THE IMPACT OF LAND USE CHANGES ON THE RIVERINE ENVIRONMENT OF LIWAGU-LABUK RIVER BASIN IN SABAH

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

a.s.l.	Above Sea Level
AN	Amoniacal Nitrogen
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DID	Department of Irrigation and Drainage
DO	Dissolved Oxygen
DOA	Department of Agriculture
DOE	Department of Environment
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization
GIS	Geographic Information System
ICM	Integrated Catchment Management
IWQS	Interim Water Quality Standards
MOSTE	Ministry of Science, Technology and Environment
NGO	Non-governmental Organization
NRO	Natural Resources Office
SIAN	Subindex of Amoniacal Nitrogen
SIBOD	Subindex of Biological Oxygen Demand
SICOD	Subindex of Chemical Oxygen Demand
SIDO	Subindex of Dissolved Oxygen
SIpH	Subindex of pH

SISS	Subindex of Suspended Solids
TSS	Total Suspended Solids
WQI	Water Quality Index
WWFM	World Wide Fund for Nature Malaysia

ABSTRACT

The impact of land use changes on the riverine environment of the Liwagu-Labuk River Basin has been studied. Intensification of several land use activities such as agricultural, tourism, industrial and settlements have led to competition for water and land resources among the stated sectors. Deterioration of the river water quality has been affirmed through declining water quality index (WQI) or river class category and increased suspended sediment loading. For most of the monitoring stations, water quality parameters are within the DOE specified range for Class II river though occasionally deteriorated to Class III for those located at the downstream. The suspended sediment loading in the river has increased significantly, from 215.4 mg/L (in 1971-1980) to 434.6 mg/L (in 1993-2000), which is approximately twice of the earlier record. Literature search, interview, ground survey, river classification and comparison between previous and current land uses have been employed for this study. Briefly, it is apparent that the effects of unplanned development activities would be the degradation of the environment, as for this study is the declining river water quality caused by total suspended solids (TSS).

ABSTRAK

Kesan perubahan guna tanah ke atas persekitaran sungai Lembangan Liwagu-Labuk telah dikaji. Intensifikasi beberapa jenis aktiviti guna tanah seperti pertanian, perlancongan, industri dan penempatan telah mengakibatkan persaingan untuk sumber air dan tanah antara sektor-sektor tersebut. Penurunan kualiti air sungai telah dikenalpasti berdasarkan penurunan Indeks Kualiti Air atau kategori kelas sungai dan peningkatan muatan pepejal terampai. Bagi kebanyakan stesen pemantauan, parameter-parameter kualiti air adalah berada dalam julat spesifik Jabatan Alam Sekitar untuk sungai Kelas II biarpun, kadang-kadang merosot ke Kelas III bagi stesen yang berada di bahagian hilir. Muatan sedimen terampai telah meningkat dengan ketara dari 215.4 mg/L (dalam 1971-1980) kepada 434.6 mg/L (dalam 1993-2000), iaitu lebih kurang dua kali ganda rekod awal. Pencarian bahan rujukan, temu-bual, lawatan ke tempat kajian, klasifikasi sungai dan perbandingan antara guna tanah terdahulu dan sekarang telah dilakukan dalam kajian ini. Ringkasnya, jelas bahawa kesan daripada aktiviti-aktiviti pembangunan yang tidak terancang adalah degradasi alam sekitar, iaitu untuk kajian ini ialah penurunan kualiti air sungai disebabkan oleh jumlah pepejal terampai.

CHAPTER 1

INTRODUCTION

1.1 Preamble

Water is a vital resource, which makes possible the survival of all living things. Only 1% of the Earth's abundant water supply is drinkable. A shortage of fresh water is probably going to be the most serious resource problem the world will face in 2020. This might seem absurd to most west Europeans, who still think of water as almost free, but increasing numbers of Californians and Australians are already being forced to alter their habits to economize on water (McRae, 1996).

Fresh water use worldwide was about 1500 km^3/year in 1940 and is projected to be 5000 km^3/year in the year 2000. The number of water-scarce countries increased from 7 in 1955 to 20 in 1995 and is projected to increase to 34 in 2025. The water scarcity is accentuated by deteriorating water quality. Soil degradation and water quality are interrelated issues (Lal, 2000).

The 1992 Earth Summit in Rio clearly recognized the importance of freshwater resources as one of the critical resources under threat from environmental degradation. More significantly, it will become a crucial commodity in the new millennium as water stress is expected to occur frequently due to destruction of water catchments, pollution of water sources, the El Nino effect and global climate change (Chan, 2000).

Nowadays, water availability and quality have become major threats to food security, human health and natural ecosystems. An estimated 1.4 billion people, amounting to a quarter of the world population, or a third of the population in developing countries, live in regions that will experience severe water scarcity by 2025 (Luijten *et al.*, 2001). People in developing countries are particularly at risk in areas experiencing high population growth and limited means of managing water resources. As population grows and water consumption increases, so does competition for this precious and dwindling freshwater supply. Besides, the availability of water often determines the rate of economic development and also set its limit.

Rivers, streams, lakes, man-made reservoirs, underground aquifers and wetlands comprise the inland water resources. Rivers have shaped and contributed generously to the survival and development of countless human settlements, provided them with clean water, food, source of livelihood, spiritual and cultural significance, allowing the communities to lead and sustain a healthy, prosperous and meaningful existence. Besides these, the inland water resources are also essential for agriculture, industry and energy production.

Unfortunately, inland waters are being polluted by both point and non-point sources of pollution. Industries and communities are major point sources of pollution. Forestry and agricultural run-off, which contains fertilizers, pesticides and eroded soils, are the major non-point sources of pollution. Silt from eroded soil is contributed primarily by deforested hill areas, sloping agricultural land and poorly designed roads and constructions.

In the state of Sabah, surface water is one of the major sources of freshwater supply. Surface water can be classified as either flowing water such as rivers and streams, or standing water such as lakes and ponds including man-made reservoirs. There are altogether about 19 river basins in Sabah. Out of these, the Kinabatangan River Basin on the East Coast is the largest, covering an area of about 15,385 km^2. The Padas River Basin on the West Coast covers an area of about 8,726 km^2. Most of the other basins cover comparatively smaller areas (Juin *et al.*, 2000).

Before the World War II, the hinterland of Sabah was largely undisturbed. Much of the economy was based on small-scale agricultural activities and natural resource exploitation was limited in extent and scale. However, within the last 30 years, most of Sabah's forests have been logged over at least once due to the post World War II timber boom and forests outside of the Permanent Forest Estate are rapidly being converted to other land uses. While the greatest increase in quality of human life has occurred during the period since

1963, so have the most pervasive causes of environmental degradation been set in motion. Some of the environmentally adverse changes are superficially well-known such as widespread logging on hill slopes, soil erosion, polluted rivers and sea, forest fires and so on.

With regard to these, in the final report of the Sabah Conservation Strategy, Volume 1 (WWFM, 1992a), seven sectors have been identified as contributing to Sabah's natural resource base, which are land, soils, freshwater resources, forests, biodiversity, coastal and marine resources and non-renewable resources. It was also stated in the report that most issues related to natural resource conservation and management are tied, either directly or indirectly, to land use and land tenure. The implications of Sabah's land alienation system have a strong and profound influence on all aspects of environment and conservation. Hence, it is appropriate to address issues and problems relating to land before those relating to more specific natural resource sectors.

Ibrahim and Pereira (2000) described "carrying capacity" of a piece of land as the minimum population size of a given species that an area can support without reducing its ability to support the same species in the future. Land degradation occurs when there is a reduction in the land's carrying capacity. The inequitable distribution of land and its related resources, which then leads to intense use of marginal lands, also causes a reduction in the carrying capacity of the land. Unsustainable land development includes the over-exploitation, pollution and destruction of natural resources as well as the resource-base.

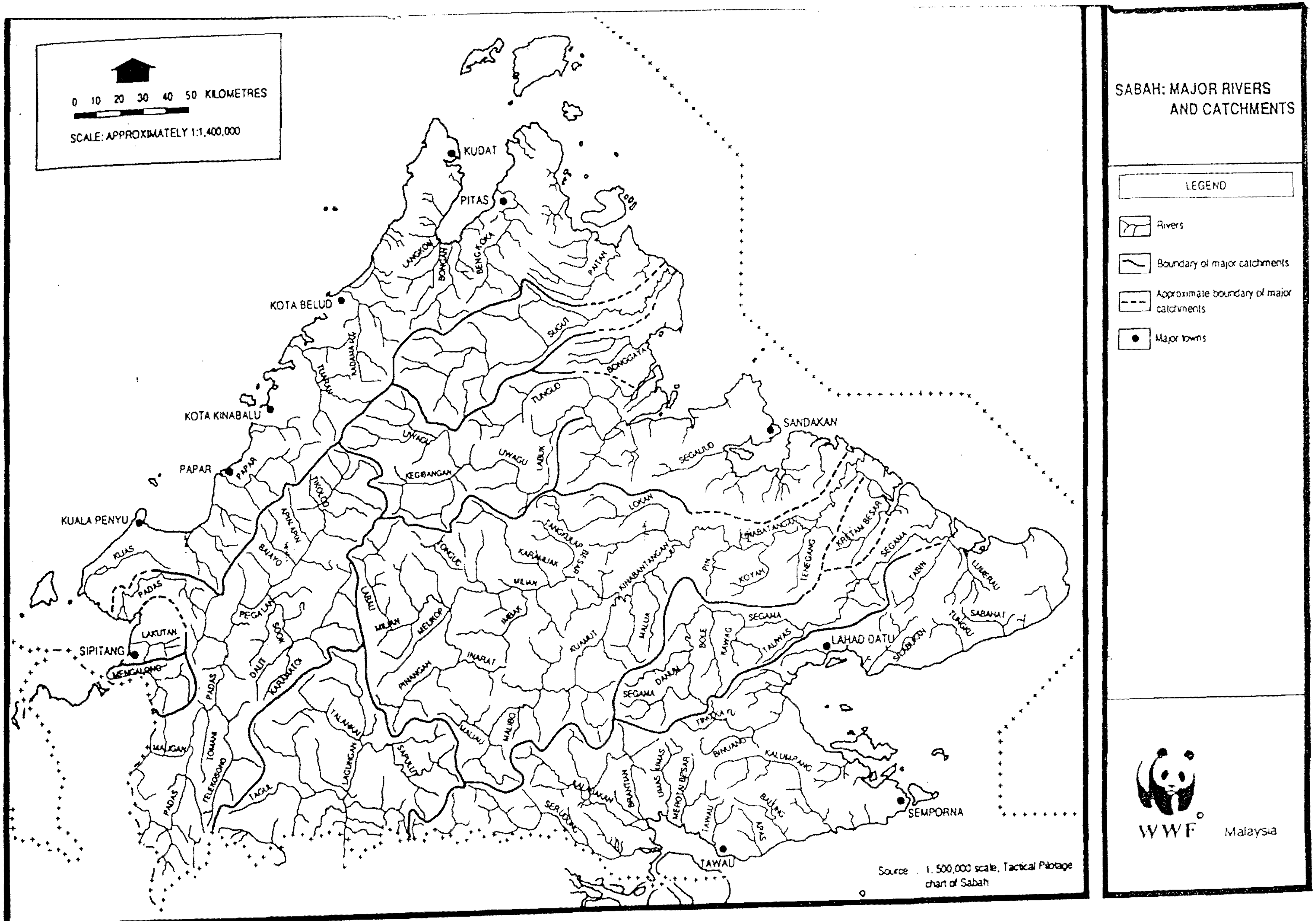
Currently, Sabah is experiencing a surge in economic development with more and more land use changes. These, coupled with the rapid increase in population have greatly put pressure on the State's natural resources especially land and forest. The expected change in land use patterns will significantly influence and alter the nature and environment of Sabah. Inappropriate land use and logging practices have resulted in the degradation of land, water, forest and the lost of biodiversity. Consequently, these activities have affected not only the quantity of water supply but also the quality of the water supply throughout the State. The surface water quality in Sabah is adversely affected by various types of pollutants that enter water bodies such as, run-off from land use activities, domestic sewage, mining, river sand and gravel extraction (Juin *et al.*, 2000).

Therefore, to help the State Government to manage the water resource of the State, a Water Resources Master Plan for Sabah was developed in 1994. The Master Plan integrates the management of water resources, including water quantity, water quality, the aquatic environment and land use. The pattern of growth and development in Sabah is being shaped by Vision 2020 and related national policies, so the Master Plan has been developed to suit the objectives of Vision 2020. It was identified in the Plan that to manage the State's water resources, there is a need for development of catchment and aquifer management plans for the protection of water resources. Besides this, coordination of water resources planning and catchment management planning are needed in providing sustainable management and use of water resources for the future of Sabah (NRO, 1994).

In addition to the Sabah Water Resources Master Plan, the Sabah Water Resources Enactment was developed later in 1998. The enactment provides a comprehensive form of catchment management through the establishment of responsibilities and provision of various powers in catchment management. Currently, other form of catchment management exists in the form of Environmental Impact Assessment (EIA) which is for specific activities under the Environmental Conservation Enactment 1996 (Chong, 2001).

1.2 Study Area

The Liwagu-Labuk River Basin (Figure 1) begins in the highlands close to the Mount Kinabalu National Park (1400 m a.s.l.). Its upper catchment is located in the Ranau district of Sabah. In the upper part of the catchment, the observed challenge for the catchment management would be the competition for water resources. With regard to this, water is a natural resource used for important purposes such as drinking water, irrigation water, or process water for mining and industrial production.



(Source: WWFM, 1992a)

Figure 1 The Liwagu-Labuk River Basin is one of the major catchments in Sabah

At the same time, sufficient pre-treatment is unavailable to treat the wastewater from private households, industrial production and mining. Ultimately, the wastewater may be disposed into the water streams in its high concentration form. Thus, both quantity and quality of water supplies in the Kundasang/Ranau area are becoming matters of considerable concern. Currently, there is no control on land use in this area outside Kinabalu Park.

Moreover, spread of shifting cultivation and intensive commercial-scale agriculture cultivation has run the risk of polluting the water resources with nutrients from fertilizers and pesticides (WWFM, 1992b). The expansion of tourism industry in the catchment area could bring in revenue for the economy sector. Yet, it will demand for more clean water while more waste and wastewater will be created. This may eventually affect the industry itself if necessary environmental protection measures were not being employed in the future development programs.

In addition, moving a bit downstream to Ranau, logging activities, a pulp-mill, previous mining activities and urban settlements create further problems for the water management in these areas. In earlier investigations, strong heavy metal pollution of the river sediments has been detected. As reported in Sabah Water Resources Master Plan (NRO, 1994), Ranau is an example of a place with water quality problems because of heavy metals and chemical residues.

For the lower part of the catchment, increasing conversions from extensive small or medium scale agriculture and forest to intensive monocultures, especially oil palm plantations posed another challenge for the catchment management in terms of soil erosion. Also, these conversions may cause water pollution due to the intensification input of agrochemicals.

1.3 Study Objective

The objective of this study is to produce data and information, which would be useful for an integrated approach to river basin management. Investigations will incorporate both scientific and social aspects that embody such management strategy.

In order to achieve the above objectives, several materials and methods have been used as follows:

- Literature Search
- Interview
- Ground Survey
- River Classification

Several major issues to be addressed with respect to the Liwagu-Labuk River Basin are listed below. These include:

- Competing water use between the different land uses, which include highland vegetable farming, resort/tourism development, hydropower needs, and the general water supply requirement of the downstream townships and villages;

- Land uses and related issues;
- Development and potential impacts of a major hydropower plant planned to be installed in the central part of the catchment;
- Large scale transformation of land into oil palm estates in the middle and lower catchment;
- Usage and leaching of agrochemicals in/from both the highland farming and oil palm plantation areas.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Catchment: The Basic Hydrologic Unit

The "catchment" or "watershed" is often a nebulous concept. Firstly, the words have different meanings in different parts of the world. Catchment is the English term for the geographic area contributing water to a given feature (river, dam, etc.) whereas the watershed is the line dividing two catchments. Confusingly, in American (and also Indian) usage the watershed is what the English refer to as the catchment. Secondly, a catchment can refer to anything from the 0.5 ha micro-catchment of a water harvesting project, up to the Amazon Basin (Moriarty, 2000). In this dissertation, both usages are used throughout.

Still, the terms watershed, catchment and basin are often used interchangeably. All areas which receive rainfall lie within a "water catchment" area but WWFM (1992a) pointed out the term water catchment typically implies

a) a specific area from which all water received drains into the same river system, and

b) an area consisting predominantly of sloping land.

A more comprehensive definition is given by Lal (2000). According to him, watershed is a basic hydrologic unit, and hydrologic and ecologic processes govern the quality of soil and water resources within the watershed. It is defined as a delineated area with a well-defined topographic boundary and water outlet. A watershed is a geographic region within which hydrological conditions are such that water becomes concentrated within a particular location, e.g., a river or a reservoir, by which the watershed is drained. Within the topographic boundary or water divide, watershed comprises a complex of soils, landforms, vegetation and land uses.

Hence, land and water are ecologically linked in this natural system. From the smallest droplet to the mightiest river, water works to shape the land, taking with it sediment and dissolved materials that drain to watercourses and, in most cases, eventually to the sea. So, a river is also a product of the land it inhabits - the type of rock and soil, the shape of the land, the amount of rainfall and type of vegetation are some of the factors that determine the river's shape, size and flow (Pottinger, 1999).

A catchment also includes all the humans, plants and animals that live in it, and all the things we have added to it such as buildings and roads. The life it supports is interconnected, meaning every creature and plant depends on other creatures and plants in the catchment for sustenance. Everything we do affects our catchment - from washing clothes and growing food to larger-scale activities such as mining, commercial farming, and building roads or dams. The reverse is also true. Our catchment affects everything we do, by determining what kinds of plants we can grow, the number and kinds of animals that live there, and how many people and livestock can be sustainably supported by the land.

In fact, we are all connected through catchments. One important truth about catchments is that we all live downstream from someone, and upstream from someone else. Anything dumped on the ground in the catchment can end up in its rivers, lakes or wetlands. Anything released to the air can come down again, nearby or thousands of miles away. A catchment's water may be made undrinkable by activities many kilometers away. To understand the water quality of a stream, one must look at the entire area it drains. Catchments do not respect political boundaries, and in fact can encompass several cultural, national and economic boundaries. What happens in one country's part of the catchment will impact water quality, quantity, or people who depend on it in the countries downstream.

Therefore, water catchments are appropriate as units for land-use planning. The catchment concept becomes especially important when water draining from it is used routinely by human communities. In such catchments, carefully planned management of land use is in the best interests of the majority of the community (WWFM, 1992a).

2.2 Challenges in Ecosystem Management in a Catchment Context

Catchments are environmental and land management units which determine the health of a nation. Poor ecosystems management of catchments has and will result in the impaired functioning of the catchment, which in fragile environments can lead to ecosystem collapse. Resource management problems of the Asian region is a complex of increasing soil and water loss, land degradation, sedimentation, irregular stream flow and poverty.

Until recently, research and development efforts in Asia were primarily concerned with food or biomass production with resource conservation and sustainability generally of much lesser importance in the planning process. Adequate infrastructure is not available in Laos, Myanmar, Vietnam, Cambodia, Nepal and Sri Lanka to initiate a conservation program. Besides, multiple linkages among countries of Asia are weak, primarily because of language barriers and general lack of financial resources for exchange of scientific, personnel, literature and holding of workshops, seminars, etc. (Samra and Eswaran, 2000).

An Integrated Catchment Management (ICM) approach requires a strong foundation in ecosystem sciences, crossed with effective inputs from a wide variety of other knowledge areas, including (but not limited to) hydrology, policy sciences, economics, industry, etc. The focus on such an approach is to generate knowledge about "How do these various landscape units interact?" (Bowden, 1999). As experienced in the development of the Moyog River ICM Plan, developing a catchment management plan requires many management and technical skills (Chong, 2001). Also, when economic consideration outweighs the other, a bias towards economy may occur. This may cause an imbalance between development and the environment.

In the earlier endevours, biophysical components of a catchment like soil, physiography, precipitation, etc. were given higher priority. Apart from this, the importance of other aspects, such as ethnicity, socioeconomic status, gender, demography, common property resources, participation, people' empowerment, local-level institution building, etc. is being increasing realized. However, integrating these components and enabling land users to implement this vision need a much higher level of appreciation and flexibility by the participating parties or communities.

Besides these, systems research in land resource science is yet to evolve and process models which are new research venues, Applications of modern tools and procedures like remote sensing and geographic information system (GIS) are confined to research organizations only. In many, absence of computer facilities prevents this important step in integration of information. Lack of data is another major impediment in utilizing these tools. There is a need for technology development projects, designed carefully for the viability of large-scale ecosystem management on the catchment basis. Very few countries have traditions of monitoring the biophysical resource base, and, unless governments value the need to address the health of the nation, no funds will be made available for such activities.

2.3 Examples of Integrated Catchment Management (ICM)

2.3.1 An Integrated Catchment Management (ICM) Plan for the Moyog River

An integrated catchment management (ICM) plan study was carried out in the Moyog River Catchment in 1999. The main objectives of this project were to develop an ICM plan for the Moyog River on a pilot basis and to provide technology transfer in the development of ICM plans. There were four phases involved in the study (Table 1). The study had been carried out by the Water Resources Consulting Services (an Australian consultant) together with active participation of Drainage and Irrigation Department (DID), related government agencies and NGOs. It took two years to complete and cost RM1.5 million (Chong, 2001).

Table 1. An Integrated Catchment Management (ICM) Plan for the Moyog River

Phase	**Description**
Inception Phase	Identified issues in the catchment based on available information and consultation with stakeholders. Sixteen key issues were identified.
Baseline/ Data Collection Phase	Additional data collection, data assessment and analysis were undertaken. The number of issues had been reduced to seven.
Option Phase	A range of existing and potential management measures with respect to each of the seven key issues were discussed. Fifty seven measures were identified and combined to form four management options.
Final Phase	Option 3 in the Options Report with modifications became the preferred scheme for implementation. The final plan should be approved by Cabinet before its Gazettal.

The outcome for this plan was that the selected option (Option 3) should provide a substantial improvement in catchment condition with respect to many of the key catchment issues. Key components of this option include preparation of a Floodplain Management Plan to address flooding and floodplain degradation, construction of a by-pass floodway, gazettal of a Water Protection Area for all lands upstream of Babagon Dam and also of the Madziang Water Supply Intake.

On the other hand, experience gained from the development of the pilot ICM Plan for the Moyog River Catchment had unveiled various challenges. Although some of the management and technical skills are not currently available but the plan has provided some opportunity for technology transfer, especially in GIS and hydrologic modeling.

2.3.2 The River Systems of the Cordillera and their Watersheds

The Cordillera is named as the watershed cradle of Northern Luzon, Philippines. Its forests sustain six of Northern Luzon's major river systems. Perhaps for this reason, government classifies 85% of the Cordillera as forestland, 30% of which is officially designated as forest reserve. The river basins of the Cordillera have enormous water-bearing capacity. They have a total drainage area of 5,447,500 hectares and groundwater storage of about 150 million cubic meters. According to government development planners, this is more than sufficient for supplying the irrigation and energy requirements of not only the Cordillera but the entirety of Northern Luzon (CPA, 2002).

Most of the forests that support these river systems have been declared as watershed reservations largely due to association with hydropower and irrigation dam projects. Unfortunately, all of the forest reservations in the Cordillera region are now in a critical state. For example, the Mount Data National Park is in an especially critical condition. Seventy-one percent of its area, or 3,896 hectares, has been logged over and converted to agricultural, residential, and commercial use. It is occupied by 2,277 households. Some of these are the households of former workers of Benguet Corporation, which used to operate a logging concession on Mount Data.

Now, only less than half of these forests have remained relatively untouched. Nevertheless, government has continued to issue licenses to hardwood loggers. This has caused the forest cover of the Cordillera to dwindle to less than 47%. The reforestation program of the government has proven ineffective. Until today, there have been no substantial gains in the rehabilitation of watersheds. Verdant growth can no longer be restored because the ecosystems of the areas that were once occupied by forest have been altered beyond redemption. Due to massive deforestation, the occurrence of flashfloods in areas downstream of major rivers has become a perennial problem. Erosion from the balding mountainsides has so severely silted up the reservoirs of two dams causing the water retention capacity of the reservoirs to drop. Consequently, the dams' floodgates have to be opened whenever there is heavy or continuous rainfall.

Later on, in 1998, the World Commission on Dams was formed to review the development performance of dams. Commissioners were drafted from among governments, the dam construction industry, funding institutions, dam-affected communities and anti-dam activist organizations. From the review, it was stated that dams were not as "development-effective" as technocrats thought them to be. The

Commission's report, published in year 2000, simply provided the tools and suggested guidelines for more rational decision-making on proposals to build dams – citing the need to evaluate all costs and benefits, social, environmental, as well as economic.

As to conclude, whilst it is acknowledged that there must be a certain degree of development, there must also be an adequate understanding of the impacts of development on the ecosystem and the environmental consequences, and the consideration of the economic costs which will inevitably arise from environmental damage. An integrated approach towards planning and managing development in highland area is needed to ensure that the correct optimum balance of economic, environmental and social benefits is obtained.

2.3.3 An Integrated Catchment Management Framework for the Australian Capital Territory (ACT)

Across Australia, natural resource managers and the community have increasingly recognised Integrated Catchment Management (ICM) as an effective means of dealing with environmental issues. ICM involves managing natural resources within a "whole of system" approach and avoids dealing with issues in isolation. The Australian Capital Territory (ACT) is a participant in the National Strategy for Ecologically Sustainable Development (ESD) 1992. The adoption of the principles of ESD by the ACT Government provides support for the implementation of ICM (ACT Government, 2000).

More than half the ACT is reserved for nature conservation, but there are major on-going challenges in natural resource management related to land use practices, off-reserve conservation, urban development, water quality and responsibilities to downstream communities. Only 3% of the Murrumbidgee Catchment lies within the ACT, yet the ACT contains about 58% of the catchment's population in the nation's capital, Canberra.

Land clearing and land use throughout the Murrumbidgee Catchment have left fragmented patches of indigenous vegetation. This issue is assigned a high priority in the catchment as the value of remnants has become increasingly recognized. The management of remnants is necessary to maintain biodiversity and habitat and to reduce the incidence of soil and water degradation. Examples of vegetation associations, which are poorly represented in the Murrumbidgee catchment, are Red Stringy Bark/Scribbly Gum open forest, Yellow Box/Blakely's Red Gum woodland and native grassland. Since these areas are smaller in area than the original vegetation, they are more susceptible to disturbance and less able to be self-sustaining, so active management is needed. In the ACT, these threatened associations are protected. In addition, government, community groups and Greening Australia are engaged in a number of conservation and enhancement projects.

The ACT ICM Framework was developed by a steering committee comprising ACT and regional government and community representatives after extensive consultation over a period of 18 months. It was released in early 2000 and includes a commitment that the Framework will be reviewed every two years to determine the extent to which the Framework is being implemented.

The Framework consists of principles, processes and commitments to guide community and government natural resource related activities. It identifies five "building blocks" that provide the foundation of integrated catchment management in the ACT, together with the "components for their success". The building blocks are:

- an effective partnership between the community and government;
- appropriate knowledge and skills;
- legislative and planning instruments;
- management coordination mechanisms; and
- effective resource use.

These "components for success" provide the outcomes that must be in place in order for ICM to be successfully practiced in the ACT. Many aspects of these outcomes are being achieved through existing practices whilst others require further actions in order for them to be realized.

The Implementation Plan translates the broad ideas articulated in the Framework into tangible actions that can lead to the achievement of the desired outcomes. Whilst the Framework takes the longer-term perspective of 20 years or more, the Implementation Plan looks at what can be achieved over the next two years. Combinations of quantitative and qualitative performance measures have been assigned to each action in the Plan. They have been developed with the end user in mind and are both practical and realistic within the time and resource constraints within which the Plan will operate (ACT Government, 2001).

2.4 Previous Studies of the Liwagu-Labuk River Basin

In 1982, a study had been done to determine the baseline water quality of the Liwagu-Labuk River Basin as well as the Sugut River Basin (Murtedza *et al.*, 1984). From the study, it was clearly indicated that the Mamut Copper Mine had polluted its adjacent areas, included a part of the Sugut River which was near to the mine. Surprisingly, the Sugut River's water was not seriously polluted by copper. Accumulation of heavy metals in bottom sediment was however detected as far as 40 kilometers downstream of the mine. Although the Mamut Copper Mine is located at the upstream of both the Liwagu-Labuk River Basin and Sugut River Basin, it was found that only the Sugut River was directly affected by the mine activities.

Later on, Murtedza (1992) again did a study to establish the existing status of water quality of a number of important rivers in

Sabah based on the data gathered by the Department of Environment (DOE) during the 1983-1989 period. In the study, both the Labuk River and Sugut River were included. For the case of Labuk River, the relatively unsilted water near the headwater area at Ranau which was classified as Class1 deteriorated by the input from the Kegibangan River, a tributary draining an intensely logged watershed. This caused the water quality index (WQI) to drop to Class 2. The same condition happened to the Sugut River, which had water quality of Class 1 at the upstream part of Poring but later, deteriorated to Class 2 when moving downstream to Bongkud.

2.5 Pollution Source Management

2.5.1 Sources of Surface Water Pollution

Freshwater is a scarce and valuable resource, which is easily contaminated. The water scarcity is accentuated by deteriorating water quality. Once contaminated to the extent it can be considered "polluted", freshwater quality is difficult and expensive to restore. Pollution is a qualitative term. It describes the situation that occurs when the level of contaminants is such that intended water use is impaired. It takes just a small amount of contaminant to pollute a water body intended for a drinking water supply. However, the same water might not be considered polluted if the water were to be used, for example, for agriculture.

On the other hand, physical factors of the environment can also contribute to pollution. As an example, heated water discharged from a power plant can change the temperature of an aquatic environment. Conversely, heated water or water containing some contaminant may not be a problem at any time of the year, provided it is rapidly mixed with the surface water and diluted material does not accumulate over time.

Baumgartner (1996) stated that the major sources of surface water contamination are construction, municipalities, agriculture, and industries. Construction activity is a major source of sediment contamination of streams because it involves land clearing and grading. Besides this, agriculture and forestry are also operations traditionally responsible for pollution of streams with particulate matter. When deforestation is carried out in hilly areas, especially on steep slopes of more than 20 degrees, it can be a catalyst to erosion and landslides (Chan, 2000). The runoff of fine-grained particles, especially in hilly terrain with high rainfall, can smother gravel beds that serve as spawning habitats for fish. In addition, suspended particulates and colloidal material can harbor microorganisms, necessitating increased treatment for municipal water supply facilities.

Based on the Environmental Quality Report 1996, there were 2292 sources of water pollution in Malaysia (Mohd, 1999). All these sources can be categorized into a few types as listed below:

1. Food and beverages waste
2. Rubber-based product waste
3. Chemical waste
4. Oil palm waste
5. Textile waste
6. Paper and pulp-based waste
7. Food manufacturing and livestock waste
8. Sedimentation waste from quarry and mining activities

In Sabah, the commercial-scale vegetable cultivation in Kundasang area is noted for its negative impacts on the natural environment. These impacts include changes in hydrological cycle due to conversion of forested land to arable land, deterioration in land (soil) quality and quantity due to soil erosion, deterioration in water quality of streams and rivers due to inputs of agro-chemicals (e.g. pesticides and fertilizers) and siltation by eroded materials from the agriculture sites (Lim, 1995).

Oh (2000) also indicated that economic sectors such as the tourism, temperate agriculture and power generation industries depend on the highland ecosystem and its natural resources. Development activities in the highlands inevitably affect the ecosystem, which in turn will have consequences for the natural resources found in, or provided by, the highlands. Development which is not properly planned may also destroy vital water catchment areas, and adversely affect the freshwater supplies for the Peninsular Malaysia.

Subsequently, erosion can also decrease the topsoil resource needed for sustainable plant growth. Sediment from soil erosion, nutrients from fertilizers and residues of agricultural chemicals are washed off the land surface and into streams by water. When washed from the land surface these materials are often referred to as diffuse source pollutants. Where pollutants come from places like sewage treatment plants or factory waste pipes, these are called point source pollutants (NRO, 1994).

Furthermore, rivers are the primary transport mechanism for suspended sediment, pollution and nutrients to enter the catchment areas. The significance of a given river with respect to sediment, nutrient or pollution loading depends upon both the discharge of the river and the concentrations of the various materials contained in the river water. Both these require long-term field data to be determined reliably.

In Sabah, observations gathered by Murtedza (1992) during the 1983-1989 period show that forest operations, such as extraction of timber, agricultural, industrial or urbanization activities have resulted in deterioration of the water quality of many rivers. Rivers stretches in the immediate downstream areas of Forest Reserves generally belong to Class 1. Further downstream, however, the water quality degraded to Class 2, almost exclusively due to elevated suspended solid levels. The field observations also revealed that contaminant responsible for polluting more than 80% of rivers in Sabah is suspended solids.

Later on, Murtedza *et al.* (2001) also stated that earlier studies on rivers and streams in Sabah clearly indicated that the majority of streams and rivers in the state were greatly affected by suspended solid loadings and pristine quality conditions prevailed only in the upper catchment areas. Hence, the preservation of headwater areas has been generally acknowledged as crucial for the sustainability of downstream water resources, both in terms of quantity and quality.

2.5.2 Soil Erosion Management

Ahmad (1996) defined soil erosion as a process of detachment and transport of soil particles from one place to the other by erosive agent such as water, wind and glacier. Soil erosion are mainly due to high rainfall intensities, poor soil condition, improper land use management and practice particularly in the highlands. In Malaysia, the equatorial humid climate generates heavy rainfall of high intensities, often more than a hundred millimeters per hour and is therefore highly erosive. Nevertheless, the rate of soil loss is alarmingly high in steep and hilly areas in the equatorial region (Chan, 2000).

Accelerated soil erosion is a global problem of modern times with severe economic and environmental impacts. Economic impacts are due to decrease in crop yield, and environmental impacts are due to reduction in the soil's ability to regulate water and air qualities. This phenomenon is driven by socioeconomic environments and its magnitude is determined by the interactive effects of management and key biophysical factors, like decline in soil structure, depletion of soil organic carbon (SOC), poor ground cover, low biomass production and reduction in productivity and resource use efficiency. Besides, erosion effects on temporal changes in soil quality vary with land use. Intensive cultivation can cause adverse changes in soil properties and reduce soil quality. The greatest rates of change in SOC usually occur in the first 20 years of cultivation (Lal *et al.*, 1999).

The latest report on Global Assessment of Soil Degradation estimated degraded lands (in Mha) of 1200 in Asia, 400 in Africa, 245 in South America, 215 in Europe, 150 in Central and North America and 112 in Australia. Soil erosion (by water and wind) accounts for 60% of the total land degradation and is most extensive factor of lowering environmental qualities. According to these estimates, more than 50% of the degraded land of all the continents is situated in Asia. The estimated soil loss in Asia ranged from 21 to 555 t/ha/yr (Table 2). Degradation manifests in a high rate of soil erosion, increased sedimentation, reduced farm production and livestock-carrying capacity and deforestation with consequent loss of biodiversity (Samra and Eswaran, 2000).

Table 2. Average Rate of Soil Erosion in Asian River Basin Indicating Natural Resource Degradation

River	**Country**	**Drainage Basin (10^3 km^2)**	**Estimated Annual Soil Loss (t/ha/yr)**
Chao Phraya	Thailand	106	21
Mekong	China, Thailand, Laos, Tibet, Vietnam, Myanmar	795	43
Red	China, Vietnam	120	217
Ganges	India, Bangladesh, Nepal, Tibet	1076	270
Kosi	India, Nepal	62	555

In addition, land degraded by water erosion and wind erosion constitute 82% of the total strong and extremely degraded land area. On a global basis, high sediment load is carried by rivers draining very densely populated regions of the world, for example, Yellow River in China and Ganges in India (Lal, 2000). The problems of erosion and sedimentation are accentuated by misuse and mismanagement of resources within the watersheds of these river systems. Hence, a strategy based on watershed management is essential to effective erosion control and restoration of degraded soils.

In the extensive hilly and mountainous areas of Southeast Asia, population growth and demand for tropical timber have led to widespread deforestation and intensification of agriculture. The steep slopes of the young landscapes are fragile and the region's rivers discharge a total of nearly 7500 million tones of sediment to the surrounding ocean annually (Craswell and Niamskul, 2000). Consequently, soil erosion appears to be a serious problem, although reliable information on the human-induced impacts on stream flows and sediment loads is scarce. The current fragmented and limited knowledge of the on- and off-site impacts of soil erosion in countries of the region is a major constraint to the development of appropriate policies and action plans to address the problem.

In recognition of these constraints, the International Board for Soil Research and Management (IBSRAM) and other international research agencies now advocate a new research paradigm as listed in Table 3. This paradigm is the cornerstone of a new system wide program on Soil Water and Nutrient Management (SWNM) of the Consultative Group on International Agricultural Research (Craswell and Niamskul, 2000).

Table 3. Key Elements of the New Paradigm for Research on Sustainable Land Management

Element	**Approach**
User orientation	Participatory, community based at all stages from planning to implementation
Policy	Focus on policy and institutional issues that influence farmer and community decisions
Equity	Consideration of equity, including gender analysis, in research planning and implementation
Landscape	Integration of people, soil, and water at every scale from plot to watershed
Research	Linking strategic, applied, and adaptive research

intensity	with technology development and participatory dissemination
Knowledge	Reliance on both indigenous and scientific sources
Orientation/goals	Linking increased productivity with natural conservation

MOSTE (1997) stated the severity of soil erosion under agricultural use is determined by its slope, crop types and management practices. It is evident that soil losses are highest in areas where few or no soil conservation measures are taken. Soil loss is low under tree crops, except in oil palm plantations where stem flow, enlarged rain drops, the absence of leaf litter and lack of grass cover can cause serious soil loss. Method of minimizing soil erosion include maintaining adequate vegetation cover, contour planting, strip cropping, crop rotations, and the use of terraces and mulches.

According to Post (1996), the goal of Erosion Control Practices (ECP) in the U.S.A. is to keep erosion rates within tolerances compatible with good water quality, a wholesome environment and the preservation of the productive capacity of the land. One of the most important methods of reducing erosion is the practice of farming parallel to the field contours; this practice is known as contouring. Conversely, this and some of the other agronomic control practices are not effective when the slope angle is steep or the area from which runoff concentrates is excessive. Thus, these practices must then be supplemented or replaced by other methods that include terraces, diversions, contour furrows, contour listing, contour strip cropping, waterways and control structures.

2.5.3 Sewage (Wastewater) Management

The environmental issues related to urban and industrial development are complex and often more difficult to contain. These include waste and sewage disposal, conservation of urban greens, heat problems as well as pollution of water and air. Undoubtedly, sewage is one of the major polluters of the water systems in Malaysia. SAM (2001) stated that in the mid-1990s, sewage was considered the worst culprit, accounting for up to 79% of the pollution load, followed by industrial discharges (13%) and agricultural runoff (8%). As the result, the health of the Malaysian river system is unhealthy, if not critical.

The usage of septic tanks for sewage treatment is not uncommon. Primarily, septic tanks serve as repositories where solids are separated from incoming wastewater and biological digestion of the waste organic matter can take place under anaerobic conditions. Although the concentration of contaminants in septic tank septage is typically much greater than that found in domestic wastewater, septic tanks can be an effective method of waste disposal where land is available and population densities are not too high. Thus, they are widely used in rural and suburban areas. However, as suburban population densities increase, groundwater and surface water pollution may rise, indicating the need to shift to a commercial municipal sewage system (Gerba, 1996).

In Malaysia, sewage and waste disposal services have been privatized in certain places to improve its management. However, there are still concerns regarding the environmental impacts of these facilities. Among these are the possible contamination of groundwater in old municipal landfill areas with unsuitable sub-surface conditions as well as river-water pollution due to sewage discharge from squatter settlements and inadequate sewage treatment facilities (Ibrahim & Pereira, 2000).

At any possible disposal point, the nature of the receiving environment, the manner of sewage disposal and the standard of the effluent are inter-related factors which must be carefully considered, if satisfactory, trouble-free waste disposal is to be achieved. Therefore, bio-monitoring and pollution assessments should be carried out using indicator or sensitive species to determine the health of threatened ecosystems (MOSTE, 1997).

2.5.4 Solid Waste Management

Solid wastes are waste materials having less than ~ 70% water. These includes municipal solid wastes such as household garbage, industrial wastes such as power plant fly ash and flue gas desulfurization wastes, mining wastes such as mine spoils and oil-field wastes such as drill cuttings (Artiola, 1996). Solid wastes can release pollutants into the atmosphere via dust or particulate transport. When these wastes come into contact with water, their soluble constituents can be leached out into the soil surface or below. Leachate contamination from non-sanitary landfills affects surface waters and groundwater aquifers, a hazard to public health and aquatic ecosystems.

Besides, municipal solid waste may contain a variety of pathogens, a source of which is often disposable diapers. It has been found that as many as 10% of the fecally soiled disposable diapers entering landfills contain enteroviruses. Another primary source of pathogens is sewage biosolids, where co-disposal is practiced. Pathogens may also present in domestic pet waste and food wastes. Municipal solid wastes from households have been found to average 7.7×10^8 coliforms and 4.7×10^8 fecal coliforms per gram. *Salmonella* have been detected in domestic solid waste (Gerba, 1996).

In Malaysia, approximately 5.5 million tonnes of domestic and commercial solid waste were generated in 1995. Open burning is routinely carried out at the 230-odd waste sites throughout the country, of which only 10% are equipped with the appropriate environmental controls (MOSTE, 1997). Thus, increased waste generation also raises land use for landfills. As to manage these solid wastes, landfills should be designed with adequate environmental controls and alternative methods encouraged, such as the use of incinerators on islands.

2.5.5 Towards a Catchment Approach to Water Resource Management

A catchment approach can be an alternative process of learning, of learning not by separating and isolating knowledge, but by awareness of the interaction and interdependency of people and nature, the blending and clashing of cultural, ecological, political and economic forces which constitute life and destruction. In this sense, the catchment is a unit of analysis or study known as political ecology. Far from being just an academic musing, a catchment approach is a practical way to examine and begin the search for solutions to real life problems faced by member communities of a catchment. At the heart of this approach is empathy, a respect for life downstream and in the mountain forests where water springs.

Nowadays, catchments have been widely recognized as appropriate biophysical or socioeconomic units for water resources management. Major development organizations, ranging from the World Bank to small local non-governmental organizations are promoting catchment management in many communities throughout the world. The catchment has also been adopted for organizing research and development activities at research centers such as the

International Center for Tropical Agriculture and the International Water Management Institute (Luijten *et al.*, 2001).

In addition, the goal of effectively implementing new approaches to catchment management requires recognition of several basic facts as listed in the Table 4 (Naiman, 1992).

Table 4. Essential Conditions for Implementing New Approaches to Catchment Management

1.	The scope of the issues demands unparalleled cooperation between industry, governmental agencies, private institutions and academic organizations.
2.	The increasing tendency to resort to technical solutions (e.g., hatcheries, silviculture) must be augmented with increased habitat protection and preservation of fundamental components of long-term catchment vitality.
3.	The complexity of information management and the scope of experimental manipulations needed often exceed the capacity on individual institutions.
4.	The current tendency to seek conceptual solutions at the expense of data-driven decisions must be reversed.
5.	Intra- and interagency inconsistencies in environmental regulations must be corrected.
6.	Human activities are a key element of ecosystem vitality and must be integrated with environmental considerations before long-term sustainability of the biosphere can be achieved.

2.5.6 Integrated Catchment Management (ICM)

The term "Integrated Catchment Management" or "ICM" refers to an approach which co-ordinates all the activities within a defined catchment and attempts to identify the effects of various activities on natural resources. In its broadest sense, ICM covers all natural resources, including vegetation, fauna, water and soils, and development activities (NRO, 1994). The main issue for water is the impact of catchment land use activities on its quality. The second concern is the effect of catchment land use activities on the quantity of water. A basic principle of ICM, and all the components, is that every situation should be judged on its merits, subject to the provisions of management guidelines and plans.

In Sabah, the overall objectives of catchment management are to manage natural resources in a sustainable manner, and to minimize degradation of land, water and forest and the lost of biodiversity within a catchment. Catchment management is mainly by controlling activities in the catchment. Control of activities is through determination of access to catchments, monitoring approved access and enforcement of non-compliance. Catchment management plans, policies and guidelines are developed to facilitate these controls (Chong, 2001).

CHAPTER 3

MATERIALS AND METHODS

3.1 Data Collection

Data were collected through literature search, interviews and ground surveys. Below are the details for each method that has been employed during the data collection.

3.1.1 Literature Search

Literature search can be divided into published and unpublished reports as well as baseline data.

Among the published and unpublished reports referred to are listed below:

- Sabah Water Resources Master Plan;
- Sabah Conservation Strategy, Final Report (Volume 1 and Volume 2);
- EIA Report of the Liwagu Hydropower Project;
- Environmental Acts and Ordinances.
- The baseline data were extracted from the following sources:
- Topography map;
- Land Use map;

- Soil map;
- Liwagu-Labuk River Basin map;
- Raw water quality data of Liwagu-Labuk River Basin;
- Rainfall data.

Secondary data were obtained from the following government agencies and private sectors:

- Department of Agriculture (DOA), Kota Kinabalu;
- Department of Environment (DOE), Kota Kinabalu;
- Department of Irrigation and Drainage (DID), Kota Kinabalu;
- Environmental Conservation Department (ECD), Kota Kinabalu;
- Institute for Development Studies (IDS), Kota Kinabalu;
- Universiti Malaysia Sabah (UMS);
- Malaysian Palm Oil Board (MPOB);
- PPB Oil Palms Berhad;
- KTS Plantations Sdn. Bhd.

3.1.2 Interview

Interview method in the form of open-ended structural questions has been used to obtain some information regarding the study area (Appendix A). Officers from related government agencies such as DOE, DID and MPOB, as well as some private oil palm plantation companies' staffs have been interviewed. The objectives of conducting interviews are as follows:

- To identify the environmental problems of the Liwagu-Labuk River Basin
    - Through the kind of land use activities, conversions of land use either direct or indirect and their possible side effects on the environment or any serious cases in terms of pollution that have been reported to the authorities;
- To understand the institutional framework, policy and environmental legislation of the government departments;
    - Through the functions of related government departments' units and their activities, together with inter- and intra-government coordinations;
- To determine appropriate protection measures that may be implemented within the river basin.

3.1.3 Ground Survey

Ground surveys or field visits were done to gather and verify some information regarding the actual condition of the study area. During the surveys, the elements that needed to be observed were:

- The conditions of the Liwagu-Labuk River Basin - the topography around Mount Kinabalu (through slopes steepness), the riverbank (through river width and riverbank steepness), floating waste (type of waste) and the color of the Labuk River's water (clear or turbid);

- The construction areas within the basin;
- Agricultural activities or practices; crop plantation and animal farming;
- Tourism activities at the Kundasang area;
- Water or environmental management that includes solid waste and drainage management.

Some photographs of the study area that were taken during the ground survey are attached at the back of this dissertation (Appendix B).

3.2 Data Analysis

3.2.1 River Classification

Water quality data from eight DOE monitoring stations were selected for the purpose of river classification (Table 5). For each station, approximately 3-6 sets of data per parameter were usually available for each year. The total numbers of data per water quality parameter for 6 years (1996-2001) for each station were 28.

Table 5. Streams and Locations of DOE Water Quality Monitoring Stations

Stream	Location (Grid Reference)	DOE Station Code
Kenipir	05°43'04"N, 116°27'08"E	5764603
Kenipir	05°54'12"N, 116°38'55"E	5966608
Liwagu	05°42'15"N, 116°27'00"E	5764604

Liwagu	05°58'00"N, 116°40'30"E	5966606
Labuk	05°40'05"N, 117°11'50"E	5671614
Sapi	05°46'40"N, 117°25'03"E	5774611
Sapi	05°46'40"N, 117°25'03"E	5774612
Sualong	05°56'30"N, 117°21'08"E	5972613

The classification of river water quality is facilitated by certain adopted water quality indexing (WQI). Basically, WQI relates a group of water quality parameters to a common scale, combining them into a single number according to a chosen model. The calculated WQI values can then be matched against a preset WQI range of values corresponding to specific classes of river water quality based on the Interim Water Quality Standards (IWQS) proposed by the DOE (Murtedza, 1992). The IWQS identifies five classes of beneficial water uses (Table 6).

Table 6. The Department of Environment Interim Water Quality Classification

Class	WQI	Intended use
I	92.7-100	Represents water bodies of excellent quality. Standards are set for the conservation of natural environment in its undisturbed state. Water bodies such as those in the national park areas come under this category where strictly no discharge of any kind is permitted. Water bodies in this category meet the most stringent requirements for human health and aquatic life protection.
II	76.5-92.6	Represents water bodies of good quality. Most existing raw water supply sources come under this category. In practice, no body contact activity is allowed in this water for the prevention of probable human pathogens. There is a need to introduce

		another class for water bodies not used for IIB. The determination of Class IIB standards is based on criteria for recreational use and protection of sensitive aquatic species.
III	51.9-76.4	Defined with the primary objective of protecting common and moderately tolerant aquatic species of economic value. Water under this classification may be used for water supply with extensive/advanced treatment. This class of water is also defined to suit livestock drinking needs.
IV	30.5-51.8	Defines water quality required for major agricultural irrigation activities which may not cover minor applications to sensitive crops.
V	<31.0	Represents other waters which do not meet any of the above uses.

For the current purpose, the WQI formula adopted is the one based on the opinion poll method (DOE, 1990). Calculations are not performed on the parameters themselves but based on their subindices that derived from a system of best-fit equations. The adopted WQI formula sums up the weighted subindices (SI) of six conventional water quality parameters, which include dissolved oxygen (DO % saturation), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_4), suspended solids (SS) and pH according to the below equation.

$$WQI = 0.22SIDO + 0.19\ SIBOD + 0.16\ SICOD + 0.15SINH_4 + 0.16SISS + 0.12SIpH$$

Table 7. Best-fit Equations for the Estimation of Subindices Values

Parameter	Subindex Formula	Condition
DO	SIDO = 0 SIDO = 100 SIDO = $-0.395 + 0.030X^2 - 0.00020X^3$	for $X \leq 8$ for $X \geq 92$ for $8 < X < 92$
BOD	SIBOD = $100.4 - 4.23X$ SIBOD = $108e^{-0.055X} - 0.1X$	for $X \leq 5$ for $X > 5$
COD	SICOD = $-1.33X + 99.1$ SICOD = $103e^{-0.0157X} - 0.04X$	for $X \leq 20$ for $X > 20$
TSS	SISS = $97.5e^{-0.00676X} + 0.05X$ SISS = $71e^{-0.0010X} - 0.015X$ SISS = 0	for $X \leq 100$ for $100 < X < 1000$ for $X \geq 1000$
pH	SIpH = $17.2 - 17.2X + 5.02X^2$ SIpH = $-242 + 95.5X - 6.67X^2$ SIpH = $-181 + 82.4X - 6.05X^2$ SIpH = $536 - 77.0X + 2.76X^2$	for $X < 5.5$ for $5.5 \leq X < 7$ for $7 \leq X < 8.75$ for $X \geq 8.75$
NH_3-N	SIAN = $100.5 - 105X$ SIAN = $94e^{-0.573X} - 51X - 21$ SIAN = 0	for $X \leq 0.3$ for $0.3 \leq X < 4$ for $X \geq 4$

Note: Unit for X – DO is expressed in % saturation, other parameters are in mg/L except pH is dimensionless.

The classification of river can be extended beyond the six conventional water quality parameters. Other parameters such as heavy metals, pesticides, nutrients and coliforms are also included in classification procedures. Basically, these parameters are only for subjective assessment to determine the class of a river. Such parameters and the class standard are known as the Interim National Water Quality Standards for Malaysia (INWQS) (Appendix C).

In any river classification, the river with most pristine water quality will have the highest value of WQI and thus, will be classified as Class I status. Conversely, a heavily polluted river segment will have a lower value of WQI and thus, given a Class V status.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Baseline Conditions

4.1.1 Geography

The Liwagu-Labuk River Basin is located between latitudes 5°30'N and 6°05'N and longitudes 116°25'E and 117°30'E. It is centrally located in the north of the state of Sabah draining an area of about 4,000 km^2 from Mount Kinabalu in the west to the Sulu Sea in the east, where it is generally known as the Sungai Labuk.

The basin is intersected by the main East-West Ranau-Sandakan trunk road which connects the state capital of Kota Kinabalu with the east coast town of Sandakan. This provides good access to most of the study area. Over recent years, the road surface has deteriorated. Currently, repair and reconstruction of the road is in progress for places that are in poor condition.

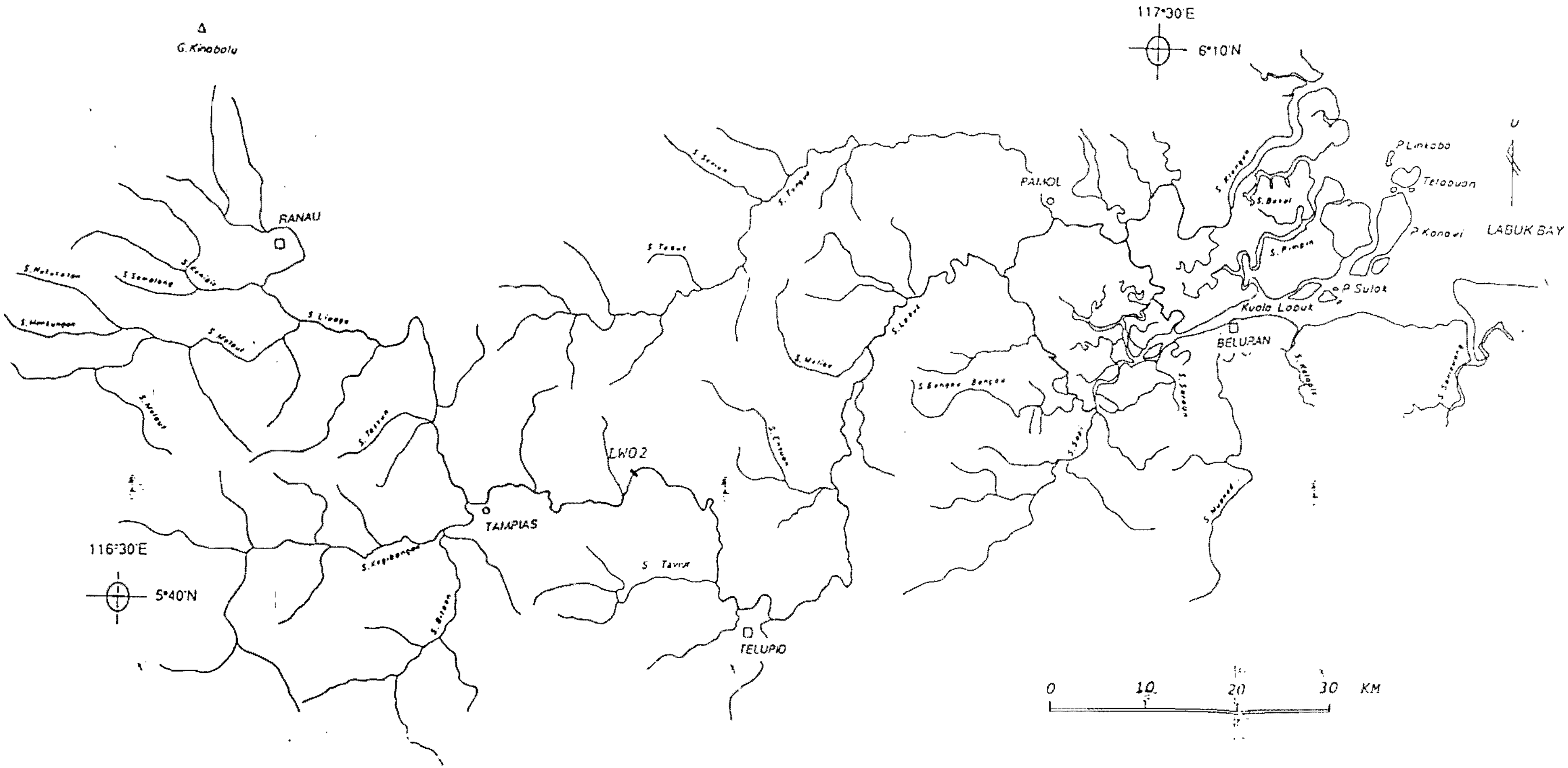
The basin is sparsely populated except for the Ranau-Kundasang area in the north-western part of the basin and the immediate district of Sandakan. A number of small villages are found alongside the main road and adjacent to the Liwagu River and its major tributary the Kegibangan River (whose source rises in the

Trusmadi Mountains to the south-west), particularly in the vicinity of the confluence of the two rivers at Tampias. Other major tributaries in the upstream area are the Kenipir and Melaut Rivers. Downstream, important tributaries include Ensuan, Meliau, and Tungud Rivers (Figure 2).

The topography of the western part of the basin is mountainous, which comprises the Crocker and Trusmadi Ranges with peaks generally rising to 2,500 m and dominated by the highest peak, Mount Kinabalu (4,095.2 m). To the east, the terrain is still undulating but falls gently towards the Sulu Sea interposed by occasional hills of which Mount Mentapok is the most well-known.

In its natural state, the mountainous terrain is jungle covered although there have been clearings for cultivation of rice while more recently, vegetables and grazing have taken place. Due to previous extensive logging in the basin, mostly the primary forest has been replaced by secondary forest and lalang. In some places, hill slopes are very steep. Thus, landslides are frequent, particularly during raining season in areas where the natural vegetation has been disturbed.

The lower part of the river is relatively flat. The Labuk River catchment area discharges into the Labuk Bay through the Kuala Labuk and Klagan estuaries. Although the channel of Kuala Labuk



(Source: UKM, 1989)

Figure 2 The Liwagu-Labuk River Basin

estuary is much bigger, both of these estuaries are interconnected by a network of upstream tributaries.

4.1.2 Climate

Generally, the Liwagu-Labuk River Basin is experiencing an equatorial type of climate, and is considered to be in the Tropical Rainy Climate (AF) classification of climates according to Koppen's system (WLPU Consultants, 1989). Temperature records for Telupid, at elevation 61 m, are believed to be approximately representative of the lower lying eastern part of the catchment. These indicate mean annual daily maximum and minimum temperatures of 32°C and 22°C respectively. Temperatures fall with increasing altitude and slightly lower temperatures are experienced at Ranau and elsewhere in the upper catchment. Overall, the temperature and humidity are relatively uniform throughout the year with approximate average of 27°C and 85%, respectively. There is little variation in the temperature.

The Liwagu Basin receives plentiful rainfall and it is well distributed over the basin (Figure 3). Most of the annual rainfalls are greater than 2,000 mm and at a maximum of over 4,000 mm on Mount Kinabalu (4,095.2 m). There is a steep orographic rainfall gradient on Mount Kinabalu. The rainfall decreases sharply

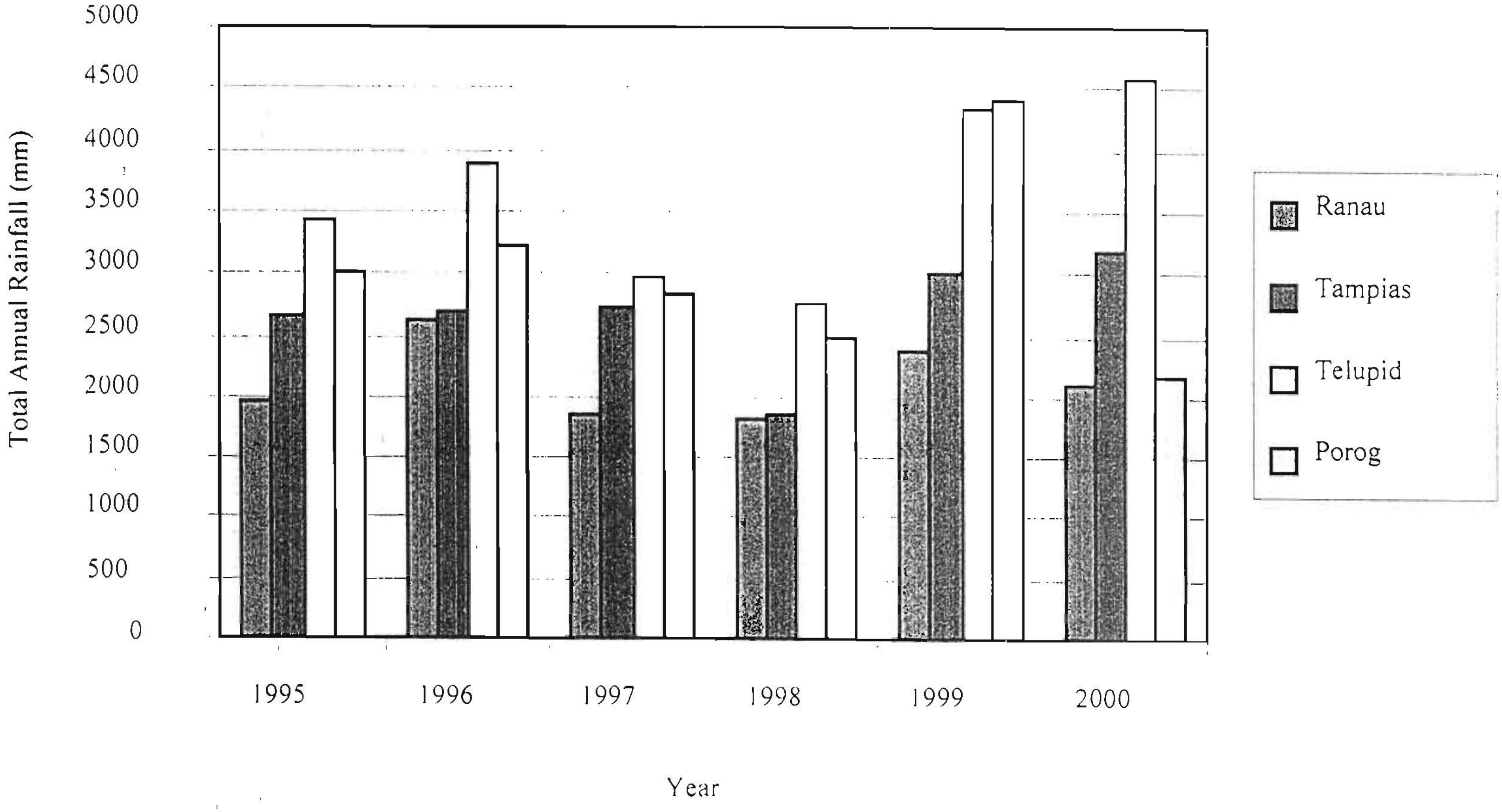


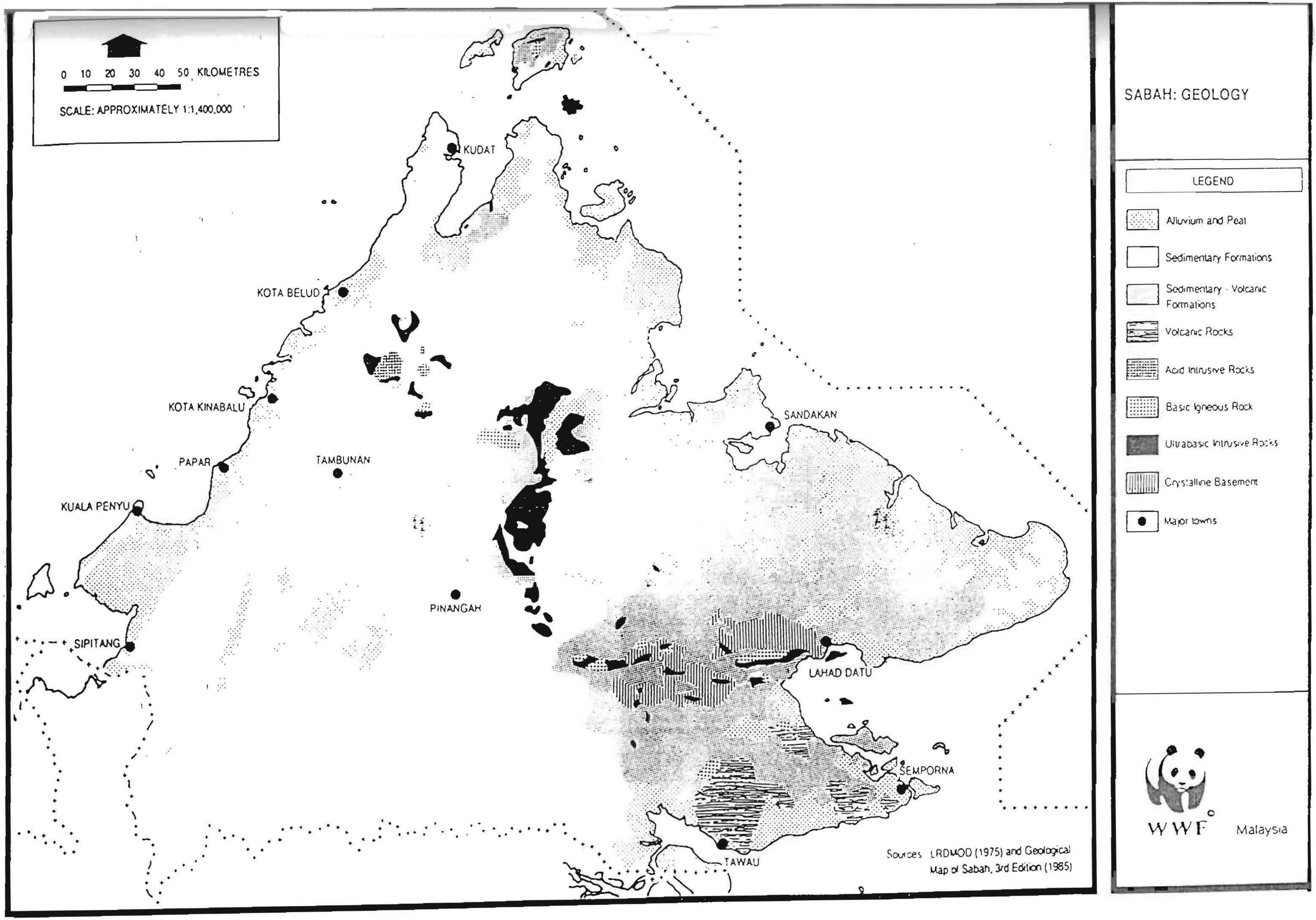
Figure 3 The Total Annual Rainfall from 1995-2000

southward, although this affects an insignificant catchment area. Again, the rainfall increases eastwards in the downstream direction of the river. There is no regular and distinct dry season and it is rather rare for no rainfall to be recorded for more than 25 days. The forest evaporation is between 900 and 1,100 mm. The average annual open water evaporation is about 1,600 mm (Murtedza *et al.*, 2002).

4.1.3 Geology

The Liwagu Basin comprises in the main Tertiary sediments of the Trusmadi and Crocker formations together with Chert Spilite and associated sedimentary rocks (Figure 4). In the upper part of the catchment, the Liwagu flows from the adamellite and granodiorite of Mount Kinabalu to the Trusmadi Formation which consists of mudstone, shale, phyllite and sandstone. At Kegibangan confluence, the river flows over the Crocker Formation consisting mainly of flysch type of deposits – sandstone, shale and siltstone.

From Telupid to Porog, the river crossed through ultrabasic rocks consisting of peridotite, dunite and gabbro. In the lower part of Labuk after Porog, the rocks consist mainly of a mixture of argillaceous and arenaceous sediments with conglomerates of Oligocene – Middle Miocene age. In most part of the Labuk Valley these rocks are overlaid with recent Alluvium (UKM, 1989).



(Source: WWFM, 1992a)

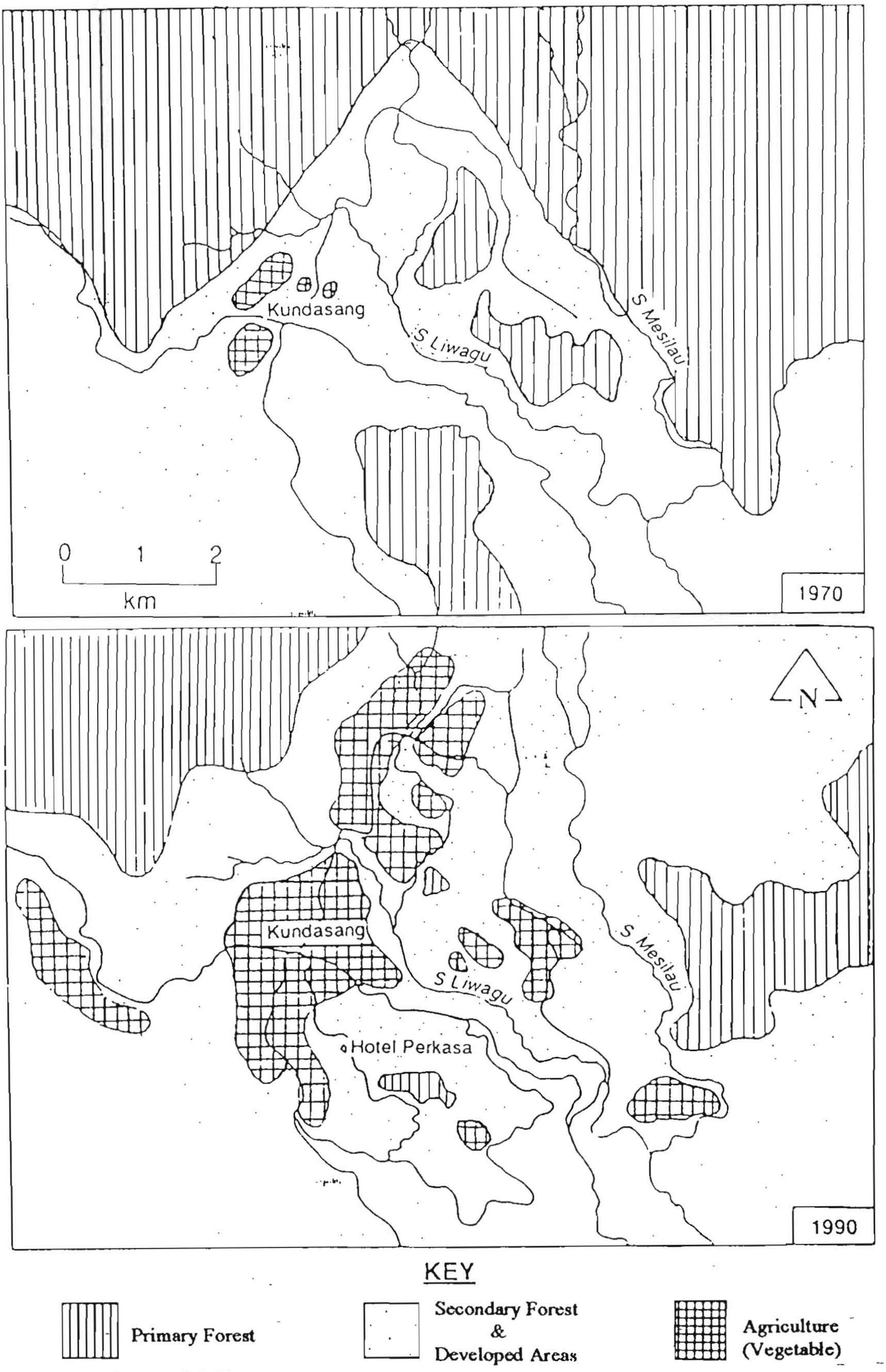
Figure 4 The Geological Map of Sabah

4.1.4 Vegetation and Wildlife

The vegetation of the study area is primarily tropical rain forest which has given way to dense areas of secondary growth subsequent to logging activities or shifting cultivation. This has resulted in the removal of large trees and primary forest as well as in the increase of the sediment load of the river. In spite of the occurrence of logging in the area between Tampias and Telupid, a rich vertebrate diversity was found in that area with most significant were the horned frog, pheasants, hornbills, orang-utan, banteng and elephant. Nevertheless, most are declining because of their habitat destruction, and will continue to disappear from the area unless deforestation is halted (WLPU Consultants, 1989).

4.2 Land and River Uses

Generally, most parts of the Liwagu Basin are covered by primary and secondary forests. These natural vegetations are good ground cover and can minimize soil erosion. Yet, logging activities have been conducted in certain areas of the basin and the exposed areas in the logging concessions are at the risk of soil erosion. Interpretations based on aerial photos of 1970 and 1990 (Figure 5)



(Source: Lim, 1995)

Figure 5 Changes in Forest Cover in Kundasang Area, 1970-1990
(Based on Aerial Photo Interpretations)

showed changes in forest cover in Kundasang area due to conversion of forested land to arable land.

In the upstream part of the basin, a wide variety of crops have been planted. This indirectly made the Kundasang area in Ranau to be known as the "temperate-vegetable district of Sabah" due to its unique upland climate and relatively fertile soils. Some areas have been utilised for commercial-scale vegetable cultivation as well as floriculture, livestock production and tree crops cultivation. These include paddy (irrigated paddy and hill paddy), vegetables (such as cabbages, tomatoes, carrots and lettuces), cocoa, fruit trees (such as durians, mangoes and rambutans), coffee, tea, coconut, maize and rubber. Apart from the upstream terrains, shifting cultivation practices are also widespread in the middle section of the Liwagu River Basin.

In the downstream part of the basin, major oil palm plantations can be found. The public trunk road and the plantation roads are the important ground transportation network. Apart from these, the Labuk River and the Kuala Labuk estuary also provide a means of communication between these plantations, especially the Sabah Palm and Pamol plantations and the further downstream towns of Beluran and Sandakan. Logging companies also used the Kuala Labuk waterway to move logs from the Tungud logging concessions to Sandakan. Most of the rivers in the estuarine system also serve as fishing grounds to the locals with mainly of the fishes are for self-consumption though some are sold in Sandakan.

Due to the low elevation of the terrain of the Lower Labuk reaches, the palm oil and cocoa trees do not require water abstraction from the river for irrigation as this is done by sluiced canals. Nevertheless, the Labuk River is prone to flooding during wet season. Ranau, Telupid and Beluran are to be considered the urban areas within the entire river basin. Besides, small villages are scattered around the river floodplain and along the East-West Ranau-Sandakan trunk road.

4.3 River Flows and Suspended Sediment

Systematic recording of river flows began in the Liwagu Basin in 1963. However, these records are incomplete and some of the previous gauging stations had been closed such as Bedukan and Tomboloi.

4.3.1 River Flows

River flow records are available at four DID gauging stations within the Liwagu River basin. These are at Kinabalu Park, Tampias, Maringkan and Porog for the year 1995-2000. The mean flows at various gauging stations are shown in Table 8.

Table 8. The Mean Flows Recorded at Four DID Gauging Stations (1995-2000)

Station	**Catchment Area (km^2)**	**Mean Flow (m^3/sec)**
Kinabalu Park	11	0.50
Maringkan	2000	38.1
Tampias	2010	115.2
Porog	3185	231.1

4.3.2 Suspended Sediment

Records of suspended sediment are available for Porog from 1971-2000. However, these records are based on discontinuous records over 10 years as shown in Table 9.

Table 9. The Mean Suspended Sediment at Porog (1971-2000)

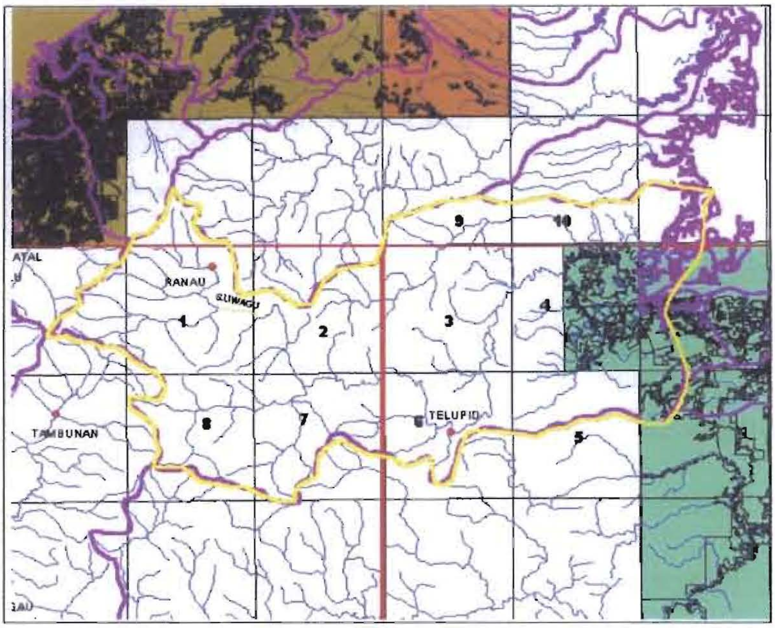
Year	**Mean Suspended sediment (mg/L)**
1971	398.0
1972	309.1
1973	91.7
1977	304.8
1978	173.0
1979	98.1
1980	133.0
1993	692.0
1994	377.0
1995	994.5

1998	161.7
1999	132.0
2000	250.3

Based on the data in Table 9, the means suspended sediment for the year 1971-1980 and 1993-2000 are 215.4 mg/L and 434.6 mg/L respectively. This clearly indicates that the suspended sediment loading had increased within the downstream part of the Liwagu River Basin. The increment could be due to changes in land use pattern or intensification of the existing land uses. The large scale transformation of land into oil palm plantations in the middle and lower catchment of the Liwagu River Basin could be a major cause for the higher suspended sediment loading.

4.4 Current Land Use Zonation

According to Murtedza (2002), the whole Liwagu River Basin has been divided into 8 zones based on the different land use and topography. The river basin boundary is denoted by the yellow line (Figure 6).



(Source: National Mapping Malaysia, 1978 & 1984)

Figure 6 Land Use Zonation of Liwagu-Labuk River Basin

Note: Total 15 sheets were used to cover the entire river basin.

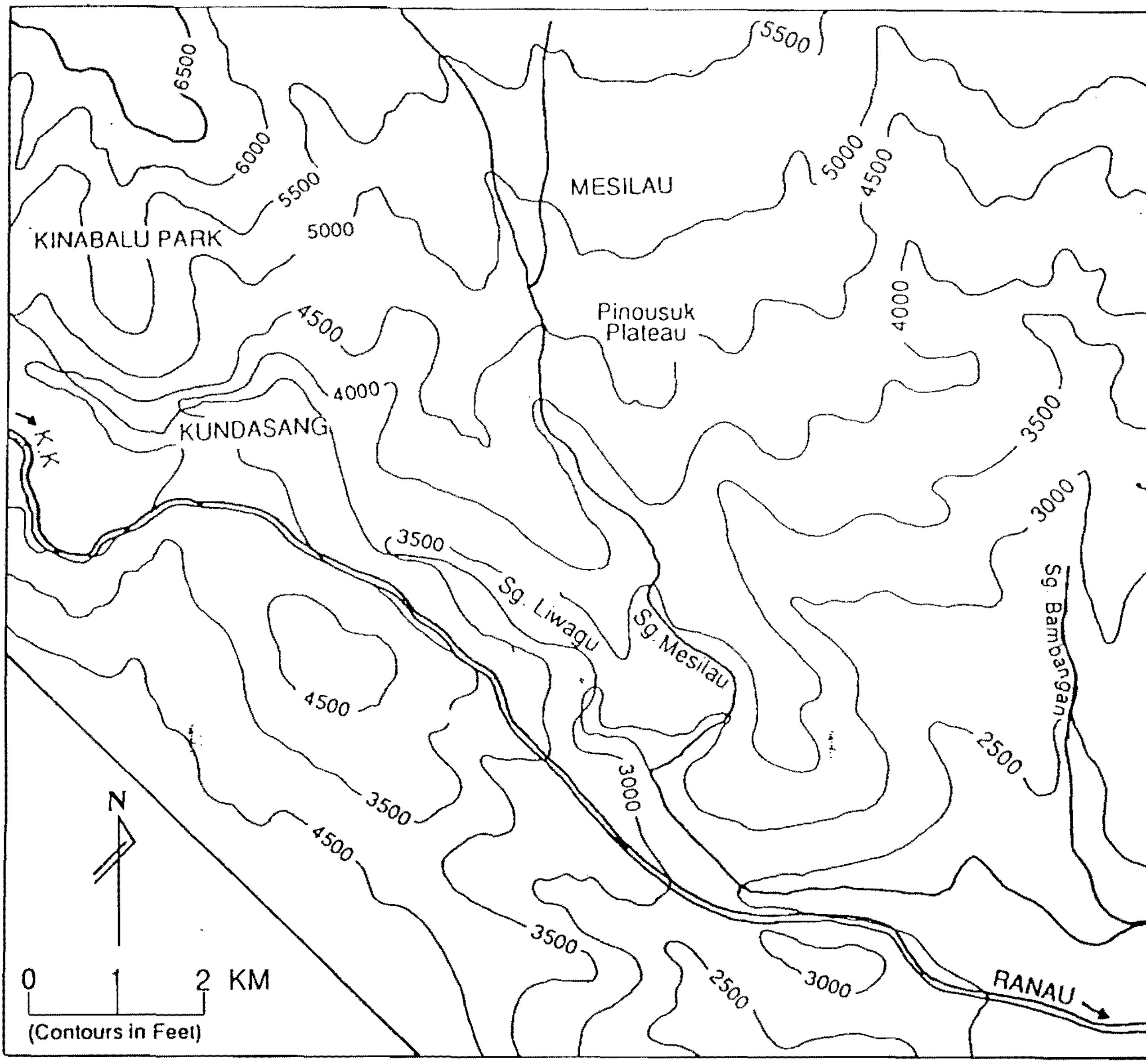
Grid No	Map Sheet No.	Year
1	5/116/3	1999
2	5/116/4	No coverage
3	5/117/1	2001
4	5/117/2	2000
5	5/117/6	2000
6	5/117/5	2000
7	5/116/8	No coverage
8	5/116/7	No coverage
9	-	No coverage
10	-	No coverage

4.4.1 Zone 1

This area is located on the south-eastern side of Mount Kinabalu. The mountain is the highest peak in South-east Asia region with an elevation of 4095.2 m. Generally, this zone is very hilly, involving slopes ranging from 5 - 60% at an average of 20% (Figure 7). Due to its average altitude of 1200-1800 m a.s.l., this area is experiencing a temperate climate. The natural vegetation is montane forests, which are under the conservation within Mount Kinabalu National Park. The park was gazetted in 1964 and covers an area of 700 km^2.

Kundasang in the district of Ranau is the uppermost town. It comprises approximately 20 villages stretching over the entire area. Besides the public trunk road, the ground transportation infrastructure consists of a few paved roads in the area close to Kundasang town. All the villages in the more remote areas can be reached by unpaved roads road with a four-wheel driven vehicle. The number of persons living in the Kundasang area is estimated to be approximately 6000-8000. The majority of the people are Dusuns, an indigenous ethnic group, but there are also many Chinese, Indonesian and Malay settlers.

Owing to the temperate climate, intensive commercial-scale vegetable cultivation, few tea plantations, floriculture and livestock production including dairy farms are the major land use activities that



(Source: Lim, 1995)

Figure 7 Topographical Map of Kundasang Area can be observed. Besides, the most well-known landmark in Sabah, the Mount Kinabalu has also contributed to tourism-related development. Thus, resort facilities are widely scattered around the Kundasang area.

4.4.2 Zone 2

Passing Ranau, the topography changed as the valley becomes narrower and the hillsides steeper. Compared to Zone 1, the land use is not intensive and many fallow fields can be observed indicating shifting cultivation may be practised. Some paddy fields are found in the valley as well as some hill paddies on the slope area. Secondary forest with interspersed fields is the main vegetation in this zone. The river in this area is quite wide and calm. It seems that paddy becomes more important in the widening valley.

At Tampias, a bridge crosses the river that has now changed its name to Labuk. Moving a few kilometers downstream from this bridge is the site for a proposed 165 MW hydropower dam (Liwagu Dam). Though its EIA is dated 1989, the hydropower dam project is still suspended currently. From the bridge, a few oil palm plantations are replacing the old rubber plantations.

4.4.3 Zone 3

There is no exploitation has been observed as it is the Dawiu Forest Reserve. The reserve is relatively small.

4.4.4 Zone 4

Zone 4 is the east side of the forest reserve. This area is a kind of transition zone in between the upland extensive cultivation areas and the intensive oil palm plantations in the lowland. As compared to Zone 2 and 3, the valley is still quite wide but the hillsides are getting less steep. There are more agricultural lands around Kg. Tabiu. Probably, the land availability is the cause for this more populated area. Some rubber plantations are planted in Kg. Wonod. Some newly established oil palm plantations can be found after Kg. Wonod.

Downstream from here, the valley widens and the forest on the hillsides seems to be degraded with few tall trees standing among low scrub. However, the degraded look of the forest may also be due to the low fertility of soils developed on ultrabasic rocks. Previously, Telupid used to be a centre for logging activities and is situated at a small junction.

4.4.5 Zone 5

Zone 5 is the east side of Telupid. In this area, oil palm plantations become more dominating as the topography changed to undulating lowland. This zone can also be described as a transition zone towards the pure oil palm plantations. The land use is more monotonous than Zone 4. Older oil palms can be observed at the further east portion. This may indicate an expansion of oil palm plantations towards the west side.

4.4.6 Zone 6

Zone 6 consists of homogenous oil palm plantations. Most of the plantations are owned be large private companies like PPB Oil Palms Berhad, IOI Corporation Berhad and IJM Plantations Berhad. Sungai Sapi Forest Reserve (Class VI), which covers an area of 625 hectares, is one of the few interruptions to the plantations. Several small villages housing the plantation workers are scattered in this area. The district has a total of 8 palm oil mills.

4.4.7 Zone 7

Zone 7 is notable for a more varied land use. Some cocoa plantations can be found and sometimes, coco palms are used as shade trees. Besides, some orchards can also be found.

4.4.8 Zone 8

Zone 8 is the remaining area towards the coast. The main land use is oil palm plantation. Some cassava fields can be found. A KTS Forest Management Unit (FMU) is located in this zone.

4.5 Existing Land Use Conflicts

There are few observed land use conflicts within the Liwagu River Basin. In the upper catchment, water is a natural resource used for important sectors such as municipal supplies, agriculture, industrial production and tourism. Hence, all these land use activities have led to competition for water resources. Unfortunately, the wastewaters from private households and industrial have not been treated sufficiently right before the disposal into rivers. Thus, both quantity and quality of water supplies in the Kundasang/Ranau area are becoming matters of considerable concern. Besides, there is no control on land use in this area outside Kinabalu Park currently.

Insufficient administrative structures and unclear responsibilities have been found to be responsible for missing regulations concerning water supply and wastewater treatment (Oksen and Müller, 1999).

The intensive agriculture cultivation has run the risk of polluting the water resources with nutrients from fertilizers and pesticides. Besides, cultivation on steep sloped land can lead to soil erosion and loss of fertile topsoil. The expansion of tourism industry in the upper catchment area could generate more waste and wastewater as well as demanding for more clean water. This may eventually affect the industry itself if necessary environmental protection measures were not being employed in the future development programs. At the middle section of the river basin, the proposed 165 MW Liwagu Hydropower Dam will flood agricultural land in the downstream areas if implemented. This may result in relocation and intensification of land use in the remaining areas in the basin.

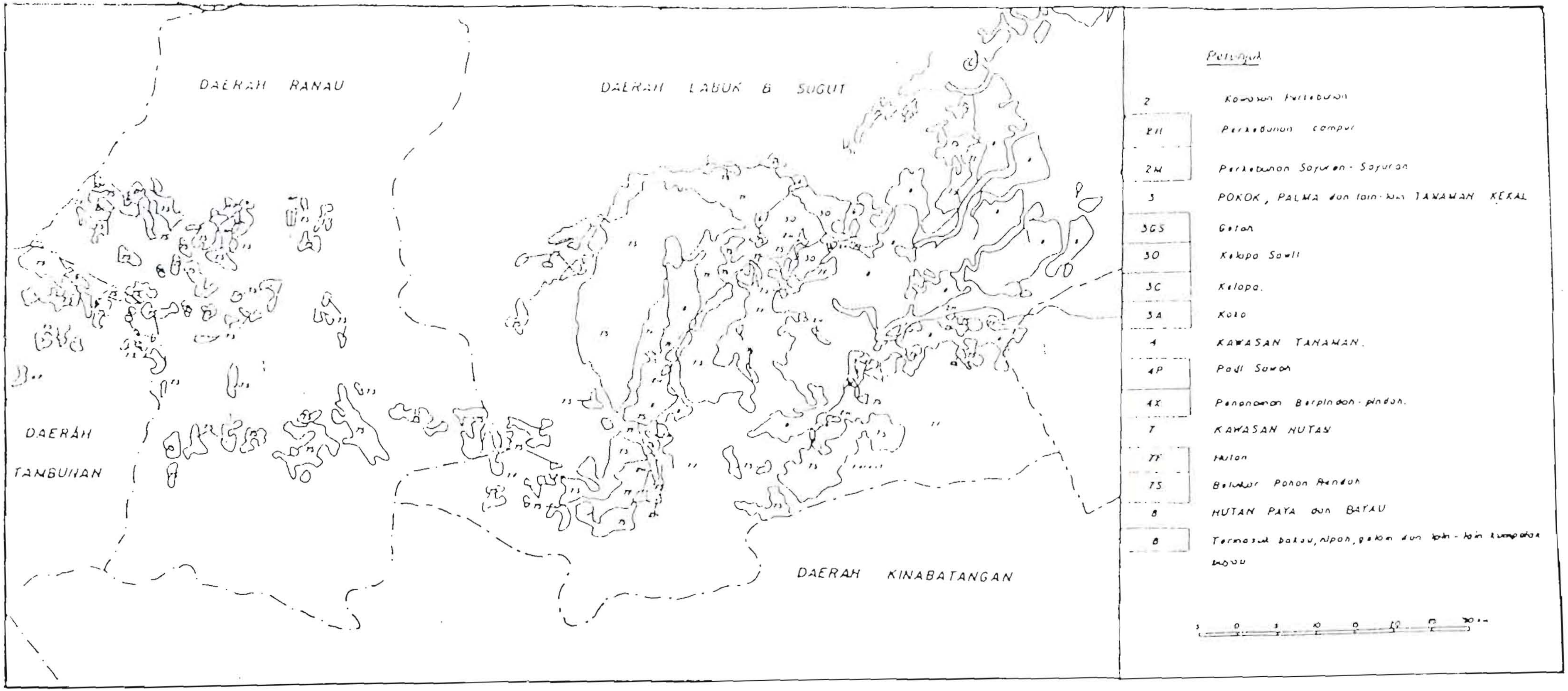
For the lower part of the catchment, increasing conversions from extensive small or medium scale agriculture and forest to intensive monocultures, especially oil palm plantations posed another challenge for the catchment management in terms of soil erosion. Also, these conversions may cause water pollution due to the intensification input of agrochemicals. Conversely, people are becoming increasingly dependent on these oil palm plantations, which are owned largely by private companies.

4.6 Previous Land Use

Figure 8 show the previous land use activities within the Liwagu-Labuk River Basin in the 1970's. Most of the areas in the Ranau district were covered with the lowland dipterocarp forests. Some smalls areas had been planted with irrigated paddy but not vegetables yet as the main road between Ranau and Kota Kinabalu was sealed in late 1970s. Therefore, intensive commercial-scale vegetable cultivation only started near the 1980's.

Moving further downstream to the Labuk district, land use was more varied. Nevertheless, the major land use was still forestry. The second major land use were mangroves and other wetland forest associations. Over small areas had been planted with vegetables. Oil palm plantations were detected in a relatively small concentrated area.

Therefore, it is quite obvious that the entire river basin were still being kept near to its natural state though some other land uses had been started to take place.



(Source: Murtedza *et al.*, 1984)

Figure 8 Previous Land Use Activities in Liwagu-Labuk River Basin

4.7 Current Land Use

The current available analog land use maps for the Liwagu River Basin (Appendix G) are not complete as mapping for some parts has not been done. For the upstream parts, only the Ranau district has been mapped. Oppositely, the downstream parts are completely mapped. The years of mapping for the available maps are between 1998-2001.

The Ranau district is located between latitudes 5°45'N and 6°00'N and longitudes 116°30'E and 116°45'E. Based on the 1998 land use maps (Map sheet No. 5/116/3), majority of the market gardening (vegetables and other food) and horticulture are located in the north-west of Ranau. In the north-east, Liwagu River started to spring. More forests can be located besides some paddy fields. The southern part of Ranau is less populated compared to the northern part. Some idle lands can be found in the south-west while the south-east part is covered almost entirely by forest.

Telupid, Kiabau, Terusan Sapi and Sungai Luan Pori are located at the downstream parts of the basin. Telupid is located between latitudes 5°30'N and 5°45'N and longitudes 117°00'E and 117°15'E. At Telupid, based on the 2000 land use maps (Map Sheet No. 5/117/5), some senile rubbers can be found particularly at the north-west. Large portions of this area are forests and mangroves.

Horticulture is being practised especially along the public trunk roads. There are a few improved permanent pastures along Liwagu River.

In the north-east, Liwagu River has now changed its name to Labuk River. Some senile oil palms estates are located along the Labuk River besides some mixed horticulture lands. The southern part of Telupid, especially the south-east is almost half planted with oil palms. The remaining are forests. The south-western part consists of some scattered oil palm estates besides some mixed horticulture lands. Almost all of the land use activities are along the main public trunk roads and rivers.

Kiabau is located between latitudes 5°45'N and 6°00'N and longitudes 117°00'E and 117°15'E. Based on the 2001 land use maps of Kiabau (Map Sheet No. 5/117/1), oil palm plantations become more dominating, especially at the south-east side, which is located north to Telupid. Apart from the plantations, forests, scrubs and mangroves are located adjacent to the Labuk River.

To the east of Kiabau, Terusan Sapi is located between latitudes 5°45'N and 6°00'N and longitudes 117°15'E and 117°30'E. Based on the 1999 and 2000 land use maps of Terusan Sapi (Map Sheet No. 5/117/2), the major land use for the north-west is oil palms though some forests can be found. The oil palm plantations are situated both the sides of the Labuk River. In the north-east, half of the areas are covered with mangroves and other wetland forest associations. The remaining half is planted with oil palms. For the southern parts, forests, mangroves and other wetland forest associations are the major land use observed.

To the south of Terusan Sapi, Sungai Luan Pori is located between latitudes 5°30'N and 5°45'N and longitudes 117°15'E and 117°30'E. Based on the 2001 land use maps of Sungai Luan Pori (Map Sheet No. 5/117/6), in the northern parts, oil palms plantations are the most dominating land use. While for the southern parts, though oil palm plantations are still the major land use, more forests can be observed as compared to the northern parts.

As a comparison to the previous land use, intensification of land use is observed. This is very obvious for the entire Liwagu River Basin, from the upstream parts until the downstream parts. The original forested land has been massively replaced by the agricultural activities. Conversions from extensive small or medium scale agriculture and forest to intensive monocultures, especially oil palm plantations are almost widespread over the downstream parts.

4.8 River Classification

Results obtained are as shown in Table 10. The result of WQI estimation indicated that these rivers or monitoring stations generally belonged to Class II river category most of the times though for certain years, some of these rivers deteriorated to Class III river category. In terms of changes in WQI over the year 1996-2001 (Appendix E), those located in the upstream parts demonstrated a more stable water quality condition while the Sapi Rivers' were more fluctuated and having lower WQI as both are located at downstream parts.

Generally, the high level of total suspended solids (TSS) of the streams could be directly linked with the on-going land conversion such as timber harvesting activities and intensive commercial-scale agriculture cultivation in the upper reaches and oil palm plantation in the middle and lower catchment of the Liwagu River Basin. Besides, natural erosion of the alluvial river channels at the Labuk River could also be a cause contributing to the recorded TSS.

The records for BOD, amoniacal-N and pH showed little variability for most monitoring stations. This could be due to insignificant input of readily biodegradable organic pollutants. The records for DO were found to be generally high (>80% saturation) except during 1997-1999 period. This could be attributed to the significant drought that struck our country in between the years as higher temperature could cause the DO level to drop. Meanwhile, the records for COD have increased over the years. The increment could be caused by the constant inputs of natural leachate from the non-readily degradable freshly humidified forest vegetation. Based on the current land use trend, it is not too surprisingly that the records for COD have gone up.

As to compare with the earlier results obtained by Murtedza (1992) for the Liwagu River Basin in 1983-1989 period, it can be said that the river water quality has deteriorated over the years. During the period, the water quality recorded were Class I category with WQI of 93.0 at the Ranau monitoring station and Class II category with WQI of 88.6 at the Hap Seng Bridge monitoring station. However, none of the monitoring stations had water quality of Class I category during the 1996-2001 period due to land use changes within the basin.

Table 10. The Water Quality Index (WQI) and the Assigned Classes for the period 1996-2000

Year	**Kenipir (5764603)**		**Kenipir (5966608)**		**Liwagu (5764604)**		**Liwagu (5966606)**	
1996	85.2	II	77.2	II	82.4	II	83.3	II
1997	77.5	II	84.5	II	82.4	II	82.2	II
1998	84.8	II	86.6	II	79.6	II	83.8	II
1999	83.7	II	82.7	II	72.7	III	82.7	II
2000	87.8	II	86.7	II	84.0	II	86.7	II
2001	86.0	II	87.7	II	82.3	II	88.3	II

Year	**Labuk (5671614)**		**Sualong (5972613)**		**Sapi (5774612)**		**Sapi (5774611)**	
1996	87.2	II	85.4	II	82.5	II	84.8	II
1997	87.9	II	91.3	II	79.9	II	80.0	II
1998	88.4	II	83.4	II	75.2	III	72.2	III
1999	85.0	II	78.3	II	78.3	II	77.5	II
2000	88.3	II	89.0	II	81.7	II	79.3	II
2001	88.0	II	89.3	II	86.7	II	78.7	II

4.9 Oil Palm Industry

The rapid rise in prominence of palm oil as a major vegetable oil is attributable to its high productivity coupled with the expansion in planted area. Oil palm is capable of producing more than three tonnes of oil per hectare, which is seven times higher than the productivity of soybeans. Compared to rapeseed and cotton seed, oil palm is respectively five and 16 times more productive (Teoh, 2000).

4.9.1 PPB Oil Palms Berhad (PPBOP)

PPB Oil Palms Berhad (PPBOP) entry into the plantation industry was through Perlis Plantations Berhad (PPB) which started its oil palm operations in Sabah and Sarawak in the mid-1980s. PPBOP was incorporated in January 1996 following the merger of PPB and its joint venture plantation companies in East Malaysia. The Group had chosen to invest in Sabah and Sarawak in response to the State Government's encouragement and incentives for development of plantations as a strategy to broaden their economic base. Furthermore, the location of plantations in East Malaysia would provide a competitive advantage in shipment of edible oils to the large emerging market in China.

Currently, PPBOP is one of the leading private oil palm plantation companies in Sandakan. As at March 2003, the company owned 8 oil palm estates with 7 already planted with oil palms. The total hectarage for all the estates is 37,004 hectares. Listed below is the hectarage for each estate (Table 11).

Table 11. PPB Oil Palms Berhad's Estates

Estate	**Planted Area (ha.)**
SPSB	13,257
Reka Halus	4,651
Kiabau	1,108
Sabahmas	9,531
Hibumas	3,296
Sri Kamusan	2,515
Ribubonus	2,826
Jebawang	0
Total	**37,004**

The main pesticides that are being used in the estates are paraquat and glyphosate. Paraquat is employed because of its broad spectrum in controlling pests while glyphosate is due to its cheaper price though less systemic in its reaction. Normally, the pesticides and fertilizers usages are only up to 80-85% of the budgeted annual requirements. Table 12 and Table 13 show the budgeted pesticides and fertilizers requirement respectively for the year 2003.

Table 12. Budgeted Pesticides Requirement 2003

Type	Name	Total
Major (Liquid)	Paraquat	62,566
	Glyphosate (Transorb)	31,159
	Glyphosate (Sentry/Dewana/Ecomax)	77,555
	Diuron	5,224
	Starane	3,132
	Garlon	412
	Total (Litre)	**180,048**
Minor (Liquid)*	Amine	753
	Basta	1,076
	Dipel	1,176
	Total (Litre)	**3,005**
Minor (Solid)*	Ally	113
	Rat Bait	12,535
	Bactospeine	79
	Total (kg)	**12,727**

* As and when is required

Table 13. Budgeted Fertilizers Requirement 2003

Type	Name	Total (Tonne)
Major	Mop	3,094
	Gafsa	4,507
	Soa 21%	2,286
	Urea	1,701
	Kieserite	533
	NPK Yellow	752
	Nitrophoska (Yellow)	31
	Nk1	4,446
	Borate	104
	Hi-Kay Plus	16,453
	Total	**33,907**
Minor (* In Litre)	Bunch Ash	1,785
	Mycocold	12
	Organigro	29
	Limestone Dust	788
	Grofas Blue/Yellow	3
	Bayfolan	889*
	Natrakelp	300
	NPK Blue	12
	Nitrophoska (Blue)	11
	Nurseryace	5
	Turfgro	1
	Woodace	25
	Total	**3,860**

Therefore, an estimated 4.87 litre/hectare/year of major liquid pesticides, 0.08 litre/hectare/year of minor liquid pesticides and 0.34 kg/hectare/year of minor solid pesticides are being applied in the estates. As to promote the growth of the oil palms, 0.92 tonne/hectare/year of major fertilizers and 0.10 tonne/hectare/year of minor fertilizers are being used.

Compared with other major seed oil crops, oil palm is more efficient in utilization of land resources and inputs such as fertilizer and energy and is less polluting to the environment. A FAO study cited by Pusparajah (1998) showed that oil palm has a lower requirement of nutrients (nitrogen and phosphates) and pesticides/herbicides per tonne oil than soybean, sunflower and rapeseed (Table 14). It also has the lowest soil and water emissions in respect of nitrogen, phosphorus and pesticides/herbicides.

Table 14. Input–output in Cultivating Oil Palm and Oilseeds

Item and unit	**Inputs per tonne of oil by crop**			
	Palm oil	**Soybean oil**	**Sunflower oil**	**Rapeseed oil**
Seed/fruit for extraction (kg)	4500*	5000	2500	2500
Inputs				
i. Nitrogen (kg N)	47	315	96	99
ii. Phosphate (kg P_2O_5)	8	77	72	42
iii. Pesticides and herbicides (kg)	2	29	28	11
iv. Others (kg)	88	117	150	124
v. Energy (Gj)	0.5	2.9	0.2	0.7

Outputs a) Emission to soil and water				
i. Nitrogen	5	32	10	10
ii. Phosphates	2	23	22	13
iii.Pesticides/herbicides	0.4	23	22	9
b) Emission to air (kg)				
- NOx	0.5	4	0.3	0.8
- SO	0.2	2	0.1	0.2
- CO	32	205	16	50
- Pesticides/herbicides	0.1	6	6	2

* Fruit bunches

Source: FAO (1996) as cited by Pushparajah (1998)

Based on Table 14, from an input of 2 kg of pesticides and herbicides, 0.5 kg of them will be the output through emission to soil, water and air. Thus, it can be roughly assumed that the percentage of pesticides and herbicides leached out from an oil palm plantation is 25%. Meanwhile, from an input of 47 kg of nitrogen, 5.5 kg of them will be the output through emission to soil, water and air. Thus, it can be roughly assumed that the percentage of nitrogen leached out from an oil palm plantation is 12%.

If the same assumption is to be applied to the estimated pesticides and fertilizers that are being used by PPB Oil Palms Berhad, 1.22 litre/hectare/year of major liquid pesticides, 0.02 litre/hectare/year of minor liquid pesticides, 0.09 kg/hectare/year of minor solid pesticides, 0.11 tonne/hectare/year of major fertilizers and 0.01 tonne/hectare/year of minor fertilizers would be probably leached out for the production of 1 tonne of palm oil.

4.10 Impacts of Land Use Changes

The effects of replacing natural forests with other land use activities can be associated with the potential impact on biodiversity, climate, hydrology, soil erosion, soil physical and chemical properties and specific management aspects. Adverse forest practices can result in serious consequences on the surrounding river ecosystems. The clearance of natural vegetation cover exposes the soil layer to erosion and run the risk of being washed away. The fate of the soil is largely dependent upon the successive land use. Unfortunately the magnitude of the erosion risk is amplified in the humid tropics due to high intensity rainfalls and the rapid rate of land conversion. Besides, clearing of forests for whatever reason obviously leads to the loss of native plant resources, many of which are sources of traditional medicines and health food products.

For the case of oil palms, forest disturbance causes loss of canopy fauna initially, followed by ground fauna, which are gradually replaced by species from the open. The monocultures plantations create an environment that is very different from that of natural forests. The uniformity of plantation crop and its regularity in spatial distribution creates a monotonous environment impoverished in variety and life.

Another major consequence of clearing or disturbance of forests is changes in the hydrology and soil erosion. The Liwagu-Labuk River Basin is frequently flooded. This could be due to the existence of the major forest and/or agricultural activities in the mid- and upstream regions, which are the main cause of siltation in rivers. According to Murtedza (1987), major agricultural development projects such as palm oil and rubber plantations affect local water quality at three stages:

i. during land clearing where surface erosion is inevitable;
ii. during the growth period where fertilizers and pesticides are applied; and
iii. during processing of products where mainly organic and solid effluent is discharged.

It is important to note that new oil palm plantations are developed mainly from logged-over forests after economic timber species have been extracted by timber concessionaires. After land preparation and terracing, it usually takes at least six months for the exposed ground to be fully covered by natural covers of legume cover crops. During this period, there would be significant runoff and loss of top soil. Therefore, the extraction of timber and land clearing for cultivation will have adverse impacts unless appropriate mitigation measures are taken.

Moreover, contamination of surface water and possibly ground water sources through the use of pesticides and fertilizers could lead to the deterioration of water quality. However, contamination of surface water by pesticides and fertilizers is much more difficult to detect in view of the dilution effect.

With regard to this, Pereira (1973) stated management is probably the most important factor. The basic tenets of the soil conservation discipline are that the soil surface should be maintained in a receptive condition for the filtration of rainfall and that surplus water should be led off along gentle gradients without reaching erosive velocities. Where a steep fall is necessary, concrete channels or other revetment should be provided. The surplus water should be guided along prepared routes which should be maintained with an erosion-resistant surface, such as permanent grass, and be kept free of obstructions.

4.11 Recommendations

4.11.1 Monitoring and Research

An important component of the pollution control program is a continuous assessment of the state of natural resources and environment including baseline studies and monitoring. The latter is necessary in order to ensure that environmental standards and goals are met. Baseline studies, on the other hand, help to identify the status of existing condition both of environment and natural resources. Baseline studies and ambient monitoring are also helpful in EIA works.

Monitoring and research require good support funds. Without meaningful allocations, the effectiveness of monitoring and research will suffer. With its small allocations, the DOE is hardly to undertake monitoring and research single handed. It is here that the state-federal cooperation is badly needed and the help from local universities appreciated.

4.11.2 Guidelines

Guidelines such as the *Guidelines for the Prevention of Erosion and Siltation* prepared by the DOE can also be applied usefully by relevant state agencies. The main feature of this strategy is the incorporation of environmental component as an integral element in the medium-term development planning process with a view bringing about an ecologically balanced relationship between development and environment.

The effectiveness of these Guidelines as a tool in the management of environment, however, is still uncertain. No study has been made to assess the extent to which these guidelines have been used effectively. For meaning results, such guidelines need to be made more binding. For what they are worth, these guidelines can be used to full advantage especially as medium-term measures in specific development areas.

4.11.3 Environmental Impact Assessment (EIA)

The past decade has been made so economically conducive for the implementation of numerous major development projects that these were often completed in record time without much attention given to Environmental Impact Assessments (EIAs). The consequence of this oversight begins to manifest itself in the post-implementation period. An EIA would have been identified the overall cost and benefits of a project and allowed for a decision to be made about its desirability based on the interest of the entire community.

Indeed environmental impact statements should be first put up for public scrutiny before project implementation. Although such measure would result in greater debate and arguments before project parameters are finalised and approved, this would certainly avoid situations of dealing with environmental problems on the basis of restorative measures after some harm has already been done to the environment – "a technology of after-thought".

4.11.4 Education

While recognizing the importance of legislation and institutions in the administration of policies and program of environmental management, public support is essential in order to ensure the success of such programs. No conservation program, however, good it may be designed can be completely successful without public support. The latter can only be expected from well-informed citizens who are aware of the problem, committed and willing enough to do something about it. Recent studies by DOE show that generally people are responsive to efforts to improve environmental quality and that the mass media plays an important role as a disseminating agent.

CHAPTER 5

SUMMARY AND CONCLUSION

The development within the Liwagu-Labuk River Basin has been attributed to several different land use activities such as agricultural, tourism, industrial and settlements. All these activities have led to competition for water and land resources. As compared to the previous land use, intensification of land use is observed. This is very obvious for the entire Liwagu-Labuk River Basin, from the upstream parts until the downstream parts. The original forested land has been massively replaced by the agricultural activities. Conversions from extensive small or medium scale agriculture and forest to intensive monocultures, especially oil palm plantations are almost widespread over the downstream parts.

Data on water quality for the Liwagu-Labuk River Basin indicates that for the most part, water quality parameters are within the DOE specified range for Class II river i.e. good and reflective of a body of water which can efficiently assimilate considerable loads of nutrients and oxygen demands. Occasionally, for some monitoring stations, which are located at the downstream part, the water quality has deteriorated to Class III i.e. suitable for use as the source for drinking water supply only after extensive treatment. Besides, the suspended sediment loading in the river has increased significantly as well, from 215.4 mg/L (in 1971-1980) to 434.6 mg/L (in 1993-2000). Hence, it can be said that the river water quality has deteriorated over the years, which is a significant impact of land use changes.

In conjunction with water and land resources, catchment management makes sense technically, but it can only work when it respects the aims, resources and ownership rights of the people who live there. It cannot be based simply on the hydrological unit, but must consider socio-economic realities and the boundaries of farms and administrative units.

On the other hand, the water carrying capacity of a basin shall determine the degree of development within the basin because it is more appropriate to put demand near the sources. Unfortunately, the lack of overall planning in the water sector has led to a hodgepodge of single-purpose uses that have not embraced responsibility for water resources development as a whole. Indeed each agency seems to be acting for its own exclusive rights, which can no longer function adequately to secure and conserve water for the entire state's needs. The fragmentation of responsibilities for the management of water resources must be reduced if an effective and holistic management it to be achieved.

Therefore, an Integrated Land Use Management Planning could be implemented to ensure proper and detailed site-specific planning as to reconcile the physical and environmental aspects of a particular area or ecosystem with the human uses to which the land will be put. There should be the formulation of guidelines and indicators to assist in the implementation of the Plan. The guidelines should also provide assistance in terms of ensuring the coordination and integration of the various decision-making processes of the agencies responsible for land use planning and management.

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APPENDIX A

Questionnaire for Structured Interview

To describe the catchment issues and resource therein

1. Please specify the activities that are occurring in the Liwagu-Labuk River Basin.
2. Are you aware that the river is under threat, especially the water quality?
3. In your own opinion, what are the causes of the problems faced by the Liwagu-Labuk River Basin?

To identify catchment management strategies undertaken by government departments

1. What is the component of the water catchment that is related to the role of your department? Land or water?
2. Does your department obtain any data concerning the component? What is/are the data?
3. What is/are the problem(s) of the component that is/are under your department's jurisdiction?
4. What is/are the solution(s) taken by your department to solve the problems?
5. Is/are the solution(s) effective in solving the problems?

6. What is/are the obstacle(s) faced by your department in implementing the catchment management/protection measures?
7. What is/are the action plan/strategies that would be taken by your department in the future?
8. What are the responses from the local inhabitants towards the action of your department?

To identify institutional framework (policy and legislation)

1. Is your department cooperating with other departments in implementing the catchment management/protection measures?
2. Do you think the law(s) or ordinance(s) that your department implied is/are clear and give(s) a comprehensive mandate, duties or tasks?
3. Does your department enforce the legislation?
4. How does your department enforce the legislation?
5. Do the enforcement officers in your department have executive powers to prosecute the offenders?
6. What is/are the limitation(s) encountered by the enforcement officers in enforcing the legislation?
7. Is the number of the enforcement officers in your department adequate?

APPENDIX B

Photographs from the Ground Survey
(Land Use Activities in the Liwagu-Labuk River Basin)

Photograph 1: Kinabalu Pine Resorts is one of the well-known resort facilities around the Kundasang area

Photograph 2: Some of the scattered villages on the hilly and mountainous area of Kundasang

Photograph 3: Kundasang area in Ranau is the "temperate-vegetable district of Sabah"

Photograph 4: Repair and construction of some parts of the East-West Ranau-Sandakan trunk road in progress

Photograph 5: The Labuk River is relatively flat, wide and calm

Photograph 6: The degraded look of the forest in Telupid may be due to the low fertility of soils developed on ultra-basic rocks

Photograph 7: Younger oil palms which may indicate an expansion of oil palm plantations westwards from Telupid

Photograph 8: A pure oil palm plantation, which is owned by IOI Corporation Berhad, a large private company

APPENDIX C

Interim National Water Quality Standards for Malaysia (INWQS)

Parameters	Units	Classes					
		I	IIA	IIB	III	IV	V
Ammonical Nitrogen	mg/L	0.1	0.3	0.3	0.9	2.7	>2
BOD	mg/L	1	3	3	6	12	>12
COD	mg/L	10	10	25	50	100	>100
DO	mg/L	7	7	5-7	3-5	<3	<1
pH		6.5-8.5	6.5-8.5	6-9	5-9	5-9	-
Colour	TCU	15	15	150	-	-	-
Electrical Conductivity	mmhos /cm	1000	1000	-	.	6000	.
Floatables		N	N	N	-	-	-
Odour		N	N	N	-	-	-
Salinity	0/00	0.5	1	.	-	-	-
Taste		N	N	N	-	-	-
Total Diss. Solids	mg/L	500	1000	-	-	-	-
Total Susp. Solids	mg/L	25	50	50	150	300	>300
Temperature	°C	-	Normal + 2	-	Normal + 2	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Caliform*	counts/ 100mL	10	100	400	5000 (2000)@	5000 (2000)@	-
Total Coliform	counts/ 100mL	100	5000	5000	50000	50000	>50000

Note:
N = No visible floatable materials/debris or no objectionable odour or no objectionable taste
* = Geometric Mean
@ = Maximum not to be exceeded

Interim National Water Quality Standards for Malaysia (INWQS) (cont'd)

Parameters	Units	Classes				
		I	IIA/IIB	III@	IV	V
Al	mg/L		-	(0.06)	0.5	
As	mg/L		0.5	0.4 (0.05)	0.1	
Ba	mg/L		1	-	-	
Cd	mg/L		0.01	0.01 (0.001)	-	
Cr(VI)	mg/L		0.01	1.4 (0.05)	0.1	
Cr(III)	mg/L	N	0.05	2.5	-	L
Cu	mg/L		1	-	0.2	
Hardness	mg/L	A	250	-	-	E
Ca	mg/L		-	-	-	
Mg	mg/L	T	-	-	-	V
Na	mg/L		-	-	3 SAR	
K	mg/L	U	-	-	-	E
Fe	mg/L	R	0.3	1	1 (leaf), 5 (others)	L
Pb	mg/L	A	0.05	0.02 (0.01)	5	S
Mn	mg/L	L	0.1	0.1	0.2	
Hg	mg/L		0.001	0.004 (0.0001)	0.002	
Ni	mg/L		0.05	0.9	0.2	
Se	mg/L		0.01	0.25	0.02	
Ag	mg/L		0.05	0.0002	-	A
Sn	mg/L	L	-	0.004	-	
U	mg/L		-	-	-	B
Zn	mg/L	E	5	0.04	2	
B	mg/L		1	(3.4)	0.8	O
Cl	mg/L	V	200	-	80	
Cl_2	mg/L		-	(0.02)	-	V
CN	mg/L	E	0.02	0.06 (0.02)	-	
F	mg/L		1.5	10	1	E
NO_2	mg/L	L	0.4	0.4 (0.03)		
NO_3	mg/L		7	-	5	
P	mg/L		0.2	0.1	-	IV
Si	mg/L		50	-	-	
SO_4	mg/L		250	-	-	

Interim National Water Quality Standards for Malaysia (INWQS) (cont'd)

S	mg/L		0.05	(0.001)	-	
CO_2	mg/L		-	-	-	
Gross - _	Bq/L		0.1	-	-	
Gross - _	Bq/L		1	-	-	
Ra - 226	Bq/L		<0.1	-	-	
Sr -90	Bq/L		<1	-	-	
CCE	mg/L		500	-	-	
MBAS/BAS	mg/L	N	500	5000 (200)	-	L
O & G (mineral)	mg/L	A	40;N	N	-	E
O & G (emulsified edible)	mg/L	T	7000;N	N	-	V
PCB	mg/L	U	0.1	6 (0.05)	-	E
Phenol	mg/L	R	10	-	-	L
Aldrin/ Dieldrin	mg/L	A	0.02	0.2 (0.01)	-	S
BHC	mg/L	L	2	9 (0.1)	-	
Chlordane	mg/L		0.08	2 (0.02)	-	A
t-DDT	mg/L	L	0.1	1 (0.01)	-	B
Endosulfan	mg/L	E	10	-	-	O
Heptachlor/ Epoxide	mg/L	V	0.05	0.9 (0.06)	-	V
Lindane	mg/L	E	2	3 (0.4)	-	E
2,4-D	mg/L	L	70	450	-	
2,4,5-T	mg/L		10	160	-	IV
2,4,5_TP	mg/L		4	850	-	
Paraquat	mg/L		10	1800	-	

Note:
@ = Maximum (unbracketed) and 24-hour (bracketed) concentrations
N = Free from visible film, sheen, discoloration and deposits

APPENDIX D

Raw Data of Total Monthly/Annual Rainfall (mm) from 1995 to 2000

Site	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ranau Agriculture Station (5966001)	1995	165.0	73.0	183.5	73.5	220.5	263.5	210.3	218.7	159.0	79.3	104.2	206.5	1957.0
	1996	260.0	421.0	83.0	104.6	244.4	368.5	139.5	207.5	101.5	155.1	155.5	385.5	2626.1
	1997	99.5	315.0	130.5	29.0	45.0	247.0	123.0	108.0	165.5	327.5	130.0	146.5	1866.5
	1998	74.5	0.0	39.5	4.5	208.5	227.5	259.5	236.0	287.5	211.0	124.4	157.6	1830.5
	1999	399.0	328.7	132.8	60.9	187.7	116.9	85.4	190.0	259.5	261.0	170.7	201.3	2393.9
	2000	231.5	304.0	196.0	333.0	45.5	140.0	1.5	118.0	215.0	118.0	242.0	159.0	2103.5
Tampias (5768001)	1995	162.0	125.0	163.0	44.0	116.5	305.9	257.1	361.5	340.8	394.2	171.0	224.0	2665.0
	1996	254.0	377.5	103.0	186.5	230.0	292.0	132.5	288.5	232.5	394.5	34.0	174.0	2699.0
	1997	130.5	577.5	196.5	114.0	100.5	194.5	164.0	368.0	250.5	381.0	71.0	172.5	2720.5
	1998	78.0	37.0	0.5	15.0	171.5	390.1	240.9	165.3	251.2	254.5	161.5	92.5	1858.0
	1999	201.3	269.0	366.2	361.0	317.0	158.0	101.8	310.7	297.0	132.5	114.5	378.0	3007.0
	2000	401.5	221.0	272.5	326.0	132.5	248.5	339.5	304.0	304.5	206.0	172.0	265.5	3193.5
Telupid (5671002)	1995	349.5	180.5	145.5	105.0	212.5	289.0	270.0	578.0	351.5	400.0	235.5	318.5	3435.5
	1996	445.5	809.5	49.5	463.5	205.0	103.5	126.5	326.0	445.0	483.0	220.0	219.7	3896.7
	1997	133.0	663.7	138.8	122.4	126.0	161.5	342.0	364.5	180.0	400.0	161.0	189.5	2982.4
	1998	175.8	5.4	4.8	31.0	147.5	420.5	258.5	397.0	280.5	421.0	321.5	290.0	2753.8
	1999	298.0	388.0	389.1	738.9	368.5	217.0	376.9	346.6	253.2	332.8	304.5	306.0	4319.5
	2000	702.0	359.1	377.6	735.5	268.5	371.0	299.0	387.5	355.3	312.5	248.0	163.5	4597.5
Porog (5872001)	1995	166.0	50.9	14.1	65.5	78.5	263.5	252.0	414.5	300.4	514.1	420.3	456.2	2996.0
	1996	471.5	756.0	93.5	263.1	331.4	235.0	84.5	19.5	111.0	357.0	182.5	315.0	3220.0
	1997	101.0	915.5	109.5	267.0	138.5	199.0	212.5	287.7	259.0	535.3	161.0	238.3	3423.4
	1998	186.0	60.5	28.5	64.0	172.0	328.5	404.5	307.0	131.5	190.0	212.5	402.7	2487.7
	1999	565.3	428.6	427.0	416.0	420.0	491.0	301.0	191.0	224.5	195.4	206.6	523.0	4389.5
	2000	734.5	379.5	330.5	415.0	224.5	75.5	?	?	?	?	?	?	2159.5

Note: Missing or incomplete data is denoted by "?"

APPENDIX E

Raw Data of Mean Monthly/Annual River Flows (m^3/sec) from 1995 to 2000

Site	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Liwagu River at Kinabalu Park (6065401)	1995	0.38	0.15	0.18	0.21	0.20	0.97	0.85	1.60	0.32	0.83	0.53	0.53	0.56
	1996	0.90	0.71	0.34	0.23	0.76	0.59	0.41	0.36	0.34	0.64	1.16	0.45	0.57
	1997	0.38	?	0.39	0.23	0.28	0.25	0.42	0.18	0.14	0.39	0.61	0.13	0.31
	1998	0.07	0.04	0.03	0.04	0.07	0.27	0.39	0.54	0.44	1.05	1.02	0.89	0.40
	1999	1.15	0.80	0.52	0.90	0.76	0.50	0.36	0.30	0.43	0.70	0.72	0.61	0.65
	2000	0.30	0.92	?	?	0.16	0.43	0.25	0.45	0.32	0.84	0.54	0.54	0.48
Labuk River at Tampias (5768401)	1995	214.1	183.9	102.6	50.7	52.5	120.2	96.2	135.6	199.3	126.6	98.2	200.9	131.7
	1996	234.3	323.6	59.2	52.3	42.0	189.9	55.0	76.6	67.4	94.9	69.8	156.6	118.5
	1997	63.9	63.2	125.3	72.2	31.8	25.7	33.3	31.3	55.2	102.7	?	74.4	61.7
	1998	53.4	4.8	3.5	2.1	9.3	52.0	132.1	145.8	107.8	70.2	62.8	48.7	57.7
	1999	309.9	221.6	224.7	213.4	236.3	119.0	97.2	94.0	146.6	120.4	91.2	199.0	172.8
	2000	101.9	?	153.6	262.0	131.0	95.8	?	?	?	?	?	?	148.9
Liwagu River at Maringkan (5768402)	1997	?	?	?	15.77	14.83	15.97	24.85	20.35	31.41	38.81	44.12	34.64	26.8
	1998	30.52	11.63	6.19	3.15	6.05	26.93	57.04	53.14	46.97	34.93	35.24	33.49	28.8
	1999	83.95	31.62	69.15	75.11	69.22	52.31	44.80	38.94	50.74	42.59	46.68	66.81	56.0
	2000	50.77	53.39	55.15	78.85	25.21	35.89	24.90	35.07	23.73	47.46	25.52	31.52	40.6
Labuk at Porog (5872401)	1995	203.9	84.2	120.3	77.2	95.1	197.8	168.1	239.7	187.9	235.6	135.6	230.1	164.6
	1996	327.6	790.6	78.8	101.8	164.7	194.9	114.1	119.8	149.7	167.1	96.1	229.7	211.2
	1997	103.2	395.0	148.3	101.9	47.9	41.0	64.7	67.9	91.4	140.9	109.4	109.0	118.4
	1998	115.9	21.0	10.8	8.8	18.2	87.2	180.5	226.1	138.5	158.3	112.9	104.7	98.6
	1999	205.4	378.8	447.5	370.6	232.0	?	?	182.4	221.6	151.2	147.9	288.7	262.6
	2000	1196.5	447.0	259.3	224.7	?	?	?	?	?	?	?	?	531.2

Note: Missing or incomplete data is denoted by "?"

APPENDIX F

Raw Data of Water Quality Parameters from 1996 to 2001

Year	River (DOE Station Code)	n	DO	BOD	COD	NH_4	SS	pH	WQI	CLASS
1996	Labuk (5671614)	4	91.5	1.0	9.4	0.09	84.0	8.3	87.2	2
1996	Liawan (5764603)	4	90.0	0.5	19.6	0.08	218.0	7.9	85.2	2
1996	Liwagu (5764604)	4	85.0	0.0	38.3	0.08	165.5	8.0	82.4	2
1996	Sapi (5774611)	4	87.8	1.5	18.9	0.09	131.0	8.1	84.8	2
1996	Sapi (5774612)	4	83.7	1.4	16.1	0.09	128.8	8.1	82.5	2
1996	Liwagu (5966606)	4	88.9	0.5	35.2	0.08	148.0	8.0	83.3	2
1996	Liwagu (5966608)	4	89.3	0.8	27.7	0.08	622.3	8.3	77.2	2
1996	Sualong (5972613)	4	89.6	1.3	14.7	0.06	97.3	8.2	85.4	2
1997	Labuk (5671614)	4	89.0	0.3	4.4	0.19	83.5	7.7	87.9	2
1997	Liawan (5764603)	4	99.5	3.6	13.6	0.33	215.8	7.3	77.5	2
1997	Liwagu (5764604)	4	120.0	3.8	9.4	0.29	252.3	7.3	82.4	2
1997	Sapi (5774611)	4	52.0	1.0	12.5	0.00	133.0	7.6	80.0	2
1997	Sapi (5774612)	4	53.0	1.1	12.6	0.00	167.3	7.5	79.9	2
1997	Liwagu (5966606)	4	92.0	1.8	14.5	0.30	302.3	7.4	82.2	2
1997	Liwagu (5966608)	4	75.0	0.7	6.1	0.15	83.5	8.1	84.5	2
1997	Sualong (5972613)	4	90.0	1.2	4.6	0.00	78.3	7.7	91.3	2
1998	Labuk (5671614)	5	75.4	1.3	3.4	0.25	102.6	7.3	88.4	2
1998	Kenipir (5764603)	5	69.5	1.3	5.4	0.17	69.8	7.4	84.8	2

Raw Data of Water Quality Parameters from 1996 to 2001 (cont'd)

1998	Liwagu (5764604)	5	58.7	1.4	14.2	0.29	183.0	7.1	79.6	2
1998	Sapi (5774611)	5	49.2	3.4	19.8	0.39	117.8	6.4	72.2	3
1998	Sapi (5774612)	5	58.8	1.6	23.2	0.38	128.0	6.3	75.2	3
1998	Liwagu (5966606)	5	73.0	1.4	4.2	0.22	253.8	7.0	83.8	2
1998	Kenipir (5966608)	5	71.1	1.2	5.4	0.24	112.8	7.2	86.6	2
1998	Sualong (5972613)	5	68.7	1.7	14.4	0.22	188.8	6.8	83.4	2
1999	Labuk (5671614)	6	78.3	3.7	18.8	0.07	80.2	6.1	85.0	2
1999	Kenipir (5764603)	6	65.9	2.3	11.5	0.06	77.2	6.3	83.7	2
1999	Liwagu (5764604)	6	76.0	4.3	31.3	0.10	518.0	6.0	72.7	3
1999	Sapi (5774611)	6	69.4	3.8	24.3	0.23	150.2	6.4	77.5	2
1999	Sapi (5774612)	6	72.2	4.3	26.8	0.21	142.8	6.7	78.3	2
1999	Liwagu (5966606)	6	67.7	2.0	15.0	0.04	146.8	5.9	82.7	2
1999	Kenipir (5966608)	6	78.9	2.5	14.8	0.07	475.2	6.5	82.7	2
1999	Sualong (5972613)	6	74.2	4.5	22.0	0.22	197.8	6.7	78.3	2
2000	Labuk (5671614)	6	80.6	2.7	19.3	0.04	63.3	6.7	88.3	2
2000	Kenipir (5764603)	6	83.9	1.3	20.3	0.03	84.0	6.6	87.8	2
2000	Liwagu (5764604)	6	90.4	2.2	20.5	0.20	214.8	7.0	84.0	2
2000	Sapi (5774611)	6	73.3	2.7	22.7	0.09	375.7	6.8	79.3	2
2000	Sapi (5774612)	6	78.2	3.0	21.3	0.09	284.0	7.0	81.7	2
2000	Liwagu (5966606)	6	82.9	1.5	18.5	0.38	108.8	7.0	86.7	2
2000	Kenipir (5966608)	6	78.0	1.5	19.7	0.07	106.3	6.8	86.7	2

Raw Data of Water Quality Parameters from 1996 to 2001 (cont'd)

2000	Sualong (5972613)	6	86.6	2.5	19.3	0.04	98.0	6.6	89.0	2
2001	Labuk (5671614)	3	94.3	89.3	69.3	100.0	81.3	91.0	88.0	2
2001	Kenipir (5764603)	3	82.3	92.0	71.7	94.0	87.0	91.7	86.0	2
2001	Liwagu (5764604)	3	95.3	85.0	55.3	87.3	78.3	90.7	82.3	2
2001	Sapi (5774611)	3	86.3	84.3	56.0	66.7	85.7	91.7	78.7	2
2001	Sapi (5774612)	3	98.7	93.3	72.0	70.7	88.3	93.3	86.7	2
2001	Liwagu (5966606)	3	86.0	93.3	73.0	98.7	90.3	91.0	88.3	2
2001	Kenipir (5966608)	3	93.3	92.0	68.7	98.7	77.3	94.3	87.7	2
2001	Sualong (5972613)	3	82.0	96.0	74.0	100.0	94.3	90.7	89.3	2

Note:
n – number of data sets; DO is expressed in % saturation, other parameters are in mg/L except for data year 2001, which are in subindices form

APPENDIX G

PETUNJUK PENGELASAN PENGGUNAAN TANAH

LAND USE CLASSIFICATION LEGEND

1 KAWASAN TEMPAT TINGGAL DAN KAWASAN BERKAITAN BUKAN PERTANIAN
Settlements and Associated Non-Agricultural Areas

1U	KAWASAN BANDARAN DAN YANG BERKAITAN Urban and Associated Areas
1E	KAWASAN BANGUNAN LADANG DAN YANG BERKAITAN Estate Buildings and Associated Areas
1T	KAWASAN LOMBONG BIJIH TIMAH Tin Mining Areas
1X	KAWASAN LOMBONG LAIN-LAIN GALIAN Other Mining Areas
1P	HAK LALU TALIAN LETRIK Power Line Right of Way

2 KAWASAN PERKEBUNAN
Horticultural Lands

2H	PERKEBUNAN CAMPUR Mixed Horticulture
2M	PERKEBUNAN SAYUR-SAYUR DAN BENDA-BENDA MAKANAN Market Gardening
2E	PUSAT PERCUBAAN PERTANIAN Agricultural Stations

3 POKOK, PALMA DAN LAIN-LAIN TANAMAN KEKAL
Tree, Palm and Other Permanent Crops

3GY	ANAK GETAH Young Rubber
3GM	GETAH DEWASA Mature Rubber
3GS	GETAH TUA Senile Rubber
3OY	ANAK KELAPA SAWIT Young Oil Palm
3OM	KELAPA SAWIT DEWASA Mature Oil Palm
3OS	KELAPA SAWIT TUA Senile Oil Palm
3CY	ANAK KELAPA Young Coconut
3CM	KELAPA DEWASA Mature Coconut
3CS	KELAPA TUA Senile Coconut
3N	NENAS Pineapple
3T	TEH Tea
3K	KOPI Coffee
3A	KOKO Cocoa
3P	LADA HITAM Pepper
3Y	TEBU Sugarcane
3X	DUSUN-(RAMBUTAN DURIAN, LIMAU, CENGKIH, PALA, DLL.) Orchards-(Rambutan, Durian, Citrus, Cloves, Nutmeg etc.)
3F	TANAMAN GENTIAN Fibre Crops
3S	REMBIA Sago
3B	PISANG Banana
3H	KOLAM IKAN DAN LEMBAYUNG (KIAMBANG ATAU KELADI BUNTING) Fish and Hyacinth Ponds
3R	PINANG Arecanut

4. KAWASAN TANAMAN
Cropland

4P	PADI padi
4C	PELBAGAI TANAMAN Diversified Crops
4X	PENANAMAN BERPINDAH-PINDAH Shifting Cultivation

5. PADANG TERNAK KEKAL YANG DIPERBAIKI
Improved Permanent Pasture

5	PADANG TERNAK KEKAL YANG DIPERBAIKI Improved Permanent Pasture

6. PADANG RUMPUT
Grasslands

6	LALANG, PADANG TERNAK YANG TERBIAR DAN/ATAU PADANG RUMPUT SEMAK Lalang, Unimproved Coarse Pasture and/or Scrub-Grassland
6/7S	TANAH TERBIAR (SEMAK BERCAMPUR TANAH LAPANG) Idle Lands (Grasses & Scrub Forest)
6E	TAPAK-TAPAK HAKISAN BERUMPUT DAN TANAH-TANAH RUNTUH Grass Covered Erosion Scars and Landslides

7. KAWASAN HUTAN
Forest Land

7F	HUTAN Forest
7FC	TANAMAN KAYU CEPAT MEMBESAR Cultivated Forest
7S	SEMAK Scrub
7C	CERANG BAHARU (KAWASAN YANG DIBERSIHKAN DARIPADA HUTAN DAN GETAH TUA) Newly Cleared Land (Areas generally cleared from Forest or Senile Rubber)
7C/6	TANAH BARU DIBUKA TAPI PEMBANGUNAN TERGENDALA Cleared lands with delayed agricultural development

8. HUTAN-HUTAN PAYA DAN BAKAU
Swamps, Marshlands and Wetland Forests

8	TERMASUK BAKAU NIPAH, GELAM DAN LAIN-LAIN KUMPULAN HUTAN PAYAU Includes Mangrove, Nipah, Gelam and Other Wetland Forest Associations

9. KAWASAN YANG TIDAK DIUSAHAKAN
Unused Land

9	KAWASAN YANG TIDAK DIUSAHAKAN Unused Land

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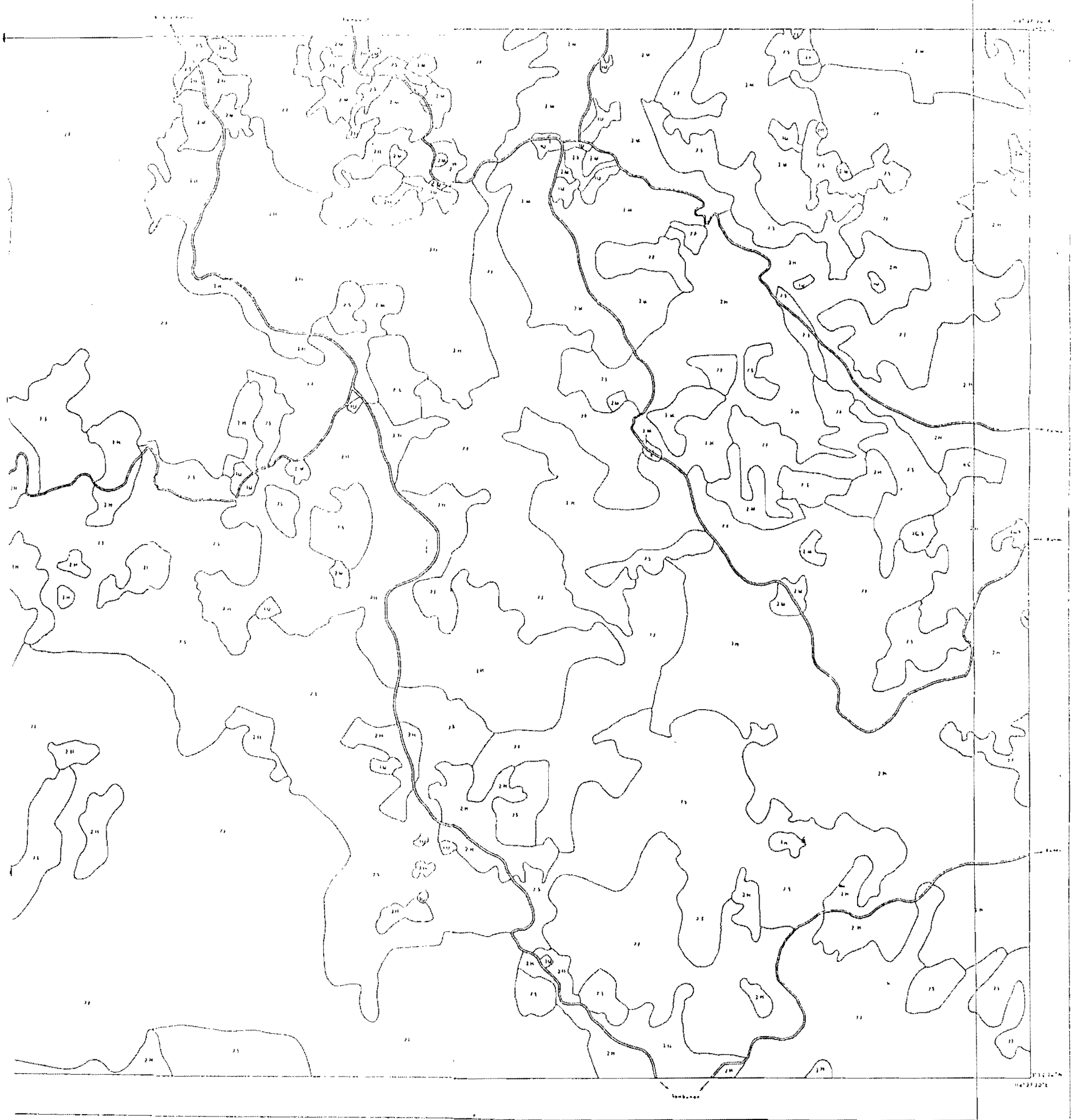

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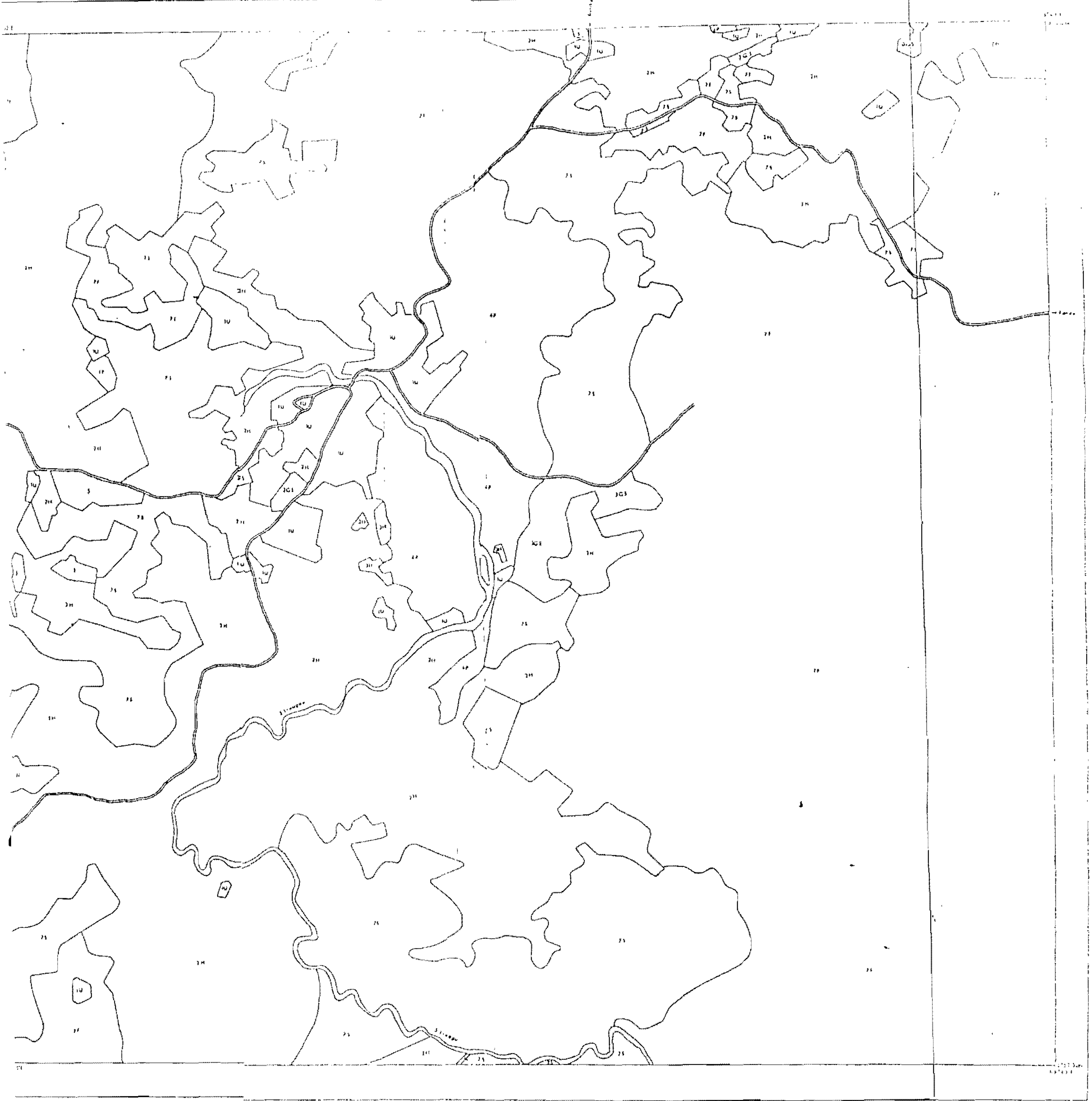
RANAU

5/116/3 N E



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RANAU

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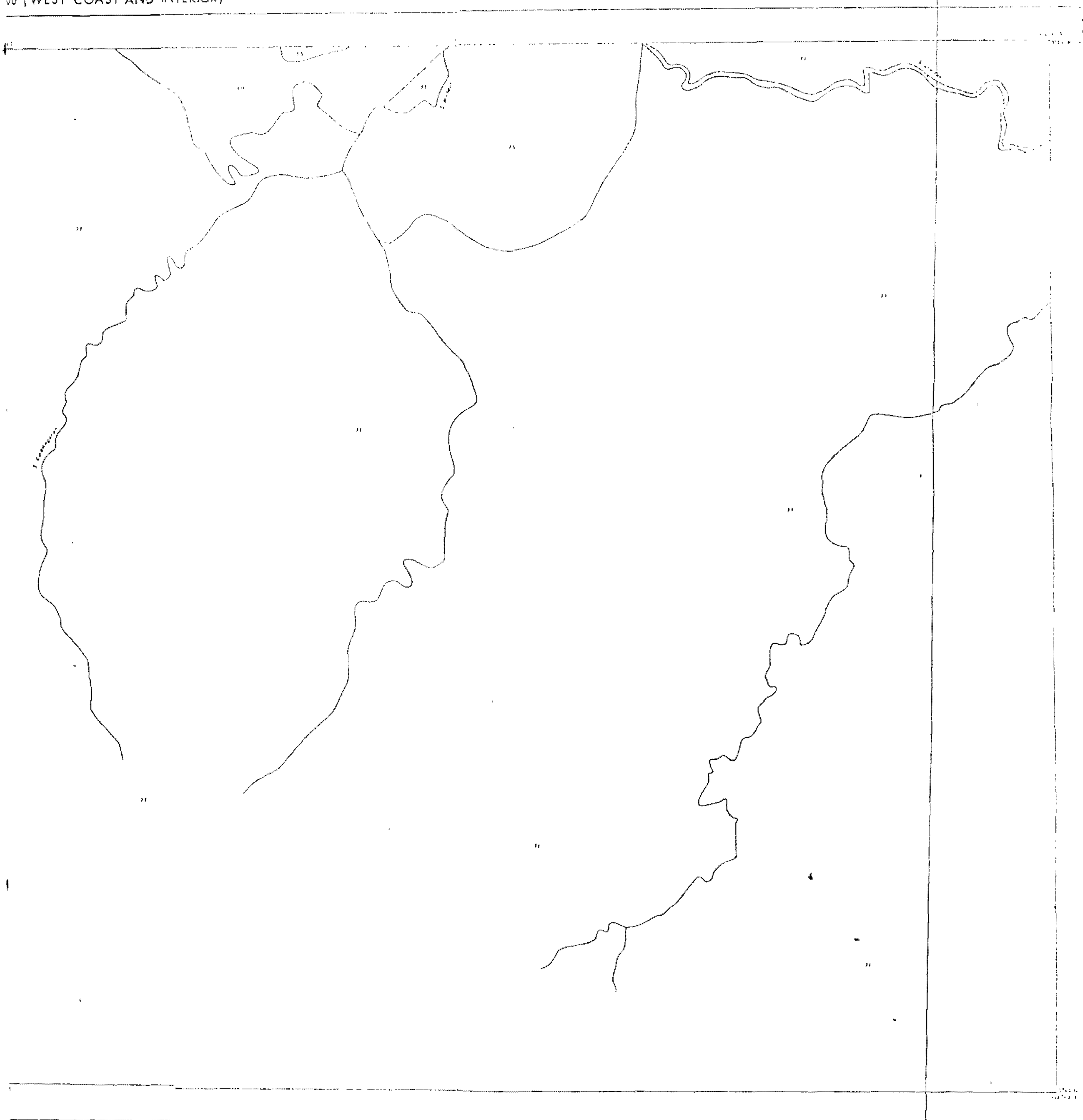
5/116/3 S E



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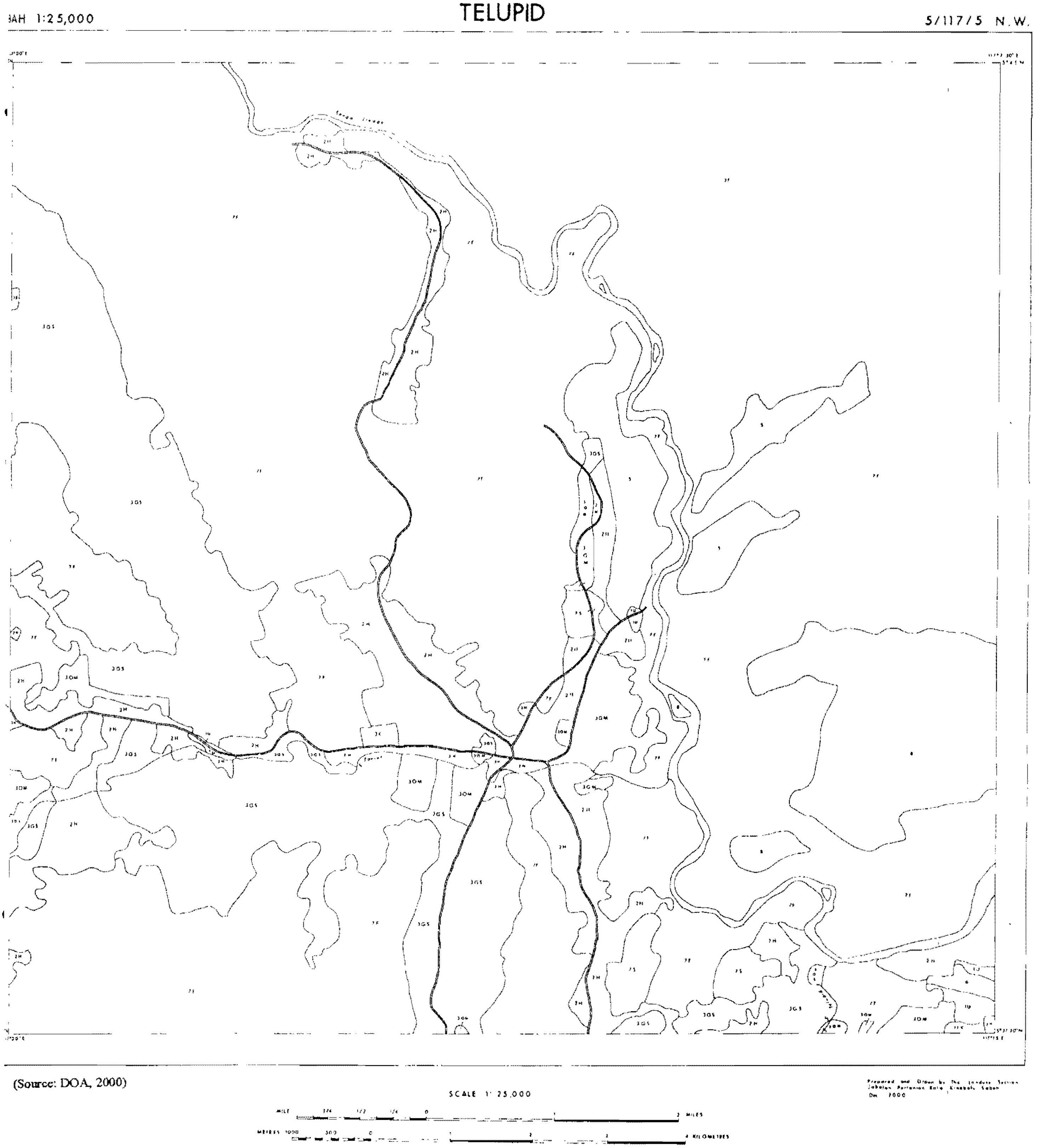

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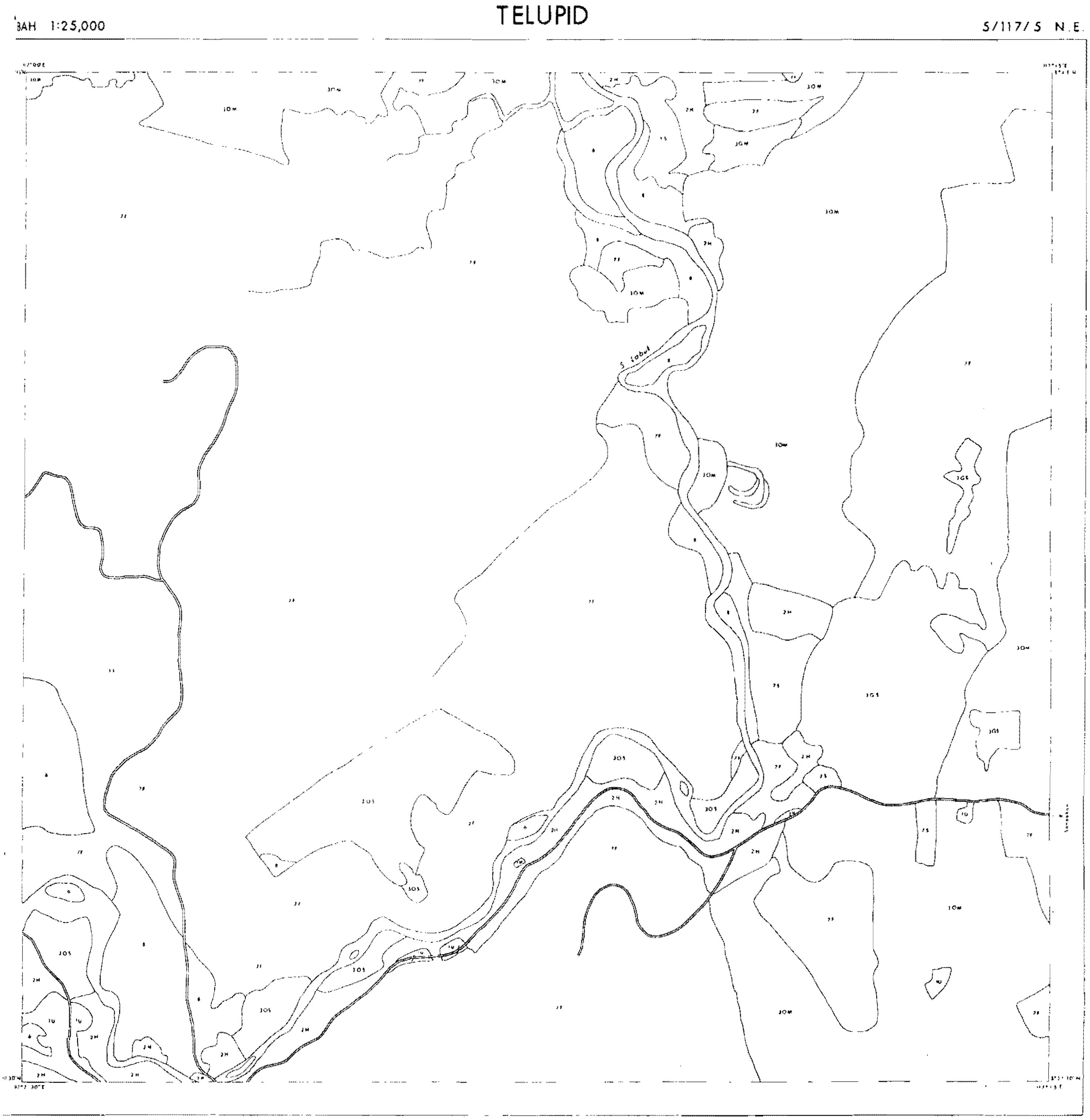

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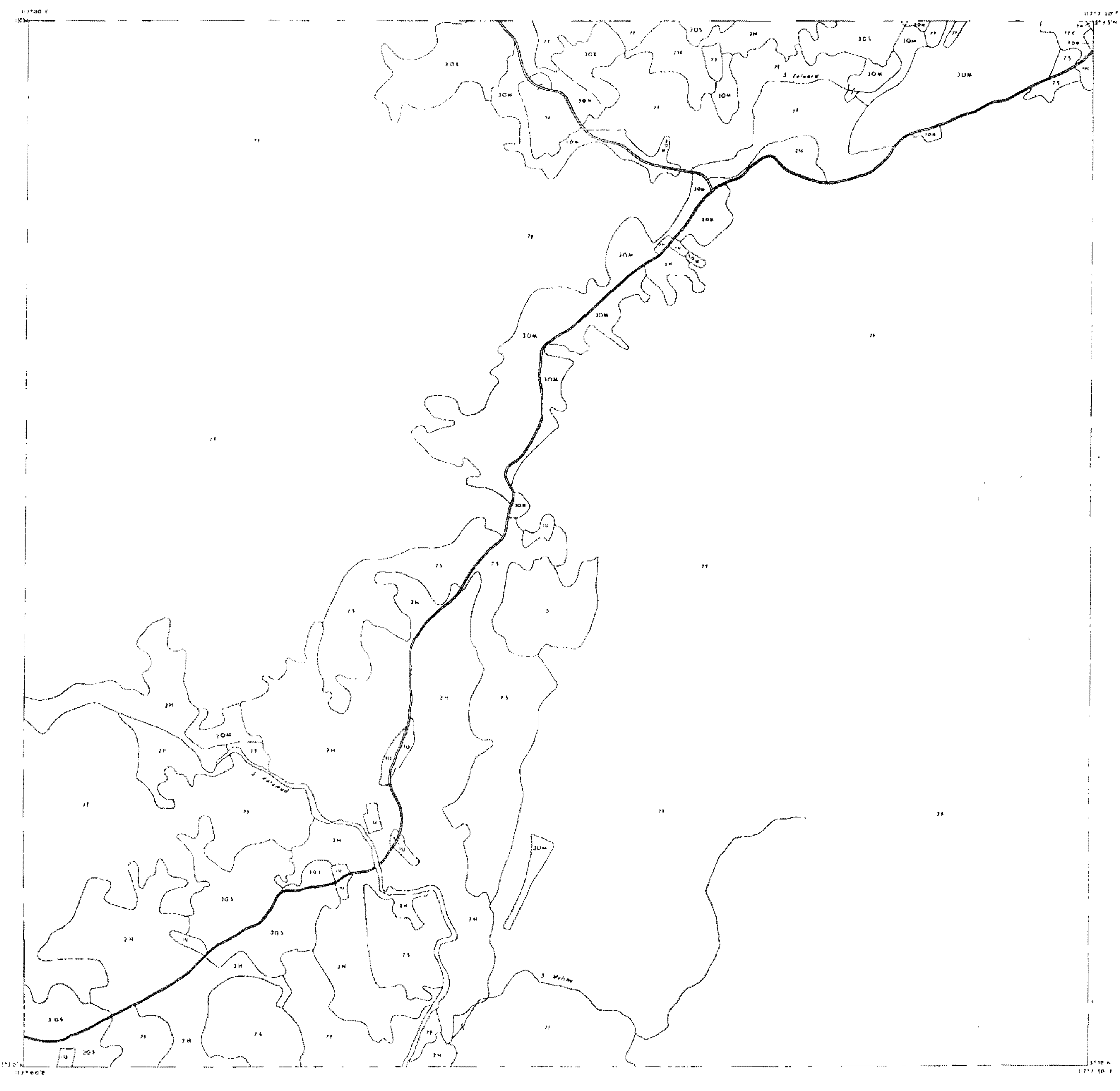

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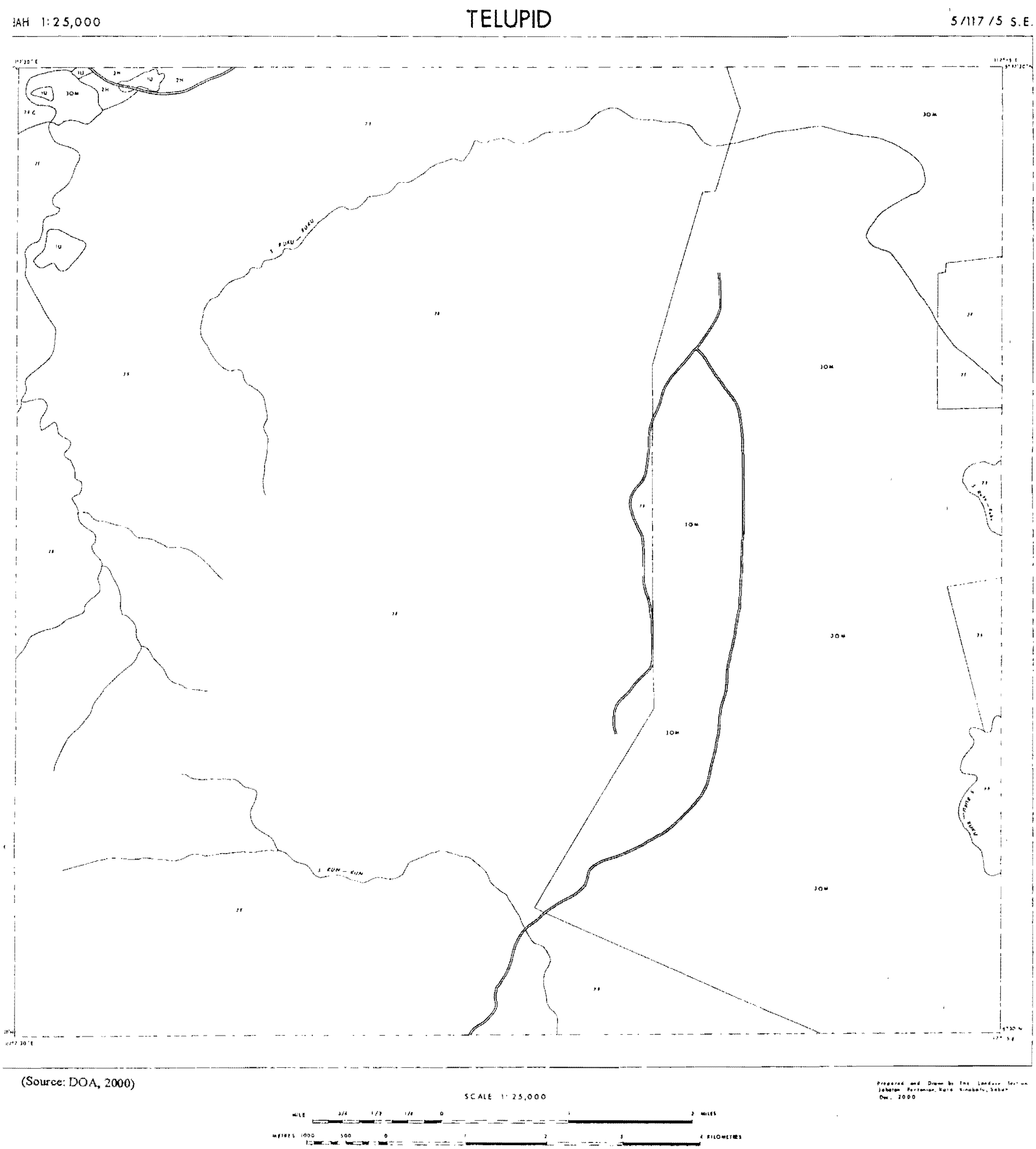

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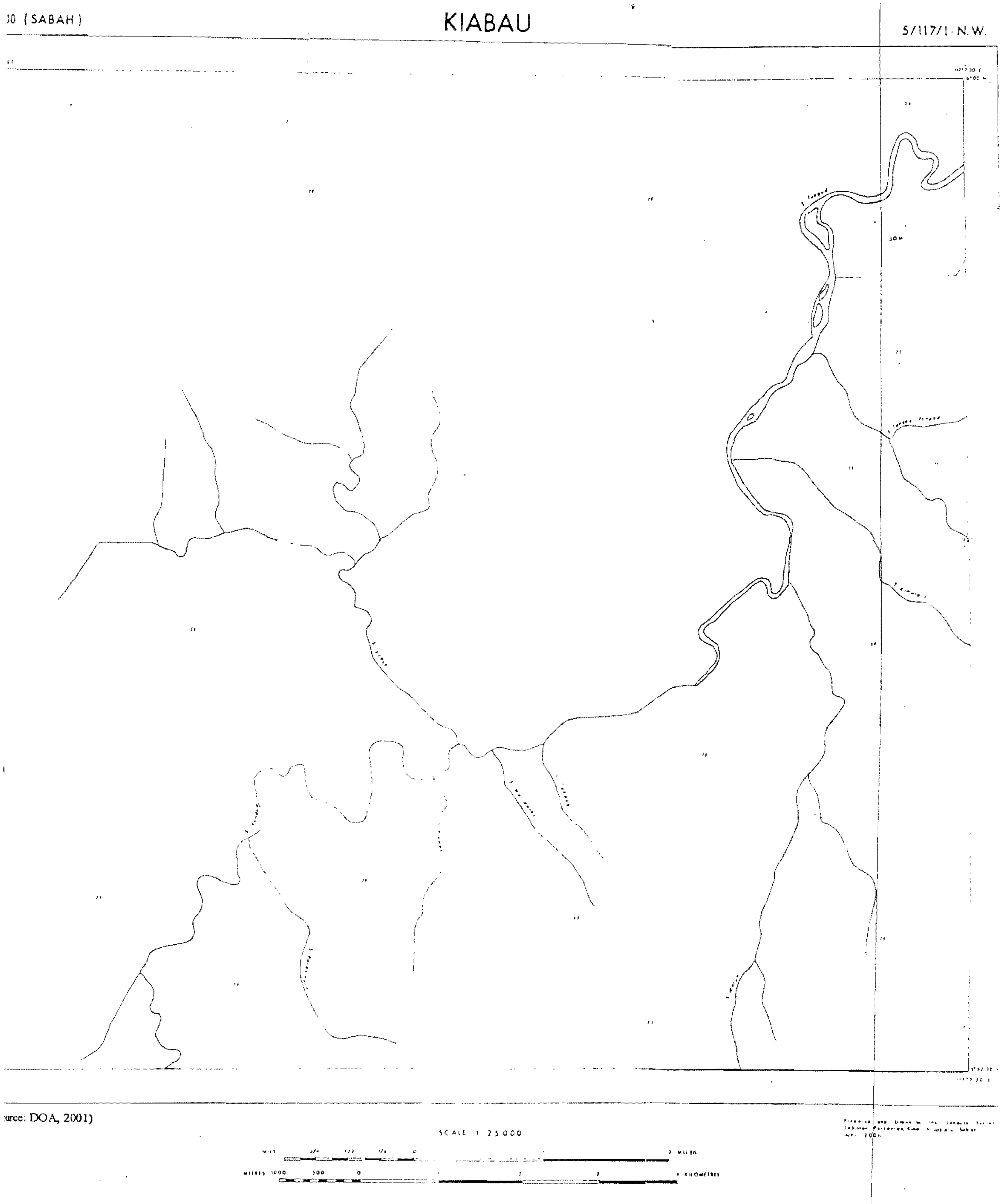

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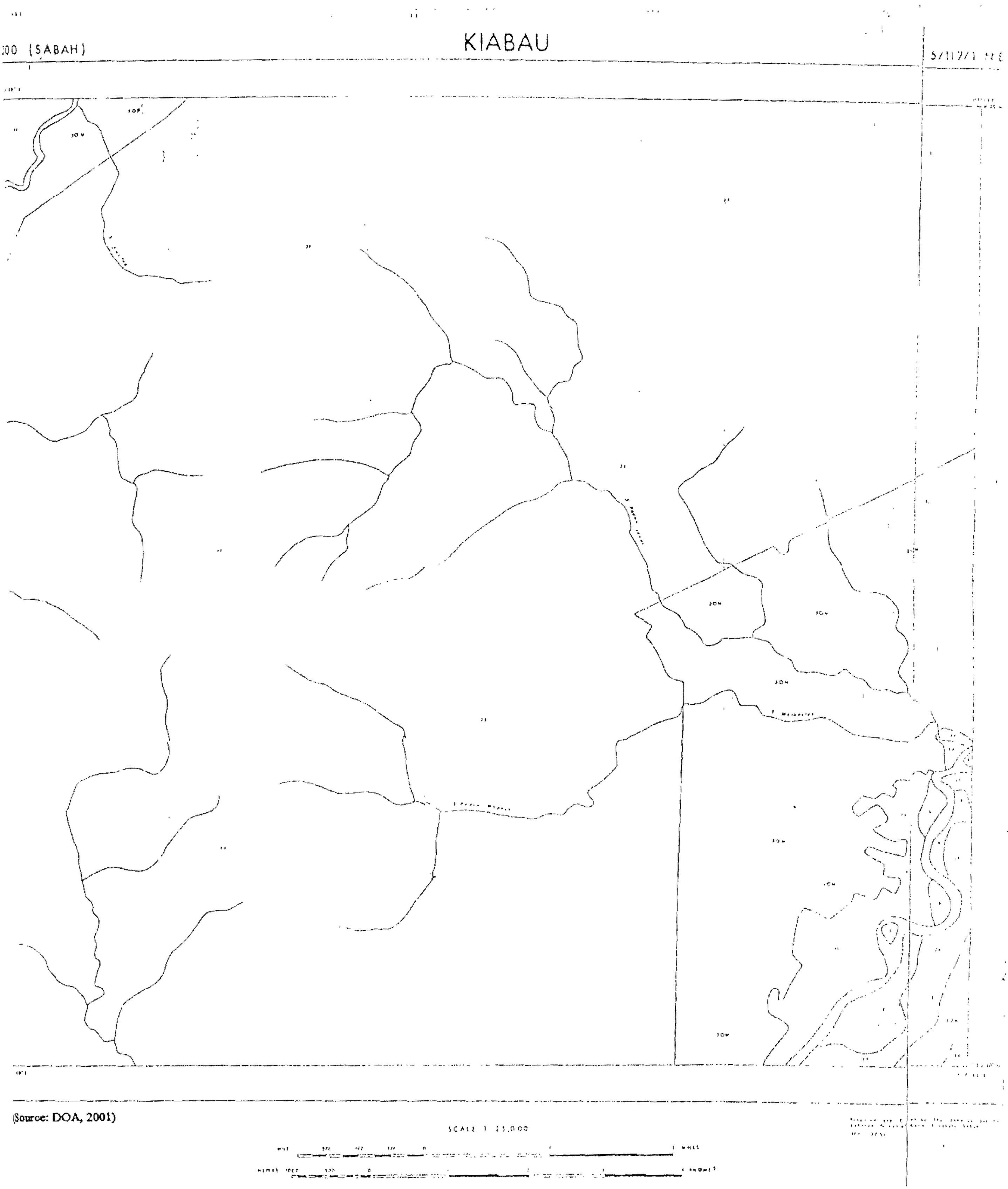

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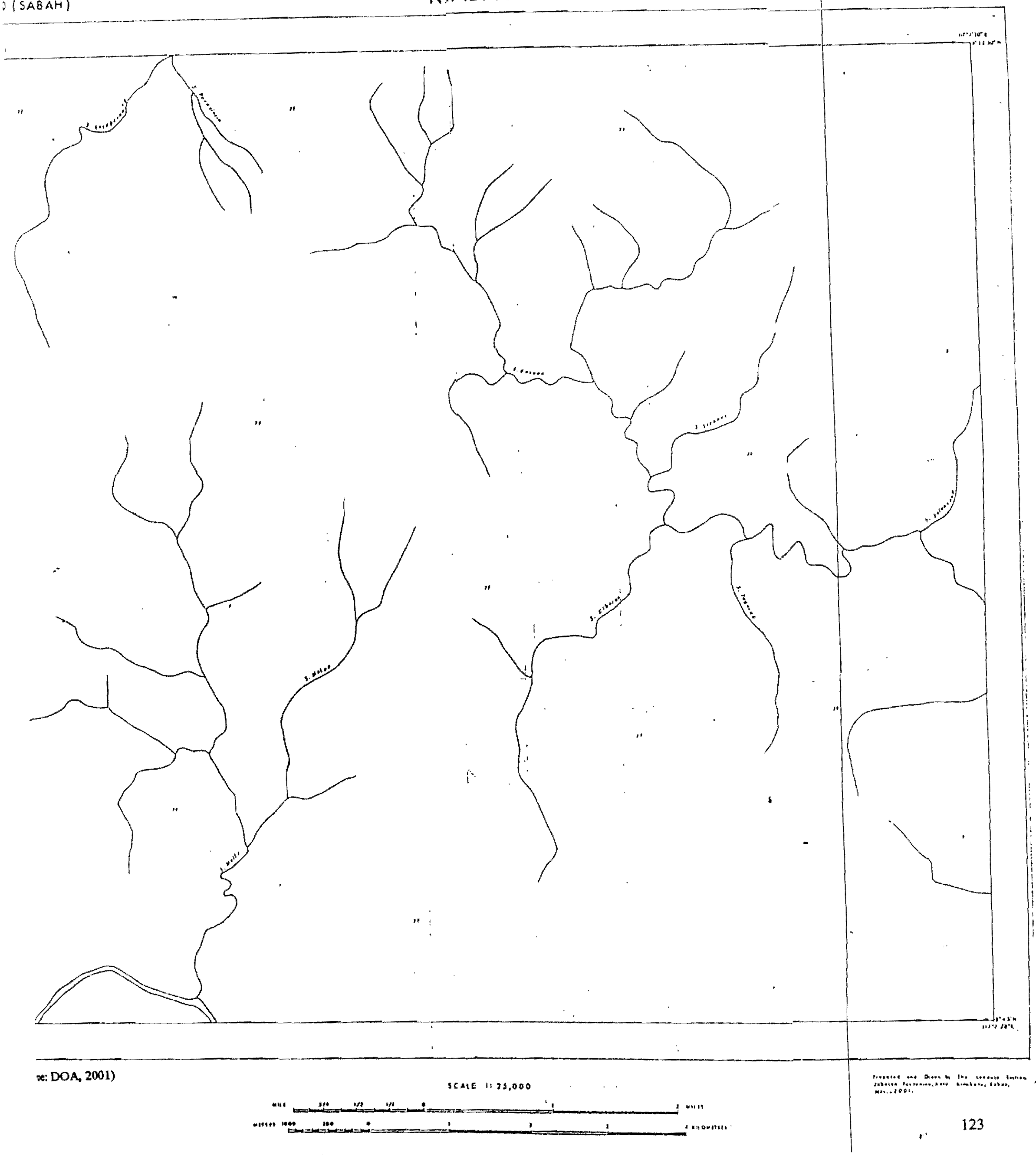

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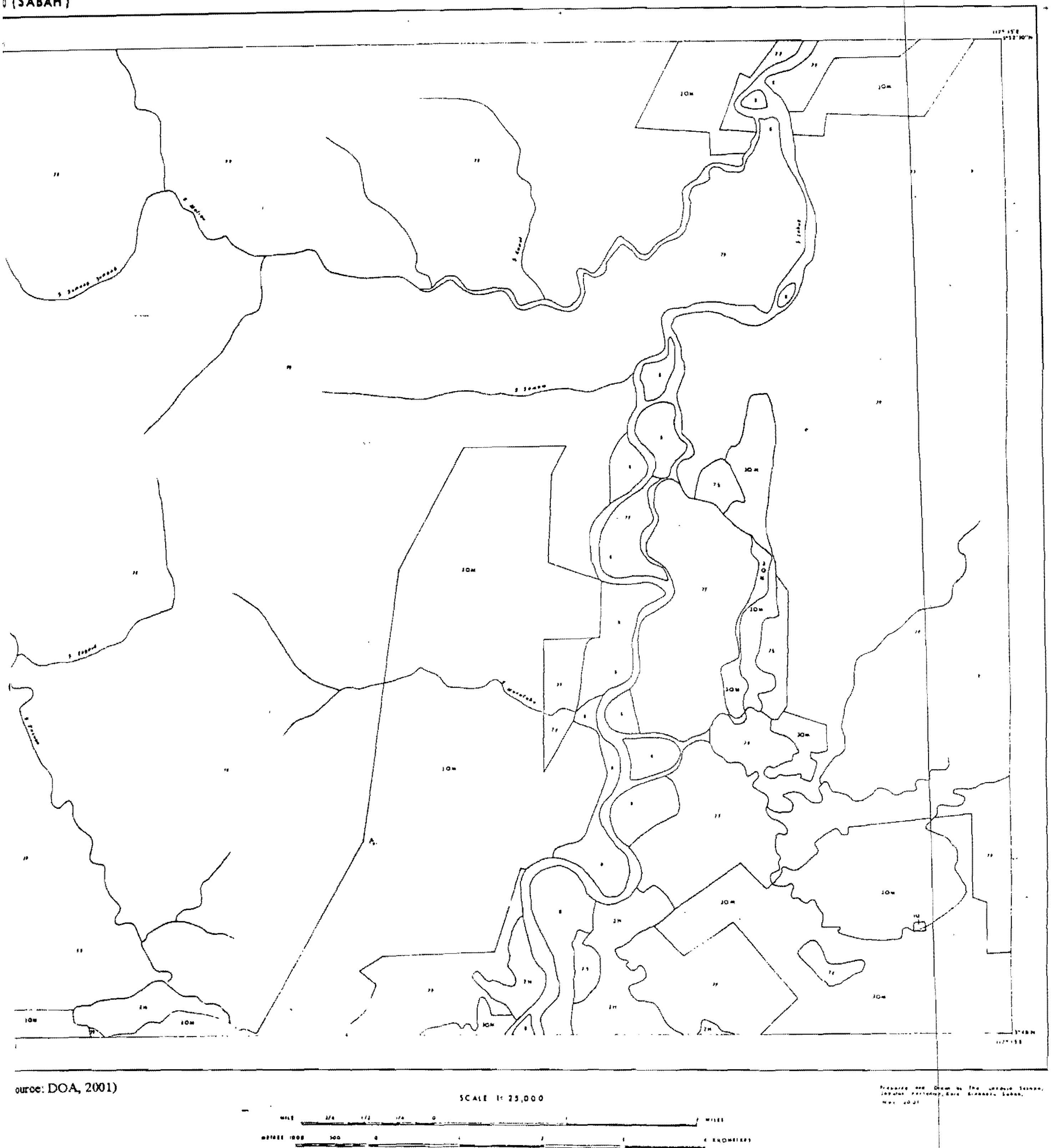

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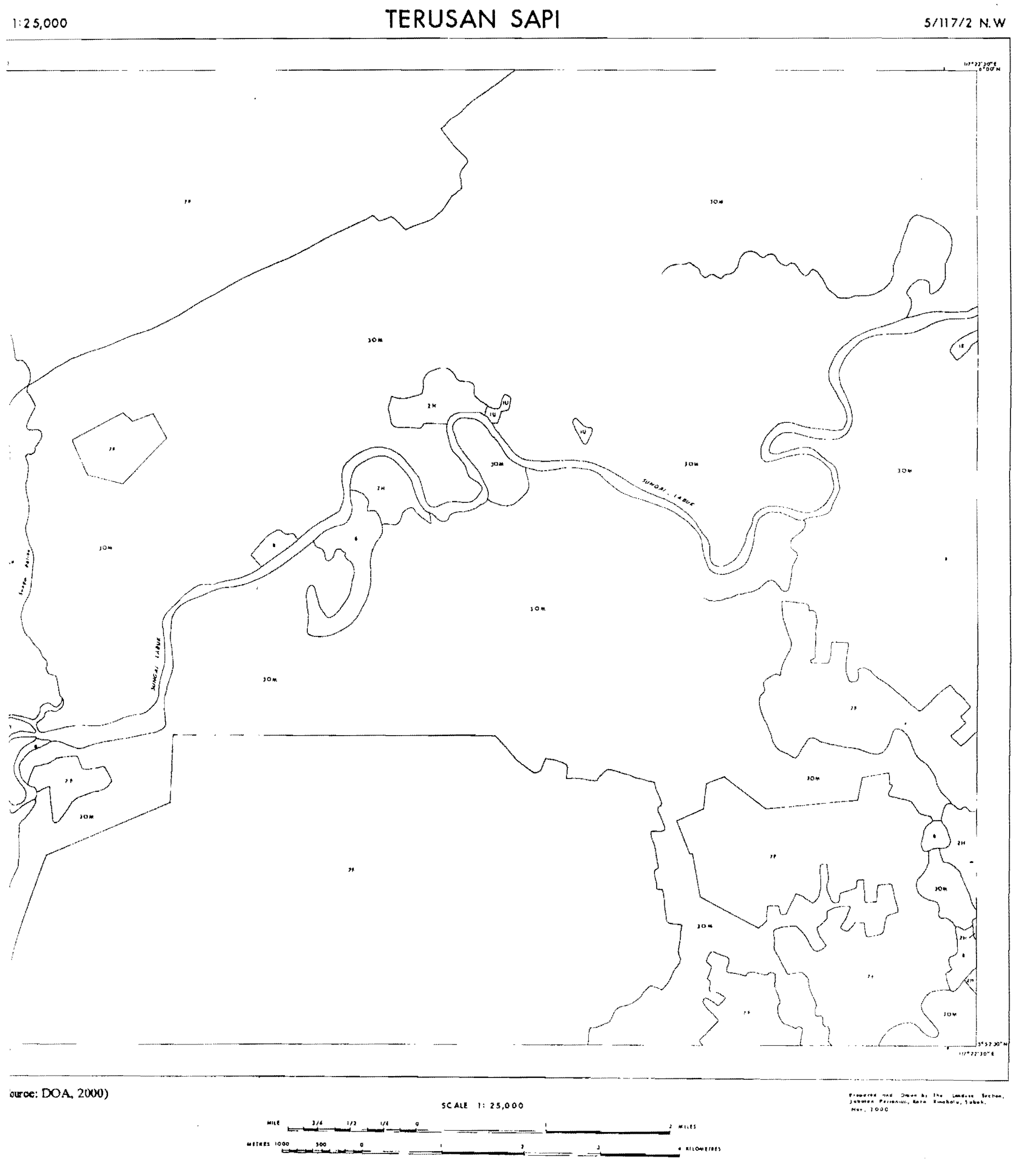

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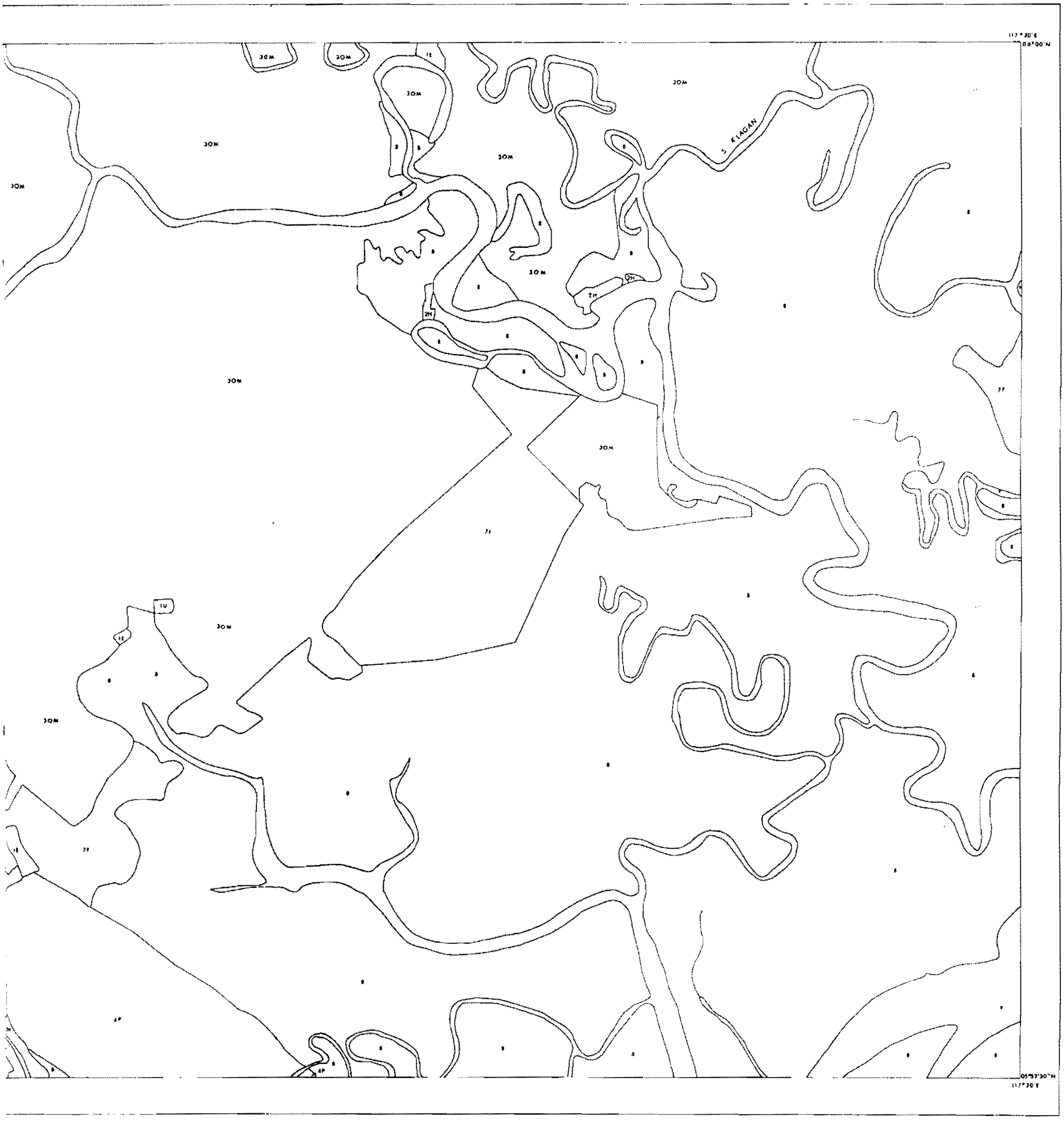

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METRES 1000 500 0 1 2 3 4 KILOMETRES

Prepared and Drawn by The Land Use Section, Jabatan Pertanian, Kota Kinabalu, Sabah, March 1999

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TERUSAN SAPI

5/117/2 S.W.

ce: DOA, 2000)

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Source: DOA, 1999)

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METRES 1000 500 0 1 2 3 4 KILOMETRES

Prepared and Drawn by The Land Use Section, Jabatan Pertanian, Kota Kinabalu, Sabah, March 1999

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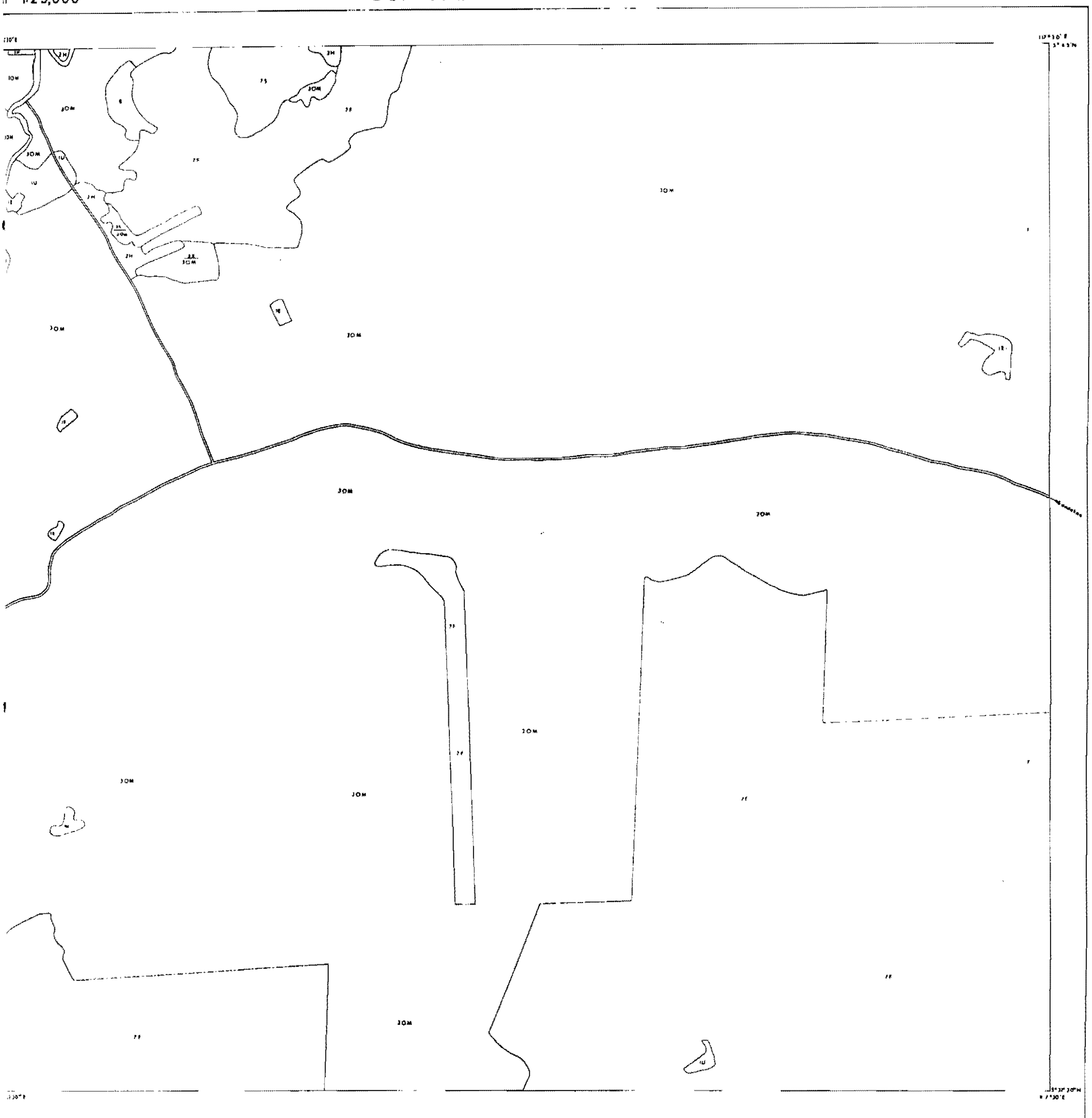

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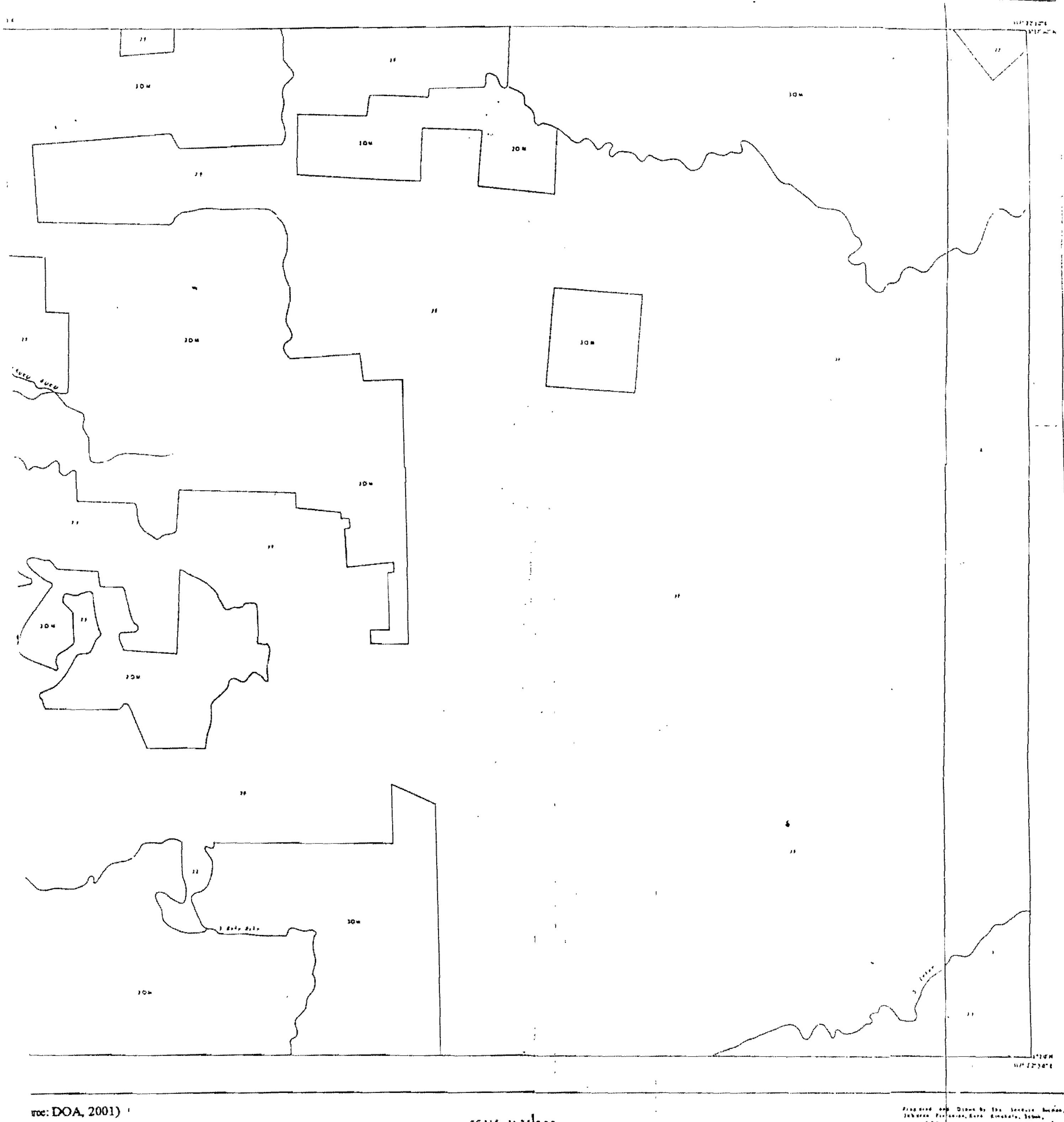

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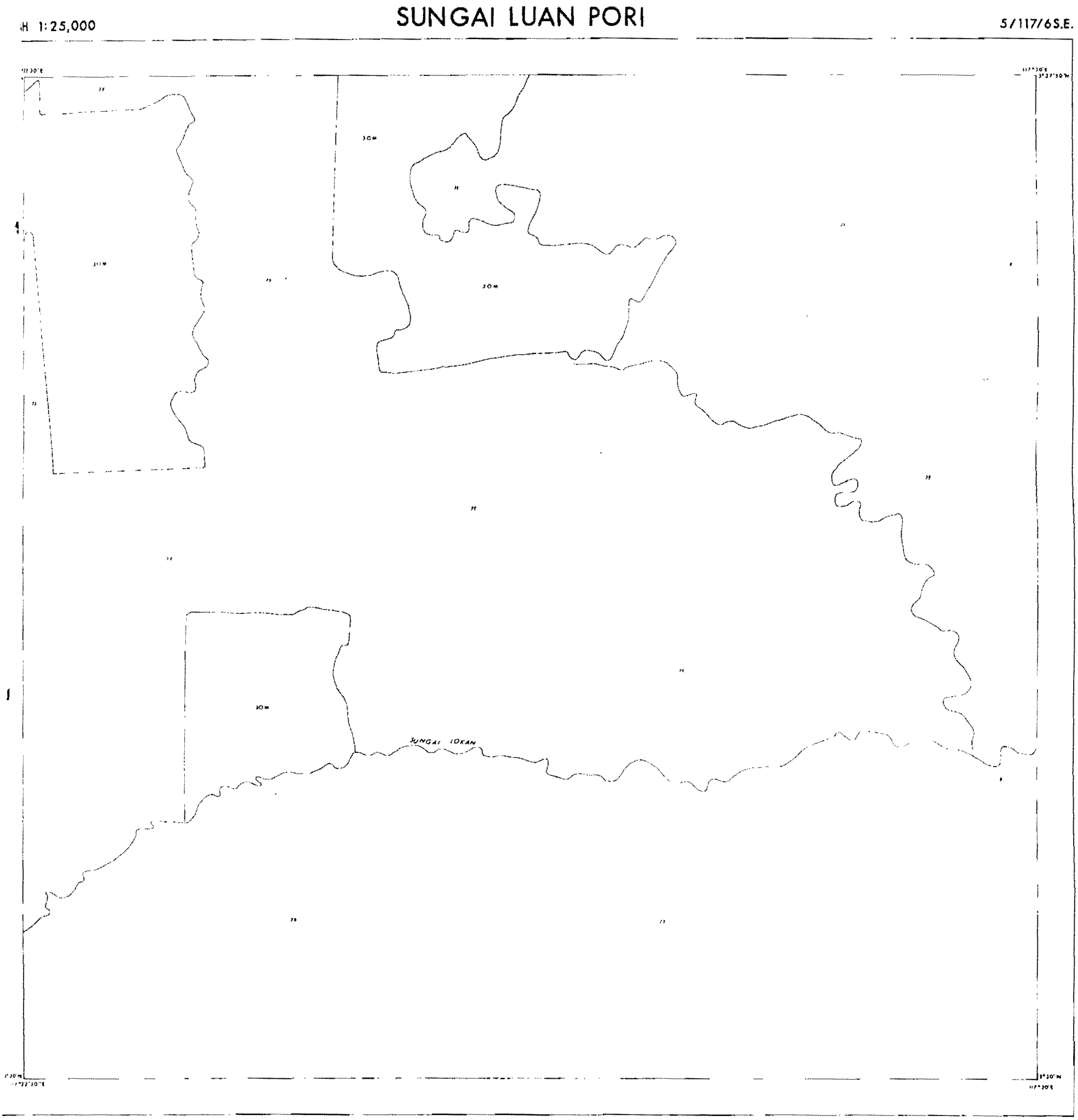

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