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BANGKOK
AUGUST 1990

An Analysis of Deforestation and Associated Environmental Hazards in Northern Thailand: A joint Thailand-UNEP/GRID case study

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List of Maps and Photographs

Acknowledgements

This report presents the results of a project which was developed by several departments of the Government of Thailand, with the Office of the National Environment Board (ONEB) as the focal point. The project was devoted to a study of deforestation and related environmental effects in Chiang Mai Province in Northern Thailand.

The organizations from Thailand participating in the project were the National Environment Board, Royal Forestry Department, Land Development Department, Meteorological Department, National Research Council, Department of Mineral Resources, Royal Irrigation Department, Department of Lands, National Economic and Social Development Board, Kasetsart University and Chulalongkorn University. The units participating from the United Nations Environment Programme (UNEP) were the Regional Office for Asia and the Pacific (ROAP) and the Global Resource Information Database (GRID).

The project team wishes to acknowledge the enthusiastic support received from all participating organizations without which the study could not have been completed in such a short time frame. The opinions expressed in this report do not necessarily reflect those of UNEP.

Executive Summary

This report is a summary of the joint activities carried out by a number of departments of the Government of Thailand, UNEP - ROAP and GRID. The project was devoted to an analysis of deforestation and associated environmental hazards in Chiang Mai Province in Northern Thailand. The basic objective was to demonstrate the potential of computer-based GIS technology for resource management and environmental planning.

The study was focused on two issues, namely :

- Assessment of deforestation in Chiang Mai Province between 1975 to 1985.

- Assessment of soil-loss in Mae Klang watershed.

The magnitude and rate of deforestation in Chiang Mai Province was assessed using Landsat MSS data for the years 1975, 1979 and 1985. The study revealed that the rate of deforestation between the period 1975-79 was more than that during 1979-1985. The plausible explanation for this is that during the 1970's the Government of Thailand tried to boost agricultural production which, among other things, necessitated clearance of more forest areas for expansion of agriculture. This process slowed down during subsequent years, however, destruction of forests for shifting cultivation by the hill-tribes continues and remains a major cause of deforestation in the area.

The soil-loss analysis for Mae Klang watershed was conducted using the Universal Soil Loss Equation (USLE). Several data sets such as remote sensing data, a land use map, soils maps, elevation data, and rainfall data were utilized in the study. Thematic maps were digitized and analysis was carried out using appropriate GIS software at UNEP-GRID. The results indicated that soil erosion was minimum in paddy fields of lowland areas and densely forested areas at higher altitudes which were covered with thick litter and undergrowth. While there is a marked increase in soil loss in shifting cultivation areas, it is the associated loss of ground litter/flora in sparsely vegetated areas or steep slopes that causes the most significant soil erosion hazards.

The study also demonstrated the potential of GIS technology for creating a computerized geo-referenced environmental data base which can be used for further analysis, updating and modelling.

AN ANALYSIS OF DEFORESTATION AND ASSOCIATED ENVIRONMENTAL HAZARDS IN NORTHERN THAILAND: A JOINT THAILAND-UNEP/GRID CASE STUDY

1. INTRODUCTION

1.1 Background

The United Nations Environment Programme (UNEP), through the Global Environment Monitoring System, initiated a new programme in 1985 for the purpose of bringing together the pertinent environmental data for the world into a common database.

The programme, entitled Global Resource Information Database (GRID), has four basic objectives:

1. To maintain and disseminate geo-referenced environmental data sets and develop geographic information system (GIS) methodologies and procedures for constructing, manipulating and making available to users global environmental data sets for the purpose of conducting environmental analyses and assessments.

2. To demonstrate the utility and effectiveness of GIS - technology which combines multiple data sets for resource management and environmental planning applications at the national and local level in a number of demonstration case studies.

3. To establish a framework for cooperation and data exchange within international and inter-governmental organizations which deal with environment-related matters, such as, FAO, ICSU, ILEC, IUCN, WHO, and WMO.

4. To provide training opportunities in GIS and data base management technologies to scientists and resource managers from participating developing countries.

Under the second objective, several national case studies were designed to demonstrate the utility of the technology employed by the GRID programme for decision makers and resource managers at both the national and local level.

1.2 The study objectives

The forests of Northern Thailand, like the majority of the tropical forests of the world, are under pressure from both increasing human populations and the demand for increased agricultural production. In hilly areas, as the population of the hill-tribes increases, more and more forests are cleared to provide land for increased requirements for food. The shifting cultivation cycle which earlier used to be 20 to 50 years, is now reduced to 7 to 15 years, which does not allow the forests time to reestablish themselves. The shifting cultivation in Northern Thailand mostly occurs on hillsides with slopes that vary from moderate to steep and, therefore, are susceptible to significant soil erosion when forest is removed for farming. The general practice in this area is to slash and burn the forests, which not only clears the land but also provides some nutrients for the crops. Because the hill soils are generally low in nutrients, they are farmed a year or so and then left fallow. If left fallow long enough (15 to 20 years) the areas will normally regenerate and return to forest. However, during the first years of the fallow period the soil is exposed to the sun and heavy rains which degrade and erode the soil.

In the recent past, as Thailand began to export agricultural products to improve the national economy, the lowland farmers in an effort to increase production began to expand farming into surrounding hillsides. Consequently, hill terracing for rice production has become a significant factor in deforestation. While these farmers are more conscious of terracing to manage water and to help prevent soil erosion, there is still a significant increase in soil-loss, especially in the areas where double cropping is practiced such as rice-soybean rotation.

The objective of this pilot study was to demonstrate to officials of the Government of Thailand that the technologies available in computerized geographic information systems such as those at GRID, which are capable of combining satellite data with other sources of data such as soils, topography and climate, can be used as a tool to develop alternatives for decision-makers in resource and environmental management.

Two study objectives were addressed : - The first was the assessment of deforestation activity for Chiang Mai Province which looked at ten years of forest change from 1975-1985. The second objective was to study soil loss in Mae Klang watershed, using the capabilities of GIS to map vegetative cover from current satellite data and combine these with soils, topography, rainfall and farming practices information to calculate potential soil-loss in the watershed.

2. DESCRIPTION OF THE STUDY AREA

Chiang Mai Province of Northern Thailand is located between Latitude 17°N and 20°N (Figure I). The terrain is hilly to mountainous, with an extension of a flat plain area associated with the Ping River Basin in which the city of Chiang Mai is located. The region is characterized by commercial rice plantations in the lowland areas where soil is capable of being farmed year after year and by shifting cultivation practices of the local tribes in the hills and mountains.

The forest types are distinguished by changes in elevation, with dense evergreen forest in the upper regions of the mountains, changing to mixed deciduous at an elevation of approximately between 300 and 600 meters above sea level, and wet to dry dipterocarps type forest in the lower elevation of the mountains and the hills.

The economy of Chiang Mai Province is based primarily on agriculture, with some forest based industry, particularly the manufacture of furniture.

The farming practices vary significantly from the lowlands to the highlands. In the lowland areas where rice is the principal crop, double cropping practices are often employed. The rice crop is harvested at the end of the wet season, and is followed by soybeans or other crops in the dry season.

CHIANG MAI PROVINCE AND MAE KLANG WATERSHED

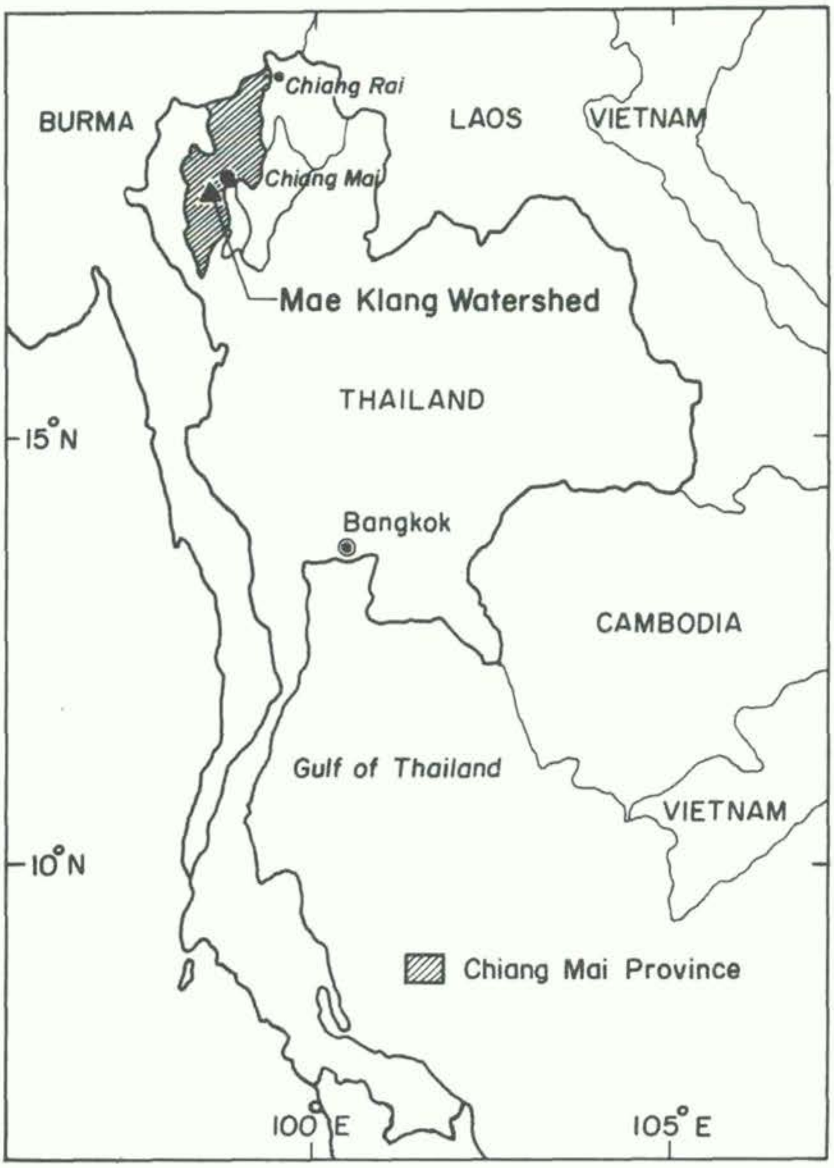

Figure 1. Location of the study area.

In the mountainous areas where the soils are less productive, the hill tribes have been practicing shifting cultivation for centuries. This practice generally involves slashing and burning of the forest on a rotational basis where the land is in cultivation for only one or two years. After one or two crop seasons, the land is abandoned and left to recover by natural processes. If left long enough (20 to 50 years) the land will return to its normal forest condition. However, if a cycle of slash and burn is repeated too often, the land never recovers to a stable condition and the soil is degraded and eroded, thereby decreasing its production potential.

Chiang Mai had a total population of 1,296,373 in 1986. Of this, 141,494 were hill-tribes people, which represented 10.9% of the total population. The average population density was 62.3 persons per square kilometer.

The climate of the area consists of three seasons, hot, rainy and cold. In summer months, from mid-February to mid-May, the temperature is higher than in other seasons with the maximum temperature of 41°C. The rainy season begins in mid-May and lasts until the end of September or the beginning of October, with an average rainfall of 198 millimeters. From mid-October to mid- February, the temperature is lower than in any other period and this is considered the cold season. It is dry and cold with an average minimum temperature of 15.2°C and with an average rainfall of 18.2 millimeters.

The study area of Mae Klang watershed is located to the South-West of the city of Chiang Mai and in the central part of Chiang Mai Province. It covers an area of approximately 640 km . The central point of the study area is near Chom Thong and is 98°35′E and 18°30′N. Most of the terrain is hilly and mountainous and a large part of the watershed is a national park. Because of its status as a national park, commercial agricultural activities are limited to the lowland areas. However, the population of the hill tribes within the park and outside the park practice slash and burn agriculture extensively.

3. THE DATASETS AND METHODOLOGY

Two distinct datasets were utilized to meet the objectives of the study. For the first objective, which was an analysis of deforestation activities in Chiang Mai Province of Northern Thailand over the past decade, forest-nonforest maps prepared by the Royal Forestry Department for three separate time-frames were utilized. The forest-nonforest maps were prepared from Landsat satellite imagery, using data for 1975, 1979 and 1985. The forestry classification was produced by remote sensing experts from the Royal Forestry Department using standard manual image interpretation equipment and procedures. The 1975 dataset was produced at a scale of 1:500,000 and the 1979 and 1985 datasets were produced at a scale of 1:250,000.

All three datasets were digitized using the GRID facilities and transformed and geo-referenced to a common longitude-latitude projection and a common scale. Through a comparative process of subtracting one dataset from another it was possible to determine the magnitude and rate of deforestation, and in some locations to establish the cause and effect.

To accomplish the second objective, which was an analysis of soil loss within Mae Klang watershed, several datasets were used such as :

- Soils maps provided by the Land Development Department.
- Soil erodibility factors provided by Dr. Nipon Tangtham, Kasetsart University.
- Elevation contours provided by Ms. Srisa-art Tang-Praserd, Chulalongkorn University.
- Land use map for 1977 provided by the Land Development Department.
- Five sets of Landsat MSS data, provided by the National Research Council : 1973 - one set from 14 February; 1979 - one set from 18 March; 1984 - one set from 27 October; 1985 - two sets from 5 April and 25 December.
- Rainfall data for the past 20 years provided by the Meteorological Department.

The information contained on the soils maps, while adequate for lowland areas, did not provide any soil classification for the steep upland regions. Consequently, it was necessary to conduct a field study for the purpose of developing soil erodibility factors for all of the upland soils within Mae Klang watershed. This work was carried out by Dr. Nipon Tangtham and his associates at Kasetsart University and was provided to the project in the form of a very comprehensive report. The erodibility factors, or K -factors, which are necessary for calculating soil loss utilizing the Universal Soil Loss Equation (USLE) were developed on a 1 km. grid and K factors were digitized into the GRID database utilizing the grided coordinates. For the purpose of the USLE, the data was sampled at a 50 m by 50 m grid cell size.

The elevation contours, which are necessary for the calculation of percent slope and length of slope for the USLE, were digitized at Chulalongkorn University in Bangkok and provided to the GRID facility in digital map format.

Elevation, percent slope and length of slope were calculated utilizing appropriate GIS software modules and held in digital format with a resolution element of 50 m by 50 m.

The land use map for 1977 was digitized and stored in the database, however, it was used only for comparison of historical uses of the land.

Five sets of Landsat MSS data for the study area were provided by the National Research Council from the Thai Landsat Receiving Station. Two of these datasets, February 1973 and March 1979, were used for historical reference to the forest-nonforest maps. The other three sets, October 1984, April 1985 and December 1985, were used for ground truth and final ground cover classification for Mae Klang watershed.

Since the ground truth was conducted in early November 1986, the most appropriate dataset for field inspection was the one of 27 October 1984. The information derived during the ground truth exercise was adequate for the analysis to describe a nine-class ground cover classification by merging the datasets of 5 April and 25 December 1985. The merge of the two datasets was required in order to provide spectral separation in some categories between the wet season and the dry season. The final maximum likelihood classification was derived from the merged four-channel dataset consisting of channels 2 & 4 from both April and December data.

Climatic data, including rainfall and run-off information, was provided from the Department of Meteorology for Mae Klang area for the past 20 years. This information was used to develop the rainfall and run-off factors (R) of the USLE. Because the study area is small in comparison with the climatic-variation, the R factor is constant for the entire Mae Klang watershed.

4. ANALYSIS AND RESULTS

4.1 Deforestation in Chiang Mai Province

The analysis covers the time-frame from 1975 to 1985. There were three datasets provided by the Royal Forestry Department for the years 1975, 1979 and 1985. All three datasets were developed from Landsat MSS imagery which was interpreted by remote sensing experts of the Royal Forestry Department. An analysis shows that, while deforestation has been occurring in Northern Thailand for decades, the rate of deforestation during the past 10 years appears to be accelerated. Figure 2 indicates a 100 percent increase in deforested areas in the 10 year time period between 1975-1985. The 1975 area of non-forest, of approximately 325,000 hectares, represents about 15 percent of the total area of the Province. The deforested areas were mostly lowland rice farming plantations. By the year 1979 approximately 25 percent of the total Province had been cleared of the forests and in 1985 more than 28 percent of the forests had been cut. These figures represent an average of over two percent of the total of the Province being cleared of the forests each year. Of course, if deforestation should continue at this average rate of over two percent per year, in about 30 years there would be no tropical forest left in Chiang Mai Province. However, referring to Figure 2 once again, it is evident that the rate of change between 1975 and 1979 was much greater than the rate of change between 1979 and 1985 which indicates that the average rate of deforestation is nearer one percent of the Province for the past five years.

To examine the causes of variations in the rate of change, it is interesting to consider Figure 2 which is a composite of the three datasets with color coding by five year intervals. If one examines carefully the location and size of the change between 1975 and 1979, it is obvious that the newly cleared areas are quite large in size compared to other change areas, and for the most part they are located adjacent to the rather large previously cleared lowland rice growing areas. In some cases, these represent medium size valleys with extensive lowland soils that have been cleared for lowland rice plantations. Considering that during this period Thailand was developing its agricultural production and increasing yields for export to strengthen the national economy, these large clearings adjacent to the lowlands appear to represent expansion of lowland farmers into the surrounding hills and paddy being grown on terraced hill sides where the forest has been cleared.

In addition, large areas in valleys adjacent to the lowland areas were cleared, and used for growing rice in the lowland and adjacent hills.

With regard to the change between 1979 and 1985, several of the cleared areas followed the same pattern as in the previous five years, that is being adjacent to the large lowland areas, they are for the most part much smaller and much more scattered than those of the previous five years. This indicates smaller farmers increasing the extent of their farms for rice production. However, a second explanation could be an increase in subsistence crop production by the hill tribes of the area.

While the rate of deforestation between 1979 and 1985 has decreased somewhat over the previous five years, a major concern could be indicated by the increased intensity of shifting agriculture. This problem, which is most likely related to increased population of the hill tribes, is in danger of continuously increasing with population growth.

4.2 <u>Soil loss assessment in Mae Klang watershed</u>

The soil loss analysis for Mae Klang watershed was conducted using the Universal Soil Loss Equation (USLE) with procedures as outlined in USDA Handbook No. 537[1] (see Figures 3-9 & 10-16). The USLE equation :

A= KCRLSP,

where;
A= soil loss (in metric tons/hectare year)
K= soil erodibility factor
C= vegetative cover factor
R= rainfall and run-off factor
LS= slope and slope length factor
P= conservation practices factor.

The various parameters of the equation were determined in the following manner:

The soil erodibility factor (K) was developed by soil scientists at Kasetsart University, under the supervision of Dr. Nipon Tangtham. The vegetative cover identification was developed from the multi-temporal Landsat MSS dataset. From 255 spectral classes the analyst derived nine ground cover classes listed in Table 1 following.

The USDA Handbook No. 537 was utilized for calculation of the C factor related to the nine vegetative cover types. However, because of certain burning practices which occur in Northern Thailand, a subjective judgement was applied to the C factor as determined by the forestry experts of the Royal Forestry Department. In the area where shifting cultivation is practiced, the farmers, in clearing their fields during the dry season for preparation for food crops during the wet season, most often allow the fires to spread beyond the immediate fields which causes massive forest fires in the adjacent forest. As a result, the litter that normally accumulates on the forest floor is burned every year. This occurs in both the deciduous and the dry dipterocarps forest areas. The evergreen forests, which are usually wetter, are normally not burned by this practice. Therefore, the C factor for the forest areas has been modified to reflect this burning practice.

(1) Predicting Rainfall Erosion Losses: A Guide to Conservation Planning; Agriculture Handbook No. 537. United States Department of Agriculture (USDA), 1978.

Table-1. Ground Cover Classes

Cover-Class	Area (Hectares)	Percent Area	C Factor	P Factor
Evergreen forest	1,708	2.7	0.001	1
Abandoned shifting cultivation	10,022	15.7	0.35	1
Mixed deciduous forest	12,550	19.7	0.10	1
Dry dipterocarps forest	22,609	35.4	0.25	1
Open dry dipterocarps forest/scrub	10,337	16.2	0.40	1
Active shifting cultivation	770	1.2	0.65	1
Other crops	1,166	1.8	0.65	1
Orchards and villages	2,604	4.1	0.30	1
Paddy field	2,058	3.2	0.10	0.5

The rainfall run-off factor (R) was calculated using 20 years of climatic data and a USDA model for calculating this value for the USLE. The R value for entire Mae Klang watershed was determined to be 464.

The slope and slope length factor (LS) was calculated from elevation contours and slope values for the particular soil type. It should be noted that the detailed elevation data did not include the extreme southern part of the study area. In this case the LS factor was determined from soil type classification. All of the soils in this region were classified as steep uplands, and therefore this approach to LS factor derivation is a good approximation which misses only the few narrow valleys in the region.

The conservation management factor (P) was determined to be 0.5 for those areas with paddy field. For all other vegetative covers, the factor was determined to be 1.0. The reason for this is based on the fact that only the rice farmers appear to practice any sort of terracing or erosion control.

The results of the USLE model calculation were grouped into six classes of 0-20, 21-50, 51-100, 101-200, 201-300 and greater than 300 metric tons per hectare as shown in Fig. 16. Examination of Fig. 16 indicates low erosion rates in the areas of paddy rice where slope is near zero (with some increase due to double cropping) and in the rain forest areas at the higher altitudes where the forest litter and understory are not burned each year and where forest cover is nearly 100 percent.

The second class of 21 to 50 tons/ha includes areas of increasing slopes in paddy rice with double cropping and in orchards, gardens and villages with low slope factors. It also includes some flat land areas in the valleys and part of the more mountainous areas of the park.

Class 3, with soil erosion rates of 51 to 100 tons/ha includes primarily the shifting agriculture areas of the hill tribes. It should be remembered that the C factor developed for abandoned agriculture was an average for the fires from slash and burn until the forest is reestablished. Therefore, one should expect that erosion in the first few years after clearing is more severe than in later years as the grasses and forests continue to regrow.

Class 4, with erosion rates of 101 to 200 tons/ha include the mixed deciduous types of forest. The forest represents 60 to 100 percent crown closure, however, due to farming practices the forest litter is burned each year. Therefore, the soil is exposed directly to rainfall and runoff. The erosion rates here are higher than usual for this type of forest due to the lack of litter on the ground to protect the soil.

Class 5 includes large areas of dry dipterocarps forest with 20 to 50 percent crown closure and also with the ground litter lost each year as with class number 4. With low crown closure, steep slopes and bare soil under the trees, the erosion rates are severely high.

Class number 6 is composed primarily of the open dry dipterocarps forest with 10 to 30 percent crown closure. The slopes-steepness increases and the ground litter is lost with the annual burning practice. The trees are small and usually provide little to no protection for the soil. Soil loss here approaches that of bare soil or steep unprotected slopes with heavy rains and no conservation practices.

While the USLE is an approximation of potential soil loss, the results provide an insight into cause and effect of the environmental conditions resulting from man-nature interactions. While the area associated with shifting cultivation is only a small percentage of the total area, the practice of slash and burn agriculture, to clear the land during the dry season, results in the burning of the protective ground litter in all of the forested areas except the evergreen rain forests. While the erosion is caused by the clearing from shifting cultivation, it is the associated loss of ground litter, degraded forest areas or steep slopes that creates the most significant soil erosion hazards.

5. CONCLUSIONS

The results of this cooperative project have demonstrated that it is possible to quantitatively analyst deforestation and associated environmental hazards using remote sensing data and GIS techniques. The utility of combining multiple layers of data such as land cover, soils, elevation, slope, and developing a GIS for a watershed has been demonstrated. The study indicates that conversion of tropical forests into farmlands has resulted in accelerated soil erosion in the mountainous terrain. Hence, GIS technology can be a potential tool for environmental impact assessment while supporting the formulation of public policy.

Abbreviations Used

FAO	Food and Agriculture Organisation of the United Nations
FCC	False Color Composite
GEMS	Global Environment Monitoring System
GIS	Geographic Information System
GRID	Global Resource Information Database
ICSU	International Council of Scientific Unions
ILEC	International Lake Environment Committee
IUCN	International Union for the Conservation of Nature
MSS	Multispectral Scanner
ROAP	Regional Office for Asia & the Pacific
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WHO	World Health Organisation
WMO	World Meteorological Organisation

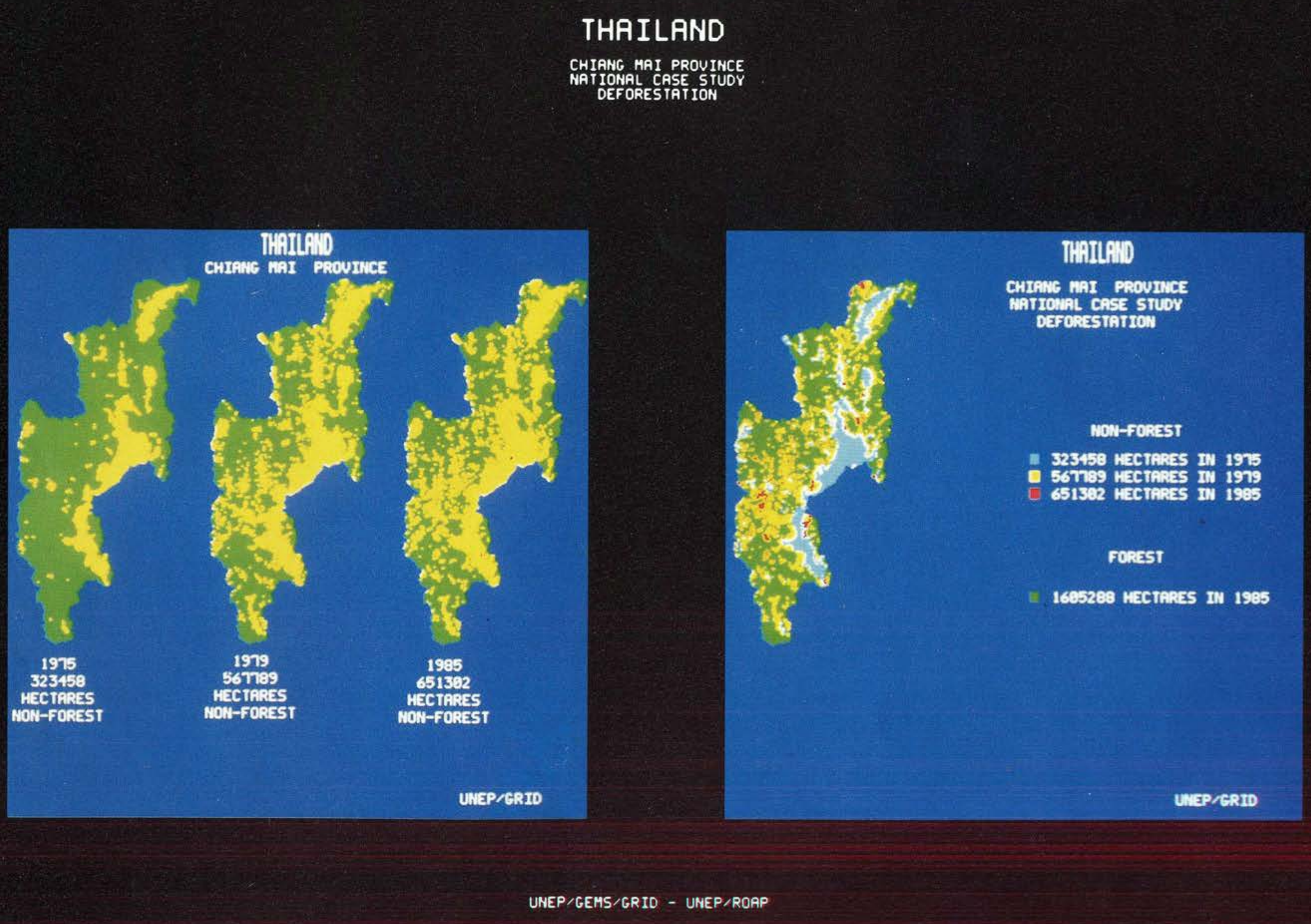
THAILAND
CHIANG MAI PROVINCE
NATIONAL CASE STUDY
DEFORESTATION
THAILAND
CHIANG MAI PROVINCE
1975
323458
HECTARES
NON-FOREST
1979
567789
HECTARES
NON-FOREST
1985
651382
HECTARES
NON-FOREST
UNEP/GRID
THAILAND
CHIANG MAI PROVINCE
NATIONAL CASE STUDY
DEFORESTATION
NON-FOREST
323458 HECTARES IN 1975
567789 HECTARES IN 1979
651382 HECTARES IN 1985
FOREST
1605288 HECTARES IN 1985
UNEP/GRID
UNEP/GEMS/GRID - UNEP/ROAP

Figure 2.


THAILAND
CHIANG MAI PROVINCE
NATIONAL CASE STUDY
INPUT DATAPLANES USED IN THE DERIVATION OF UNIVERSIAL SOIL LOSS EQUATION (USLE) TO PREDICT THE POTENTIAL RAINFALL SOIL EROSION LOSS FOR THE MAE KLANG WATERSHED
THAILAND
MAE KLANG WATERSHED
FALSE COLOR COMPOSITE
UNEP/GRID
THAILAND
MAE KLANG WATERSHED
LAND COVER
EVERGREEN FOREST
ABANDONED SHIFTING CULTIVATION
MIXED DECIDUOUS FOREST
DRY DIPTEROCARPS FOREST
SCRUB/OPEN DRY DIPTEROCARPS FOREST
ACTIVE SHIFTING CULTIVATION
OTHER CROPS
ORCHIDS/VILLAGE
PADDY FIELD
UNEP/GRID
THAILAND
MAE KLANG WATERSHED
SOILS
ALLUVIAL COMPLEX
SAN SAI
HANG CHAT (HYDROMORPHIC)
MAE RIM (ROLLING)
HANG CHAT (CALCARIOUS)
PAK CHONG (VERY STONY)
ROCK SLOPE COMPLEX
UNEP/GRID
THAILAND
MAE KLANG WATERSHED
ELEVATION
ELEVATION (KM)
UNEP/GRID
THAILAND
MAE KLANG WATERSHED
SLOPE
SLOPE
% SLOPE
DEGREES
UNEP/GRID
THAILAND
MAE KLANG WATERSHED
SLOPE LENGTH
UNEP/GRID
FALSE COLOR COMPOSITE
BLUE - BAND 5 LANDSAT MSS IMAGED 5 APRIL 1985
RED - BAND 7 LANDSAT MSS IMAGED 5 APRIL 1985
GREEN - BAND 5 LANDSAT MSS IMAGED 25 DECEMBER 1985
THE NINE LAND COVER CATEGORIES OF THE MAE KLANG WATERSHED WERE COLLECTED FROM THIRTY-NINE CLASSES RESULTING FROM THE UNSUPERVISED CLASSIFICATION USING EARTH RESOURCES LABORATORY APPLICATION SOFTWARE (ELAS) PROGRAMS SRCH AND MXAP WITH STANDARD DEFAULT VALUES. THE INPUT DATA FILE WAS A FOUR CHANNEL DATA FILE COMPRISED OF LANDSAT MSS BANDS 5 AND 7 IMAGED ON 5 APRIL 1985 DURING THE DRY SEASON PRIOR TO FIRST CROP PLANTING AS THE FIRST TWO CHANNELS AND LANDSAT MSS BAND 5 AND 7 IMAGED ON 25 DECEMBER 1985 DURING THE RAINY SEASON PRIOR TO HARVESTING WHICH WERE OVERLAIN AS THE LAST TWO CHANNELS.
UNEP/GEMS/GRID - UNEP/ROAP

Figures 3 - 9.

Figures 10 - 16.