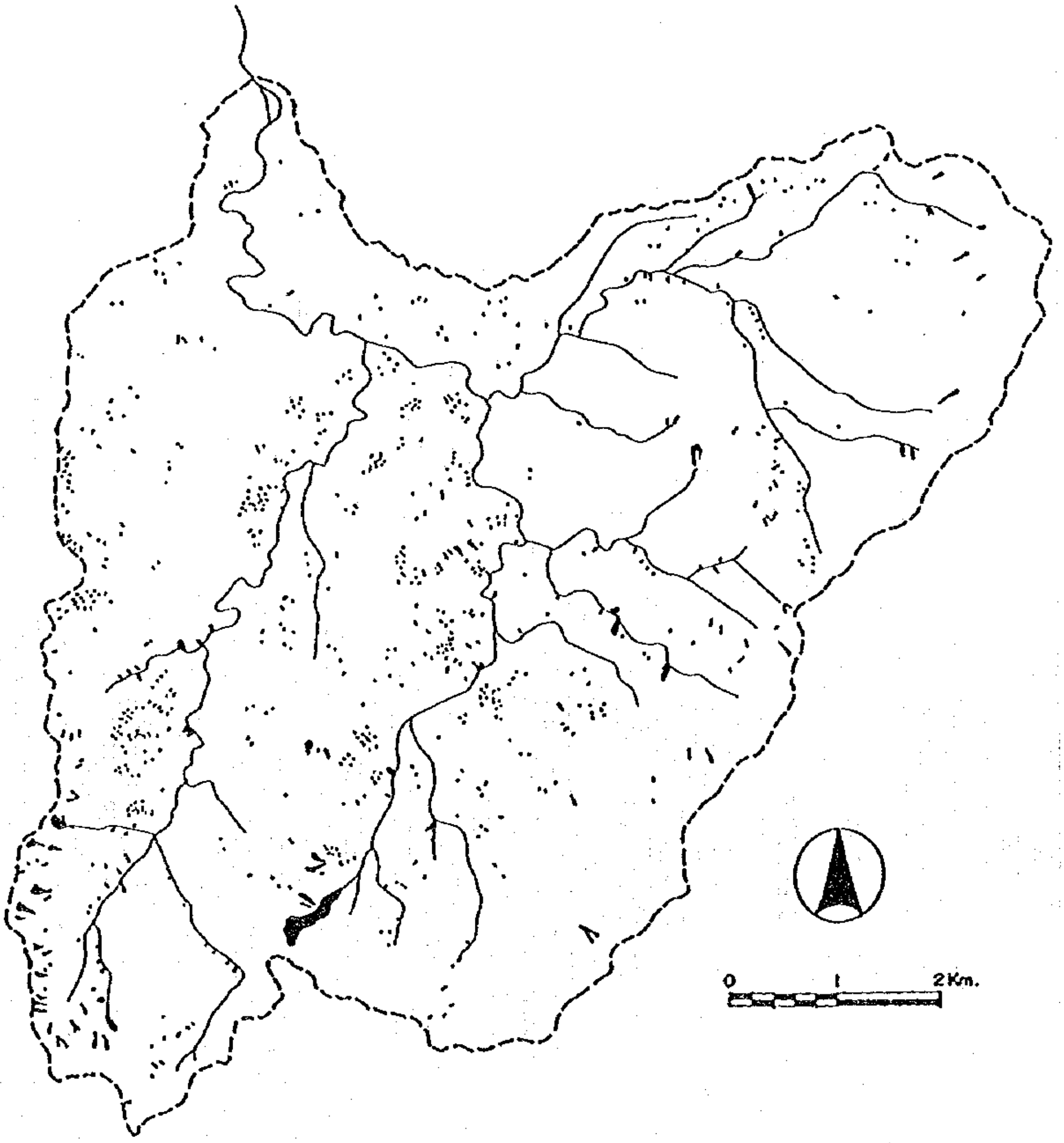


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D.3.2 (9)
JAPAN INTERNATIONAL COOPERATION AGENCY	Area of Slope Failure in Papa Watershed, 1991



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.3.2 (10) Area of Slope Failure in Papa Watershed, 1996

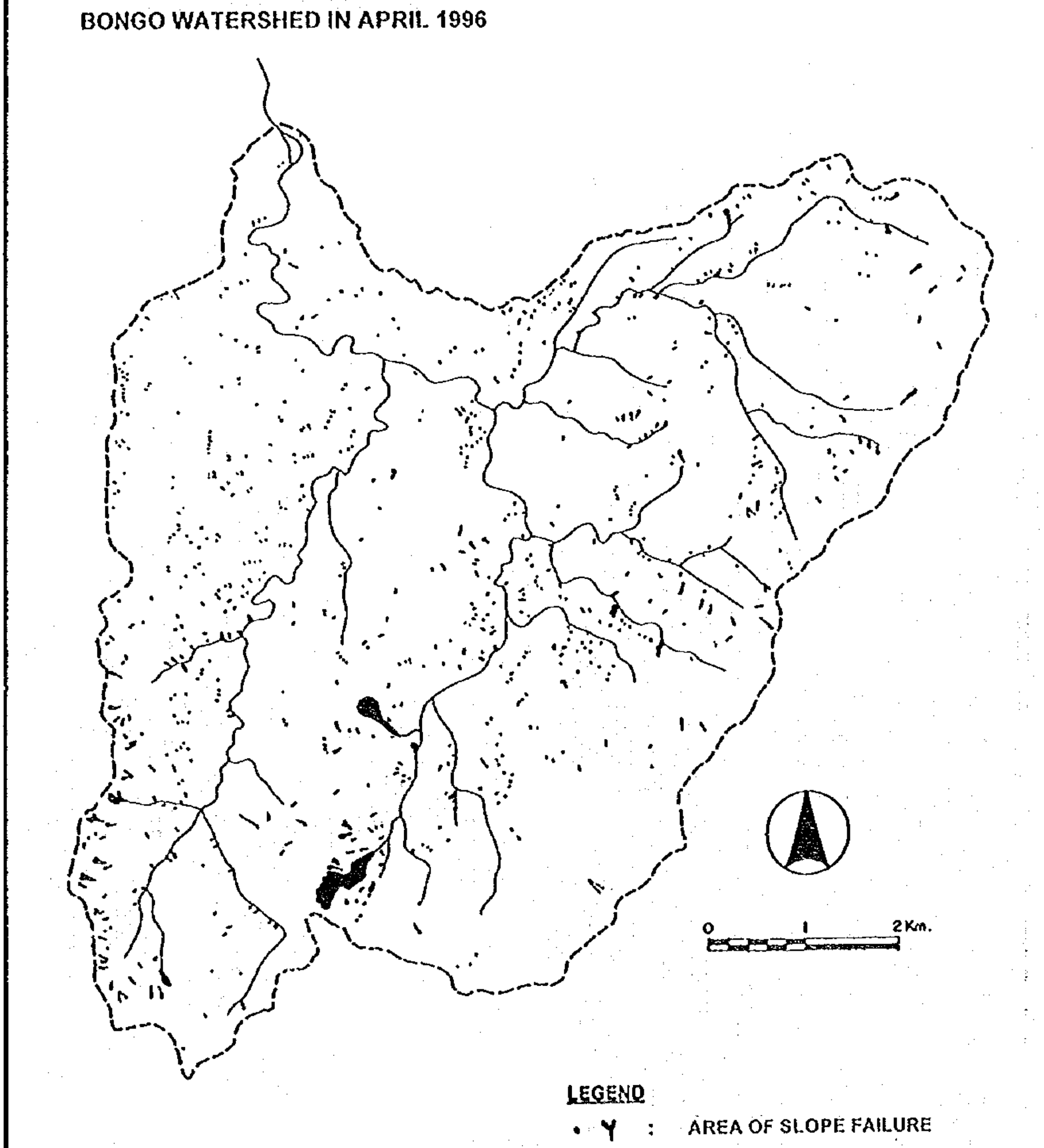
BONGO WATERSHED IN SEPTEMBER 1991



LEGEND

• Y : AREA OF SLOPE FAILURE

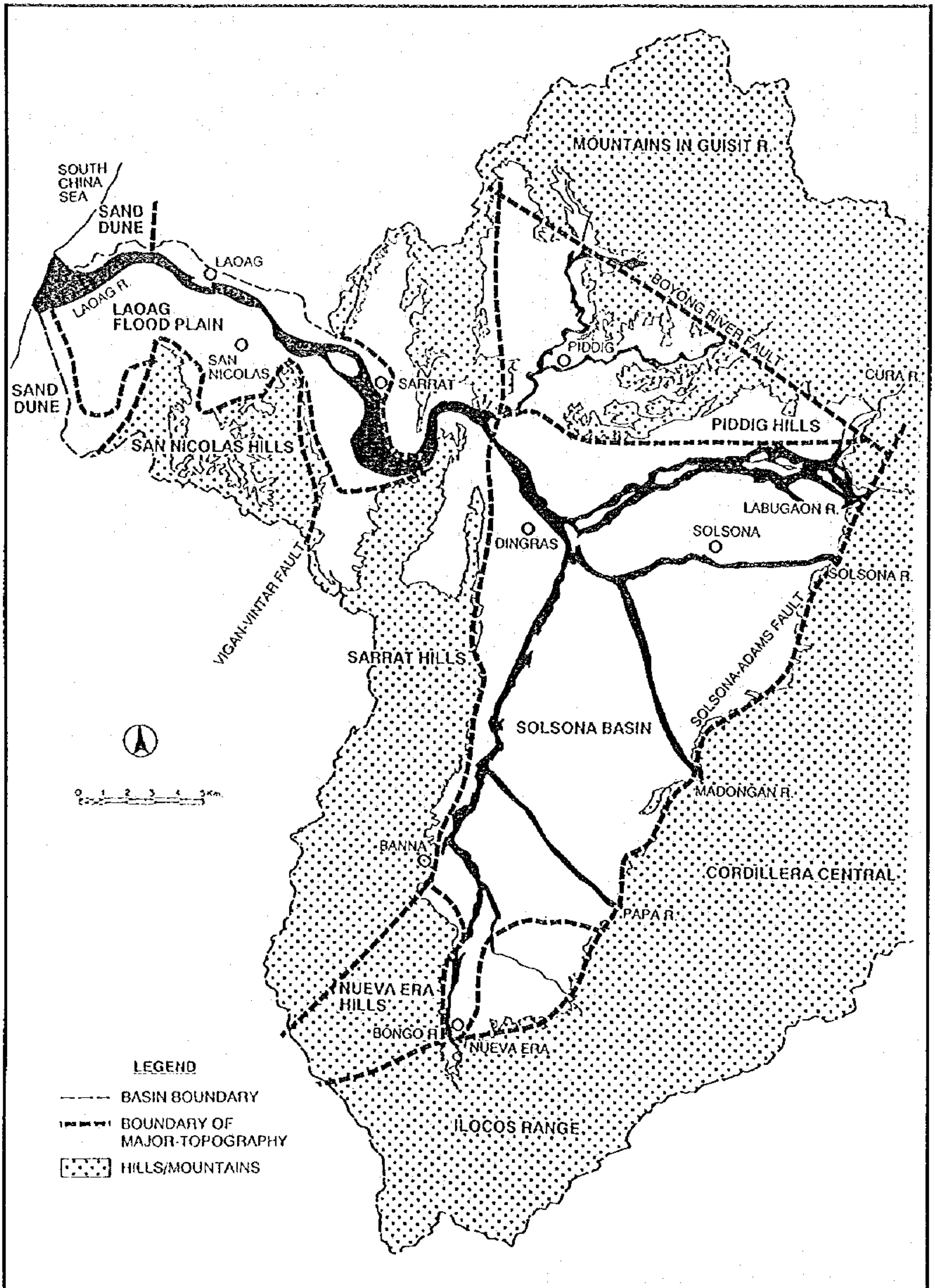
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D.3.2 (11) Area of Slope Failure in Bongo Watershed, 1991



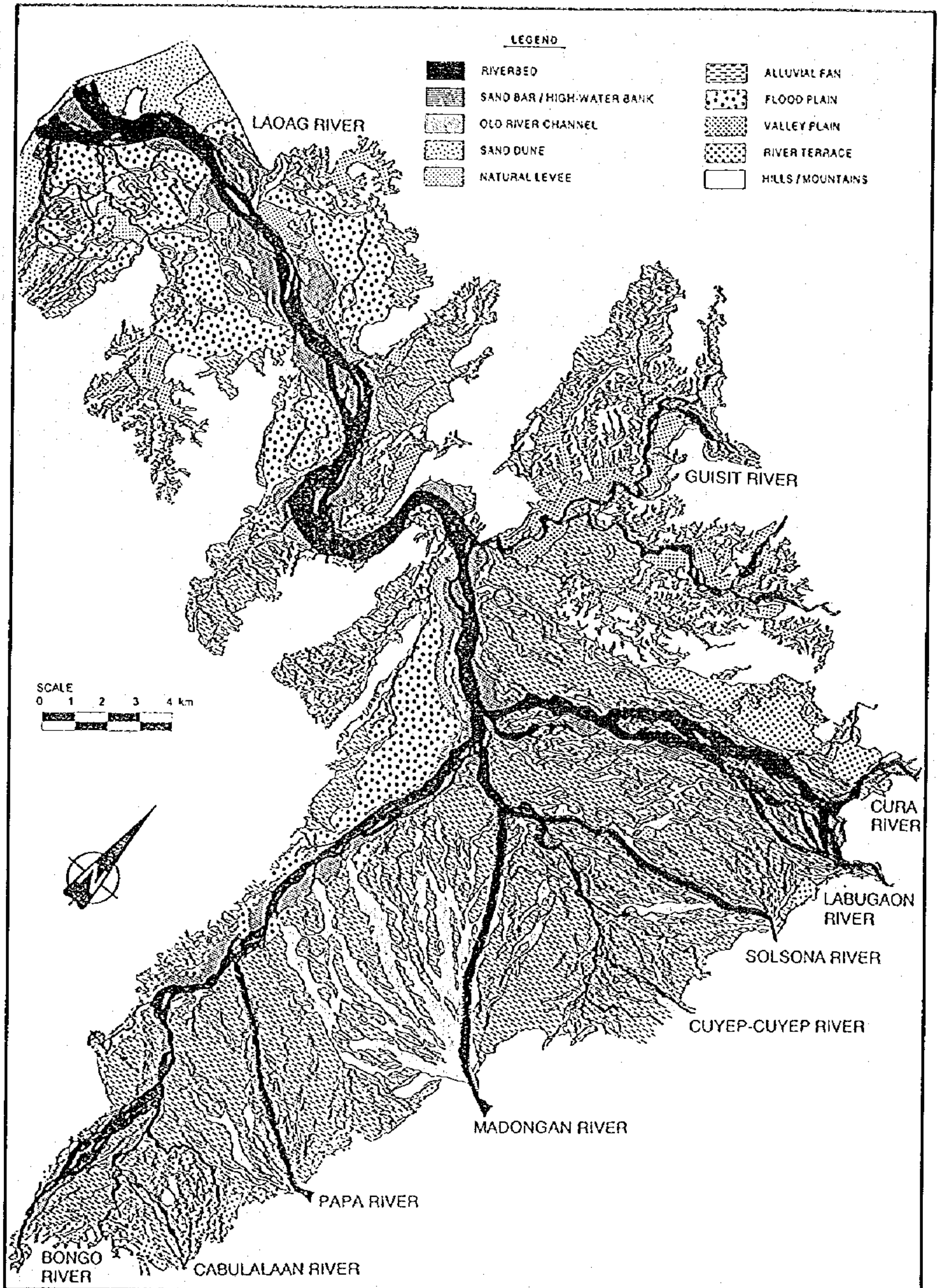
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. D.3.2 (12)
Area of Slope Failure in Bongo Watershed, 1996



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D. 4.1 Topographic Classification in Laoag River Basin



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. D. 4.2
JAPAN INTERNATIONAL COOPERATION AGENCY	Geomorphological Map in Laoag Alluvium