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WATER BALANCE STUDIES USING A GEOGRAPHIC INFORMATION SYSTEMS (GIS) APPROACH

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ABSTRACT

A surface water balance model for Ni Khu Hu and Tatha watersheds was developed by applying remote sensing and water balance modelling using a geographic information system. The study area is located at Thong Pha Phoom district, Kanchanburi province, western part of Thailand. The annual climatic data of the study area was used to determine the available water from the' water balance equations. The LANDSAT TM image of the area was classified by image processing to produce the land use map. GIS modelling produced GIS maps of rainfall, evapotranspiration, land use, soil, slope, excess moisture and surface runoff.

INTRODUCTION

Most decisions regarding watershed management are based, partly, on estimates of the quantity of the available water resources in a watershed. The most unpredictable characteristic of the water resource is its uneven spatial and temporal distribution. This suggests that some areas have too little water, but, other areas have too much water, thus, encountering some flooding problems. This uncertainty of the resource is due to the uneven distribution of water, suggesting that rainfall is excessive during the few monsoon months while almost totally absent during the rest of the year.

To minimize the environmental impact of this scarce natural resource on the watershed, planners should know how to quantify the resource before attempting to manage or utilize it. Although most sources of water , such as streams in a watershed have been gauged to have continuous records of streamflow, planners and engineers are facing problems of not having enough available information and must rely on hydrologic models to rationalize their decisions.

In determining the available water in a watershed, a water balance study is applied to the hydrologic cycle to measure the quantities of water input, output, and change in storage within the given unit area and time. The most essential input to the water balance of a system is precipitation. The output quantities are evapotranspiration, surface runoff, and groundwater recharge through infiltration and the change in storage quantities are stream channel capacity and soil moisture storage.

With the availability of sophisticated computers and the application of the new modern technologies of remote sensing and geographic information systems (GIS), the development of water balance models applied to a particular watershed will not be as tedious and complicated as it used to be. GIS and remote sensing provide a facility in solving these kind of problems, specially when a watershed is used as a planning unit for both spatial and temporal changes. These new techniques can be very useful to watershed management.

Applying RS/GIS techniques, the study aims to develop a surface water balance model for the Tatha and Ni Khu Hu sub-watersheds of the Lin Thin watershed. The availability of hydrologic information from these particular watersheds, collected from the various studies of the Mae Klong Watershed Research Station (MWRS), facilitated the development of a water balance model for the study area. The main objective of the study is to develop a surface water balance model using GIS and remote sensing to assist decision makers, planners, researchers, and engineers in the proper utilization of the water resources in the Tatha and Ni Khu Hu watersheds.

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

Remote sensing is the acquisition and interpretation of spectral measurements made at a distant location to obtain information about the earth's surface. Remote sensing, as it is known today, is an outgrowth of aerial photography. This information can be gathered from instruments mounted on board satellites or aircraft or by hand-held instruments.

The two basic processes involved in remote sensing are data acquisition and data analysis. The data acquisition process uses sensors to record variations in the way earth surface features reflect and emit electromagnetic energy. The data analysis process uses reference data about the resources being studied (such as soil map or field check data available) to assist in the data analysis. This information is then presented, generally in the form of maps with the use of geographic information systems (GIS), tables and a written discussion or report. Finally, the information is presented to users.

GIS serves as a management tool for remote sensing and is an important part of image processing and classification. GIS is defined as a means of collecting, storing, retrieving, transforming and displaying spatial data for a particular set of purpose. The use of GIS to satisfy the need of a given user is called application. Most GIS applications involve some form of geographic or spatial analysis.

The term GIS is currently applied to computerized information synthesis and processing.

modelling, analysis, display and retrieval systems with the use of the GIS hardware and software. GIS softwares such as PC ARC/INFO were specifically designed for handling geographically referenced spatial data and the corresponding attribute information.

The application of remote sensing and GIS is an efficient way for natural resource managers to review land and water resources. Data provided by satellites represent new techniques of determining the changes in land cover. The use of satellite images, from LANDSAT, together with the application of an image processing software, ERDAS, and a vector GIS, PC ARC/INFO, is applied to develop an annual water balance model in the watershed.

WATER BALANCE

The water balance study of a watershed is a method of quantifying and understanding the different processes in the hydrologic cycle. It will also show the distribution of water in the watershed. By applying the continuity equation and knowing the various inflows and outflows to the watershed, the change in storage can be determined. One way of determining the water balance is by applying the continuity equation. Assuming that storage S, inflow I , and outflow O are used to formulate the water balance in a watershed, the change in storage S can be computed from the continuity equation,

$$I - O = S$$

Using the same equation, the amount of excess moisture from rainfall that contributes to surface runoff and groundwater recharge can be determined by getting the water balance of the watershed. The following equation is used to determine the excess moisture,

$$\text{Excess Moisture} = P - AET - (S_2 - S_1)$$

where P = Precipitation
AET = Actual Evapotranspiration
$(S_2 - S_1)$ = Change in soil moisture storage

The equation requires functional relationships for actual evapotranspiration, AET, with available precipitation, P, and soil moisture, S_1, for a given potential evapotranspiration, PET, and the consequent change in soil moisture storage, S_2. The Crawford method of determining the actual evapotranspiration and soil moisture was used as follows :

$$AET = \text{Min}\{ PET,\ S_1 + P,\ P + (PET - P) * S_1/S_m \}$$

$$S_2 = \text{Min}\{ S_m,\ S_1 + (P-AET) * (1-M) \}$$

$$M = 2 * (S_1/S_m)^2 \quad \text{for } 0 < S_1/S_m \leq 0.5 \text{ and } P > AET$$

$$= 1 - 2 * (S_1/S_m)^2 \quad \text{for } 0.5 < S_i/S_m \leq 1 \text{ and } P > AET$$

$$= 0 \quad \text{for } P \leq AET$$

where PET = Potential Evapotranspiration
S_1 = Initial Soil Moisture Storage

S_m = Maximum Soil Moisture Storage
S_2 = Final Soil Moisture Storage
M = Excess Moisture Ratio

The excess moisture is then divided into streamflow discharge from surface runoff and groundwater recharge through infiltration,

$$\text{Excess Moisture} = Q_d + Q_g$$

$$Q_d = r * \text{Excess Moisture}$$

$$Q_g = (1-r) * \text{Excess Moisture}$$

$$r = Q_d/\text{Excess Moisture}$$

where Q_d = streamflow discharge
Q_g = groundwater recharge
r = streamflow ratio
= ratio of streamflow to excess moisture
= value to be calibrated (between 0 and 1)

THE STUDY AREA

Location

The study area is located at Thong Pha Phoom district, Kanchanaburi province (Fig. 1), western part of Thailand at UTM Eastings of 481,000 to 493,000 m. and UTM Northings of 1,609,000 to 1,620,000 m. Specifically, the experimental areas of Ni Khu Hu (WS1) and Tatha (WS2) watersheds of the Lin Thin watershed have been selected for the study . The two watersheds, about 200 km from Kanchanaburi district, are being managed by the Mae Klong Watershed Research Station of the Royal Forest Department. The two watersheds have a total area of 56.42 sq. km. (Ni Khu Hu watershed is about 27.66 sq.km. and Tatha is about 28.76 sq. km.) and are fed by two major tributary rivers, Huai Ni Khu Hu and Huai Ta Tha as shown in Fig. 2. The site elevation ranges from 140 to 970 m. MSL. The other smaller tributaries are Ta Mae, Phi Ka Re, and Ti Khu Ni for Ni Khu Hu and Ta Tha Tho and Ta Khu Ni for Tatha. The two experimental watersheds have southwestern aspect with an average slope of 22% ranging from 10 % to 60 %.

Geology and Soil

The study area are underlain by rocks of various origins ,but , primarily dominated by biotic granite . There are many rock growth outside of the study area such as shale, sandstone and metamorphic rock. The soil can be described as containing a reddish brown laterite soil from the parent material of residium and colluvium of sandstone, limestone, shale and quartzite . The soil types were classified as clay, sandy clay, and sandy clay loam . It was observed that clay was used for agricultural crops, sandy clay soil for mixed deciduous forest with bamboo and wild

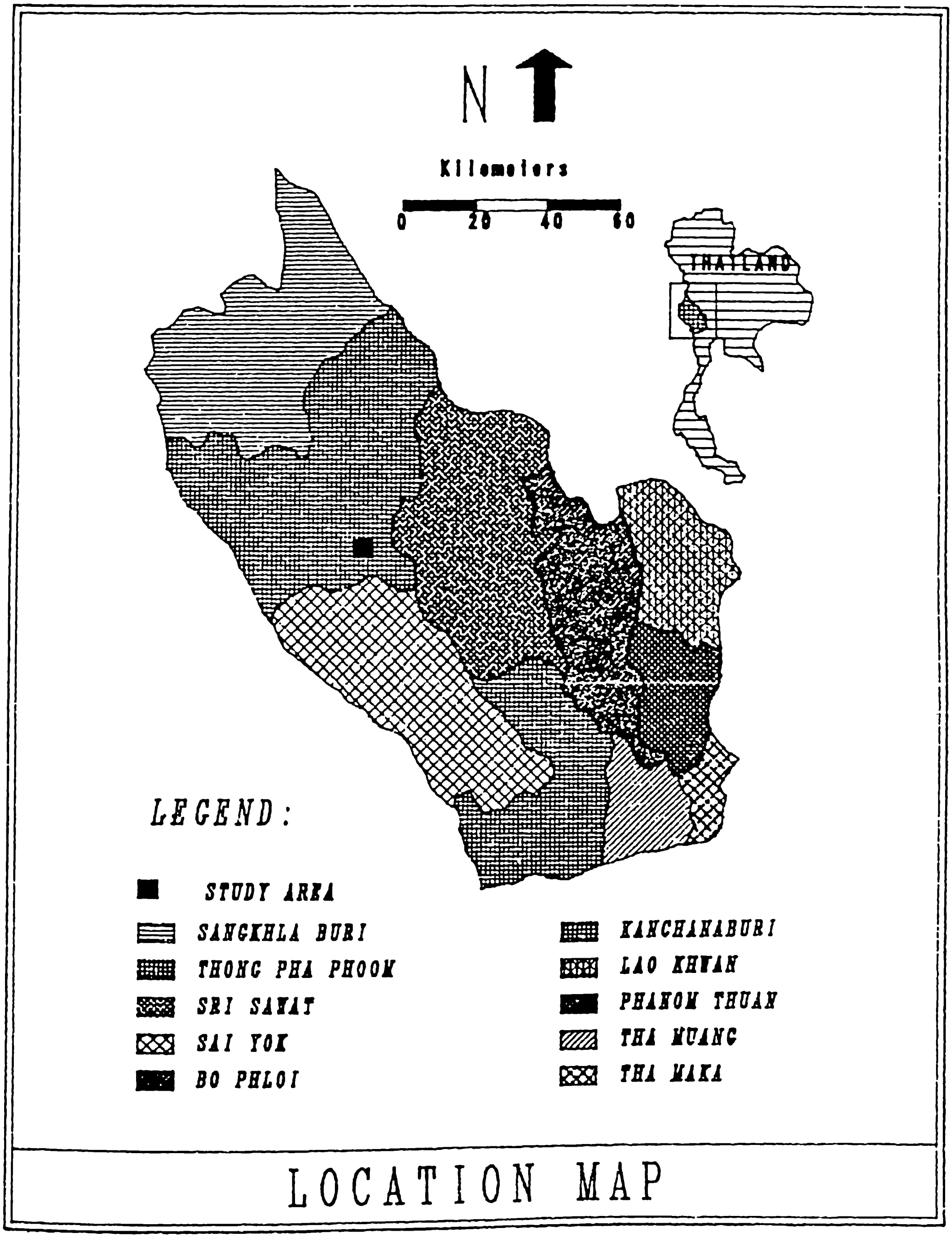


Fig.1 Location Map of Kanchanaburi Province

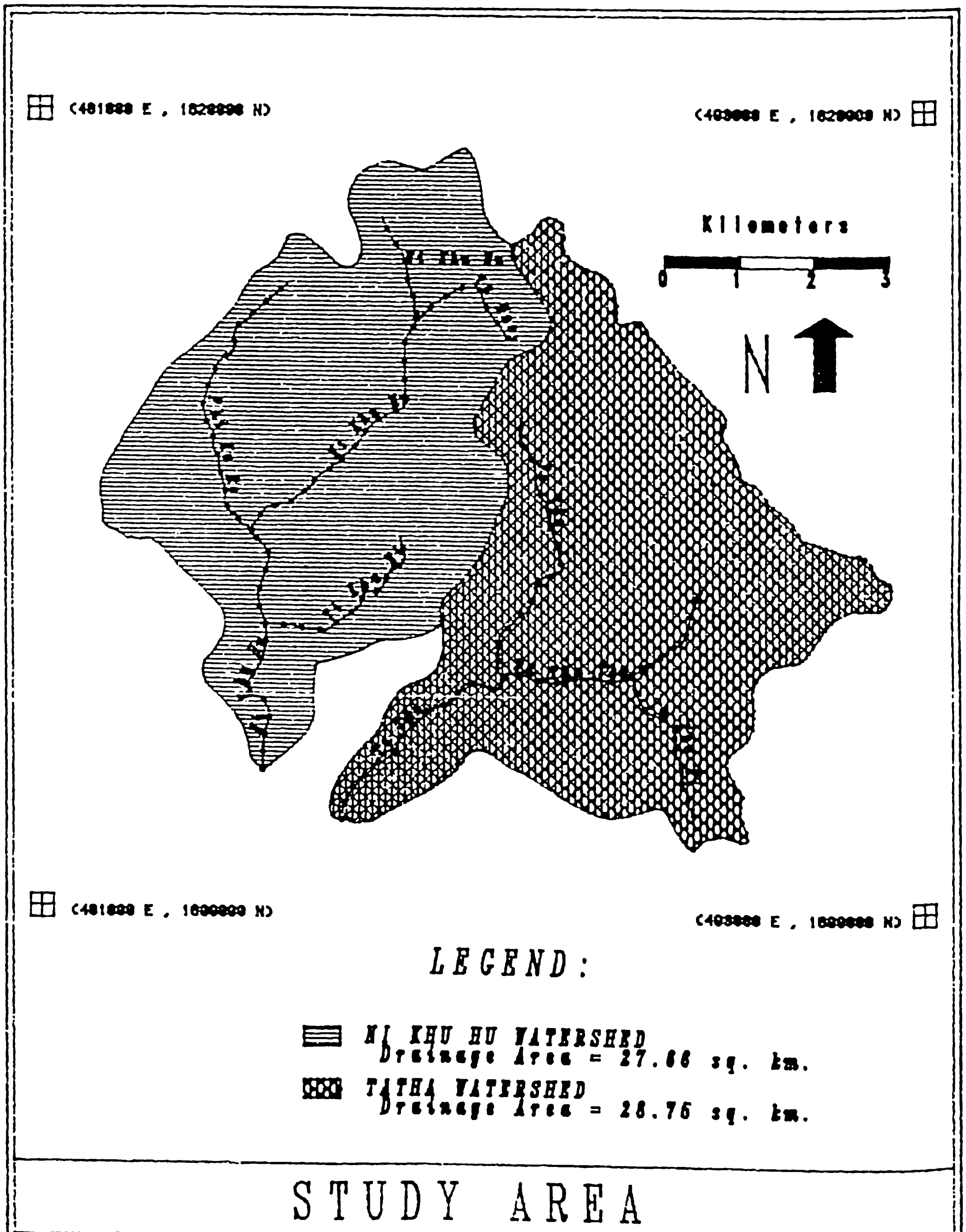


Fig. 2 Study Area: Ni Khu Hu and Tatha Watersheds

bananas, and sandy clay loam soil for deciduous forest . The color of sandy clay loam is dark reddish brown to dark brown, sandy clay is dark reddish brown and clay is reddish brown.

Vegetation

Soil differ in their capacity to produce trees because of the difference in soil properties and environment and the changes resulting from its past use. Based from the field observation, deciduous forest originally covered most of the area . The land cover in the area was classified into three types of vegetation, namely, mixed deciduous forest with bamboo and wild bananas, deciduous forest, and agricultural crops.

Climate

Throughout the year, there are three seasons in Thailand; dry from February to May, wet from June to September and winter from October to January. The study area is mainly under tropical monsoon type of climate with a mean annual rainfall of about 1748.03 mm. Monthly mean temperature does not vary much. The coolest period is experienced during the months of November and December (8.5°C) while the hottest month is in April (44.5°C).

WATER BALANCE MODELLING USING RS/GIS

The study was conducted from the last week of September 1992 to the second week of December for a duration of approximately three (3) months. The flowchart on Fig. 3 describes the methodology in developing the annual water balance model for the Ni Khu Hu and Tatha watersheds using remote sensing and GIS modelling . The study has four (4) major activities :

Study Field Trips

There were a total of three(3) study field trips to the study area. Field familiarization activities were carried out to gather some insights and problems encountered in the study area . Available information from the Mae Klong Watershed Research Station were initially collected.

Relevant information for the project were collected on the second field trip (data collection). Rainfall , pan evaporation, and other climatic data were gathered from MWRS. The actual conditions of the hydrometeorological stations at Lin Thin , Ni Khu Hu , and Tatha were observed. A standard rain gage was used to measure the daily precipitation and evaporation pan was used to measure daily evaporation. Other instruments in the stations are different types of thermometers, anemometer, sunshine recorder , and a thermohydrograph.

In the stream gaging stations located at the outlets of Ni Khu Hu and Tatha , stream gages are taken and discharges are measured using current meters. In smaller tributaries inside the watershed, the discharge was measured using a triangular weir .

Soil samples were collected and three (3) soil types were classified inside the watershed; clay, sandy clay, and sandy clay loam. Different kinds of agricultural crops, such as rice, cotton,

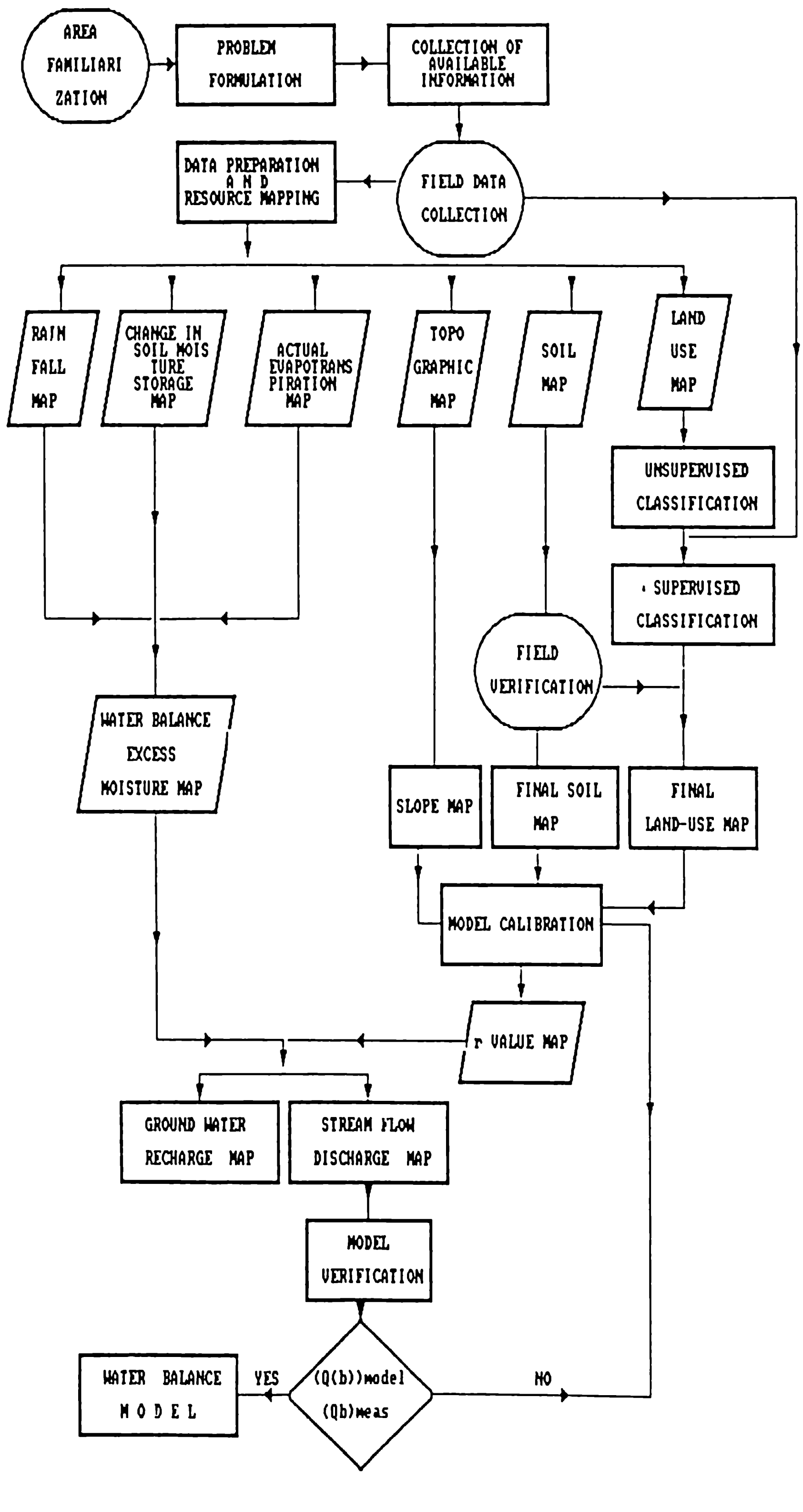


Fig. 3 Water Balance Modelling

tobacco, ginger, and rubber, were seen inside the study area. Wild bananas and different species of bamboo with forest trees were observed near the rivers. But, the watershed area is mostly covered by deciduous forest. It was observed that the soil for the agricultural plantations is clay, sandy clay for mixed deciduous forest and sandy clay loam for deciduous forest.

The third trip is for field verification after image classification. Acquisition of ground truth is an indispensable part of image classification. The clasiffied land use maps were verified in the study area. It was seen that the land cover , vegetation and soil types on the two watersheds are almost the same. In Tatha, wild bananas are more abundant and the slope is more complex than in Ni Khu Hu watershed.

Collection of Available Information

A collection of published and unpublished technical books and reports was gathered from various sources. The monthly climatic data of the Lin Thin watershed was collected from 1979 to 1989. The data is supplemented by the precipitation, pan evaporation, and runoff data of Ni Khu Hu and Tatha watersheds collected from April 1985 to March 1992 by MWRS. Location maps of the fifteen (15) rainfall gaging stations, three (3) climatic stations and streamflow gaging stations were also provided by MWRS. The LANDSAT TM image (both in print and CCT), with a spatial resolution of 30 m x 30 m and a scale of 1:50,000 taken in Dec. 1989 was used. The following maps and images for the study area were used for the study:

		Scale	Year
a.	Topographic Map -	1:50,000	1969
b.	Soil Map -	1:100,000	1985
c.	Land Use Map -	1:100,000	1985
d.	LANDSAT TM Image -	30 m x 30 m resolution	1989
	- FCC Image	1:50,000 (print)	
	- CCT		

Data Preparation and Resource Mapping

GIS Maps

Using the topographic map, the basin boundaries of Ni Khu Hu and Tatha were delineated and digitized using PC ARC/INFO. Major streams, other tributaries, and contour lines at 100 m intervals were also digitized. The location of the rainfall gaging stations were also digitized. The Thiessen method was applied to create the precipitation map **P**. In this procedure, the area is subdivided into polygonal subareas using the gaging stations as centers. The precipitation of the rainfall gaging station is assumed to be constant on each polygon.

The annual potential evapotranspiration was computed by multiplying a coefficient C (C = 0.70) to the annual pan evaporation. The available pan evaporation data from Ni Khu Hu and Tatha was used to compute the potential evapotranspiration of the two watersheds. The boundaries of the watersheds were digitized and the computed values were assigned to create the potential evapotranspiration map **PET**.

A grid with a pixel size of 250 m x 250 m was overlayed on the topographic map to manually interpolate the elevation for each pixel. The point elevation map was digitized to create the digital elevation model (DEM) in ERDAS. From the created image of the DEM, a classified slope map was derived and converted using PC ARC/INFO to produce the GIS map SLPCLASS.

Land Use and Soil Type Maps by Image Classification

a. Visual Analysis

Visual interpretation was used on the False Color Composite (FCC) of the LANDSAT TM image to define the individual classes of vegetation, bare soil, built up areas, water body, and other features. The image was classified by applying pattern recognition, differences in size and texture, and changes in reflectance values through variations in color. The classified image was then used on the second field trip for ground verification.

b. Unsupervised Classification

The LANDSAT TM image was classified using sequential'clustering wherein pixels were examined one at a time. The spectral distances between each analyzed pixel and previously defined clusters were calculated. Each pixel either contributes to an existing cluster or begins a new cluster, based on the spectral distances. Clusters were merged if too many were formed. This kind of unsupervised classification is computer-automated and usually used when less is known about the data before classification. The resulting GIS map image produced five (5) clusters; shifting agricultural area or bare soil, mixed deciduous forest with other crops, deciduous forest, forest with shadow, and water bodies.

c. Principal Component Analysis

The LANDSAT TM image was also enhanced using the principal component analysis (PCA). PCA is often used as a method of data compression. It allows redundant data to be compacted into fewer bands. There were also five (5) possible training samples which must be verified through ground truthing. The image was dominated by forest covered with shadow because the satellite image was taken in the morining.

d. Supervised Classification

After the second field trip, a supervised classification using maximum likelihood was made after the selection of the training samples. Unlike in the unsupervised classification, the training samples were explicitly selected and it required known information about the area. In this method, pattern recognition skills together with priori knowledge of the data, either spatial or spectral, were needed to determine the statistical criteria for data classification. This is followed by signature evaluation, where the statistics of the training samples, such as their mean, standard deviation ,scatterplots, and covariance matrix between bands, have to be checked for homogeneity.

Using the LANDSAT TM image enhanced by PCA, five (5) training samples were selected; agricultural area, mixed deciduous forest, deciduous forest, forest covered with shadow and water bodies. After classification, the classes of deciduous forest and forest with shadow were merged into one class. To remove the salt and pepper effect (small polygons) on the classified image, the image was filtered or smoothened.

e. Image Rectification

Remotely sensed image data, gathered by satellite, is a representation of the irregular surface of the earth, thus, the need for the classified map to be geometrically corrected to conform to a map projection system.

f. GIS Map Conversion

The land use map, the result of classification using ERDAS, must be converted to vector data for PC ARC/INFO since ERDAS uses raster data. After conversion, the converted land use map can be overlayed with the other maps digitized using PC ARC/INFO.

Model Calibration

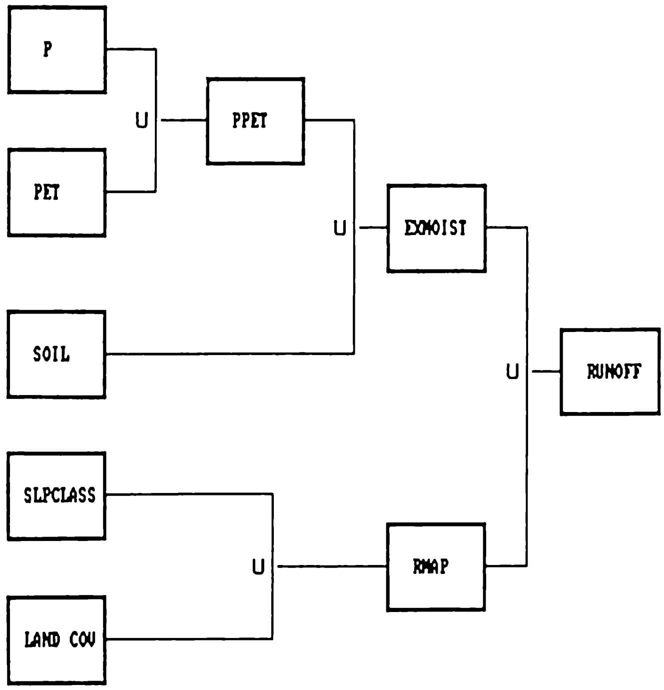
By overlaying the digitized and generated maps, the actual evapotranspiration (**AET**), final soil moisture storage (S_2) and excess moisture (**EXMOIST**) maps from the water balance equations were produced following the flowchart on Fig. 4. It can also be seen from the flowchart that from the classified land use map and the generated slope map (**SLPCLASS**), the value of the streamflow ratio r can be calibrated to produce **RMAP**. The resulting RMAP and excess moisture map are then overlayed to produce the streamflow discharge map **RUNOFF**.

The resulting runoff from the model for NI Khu Hu and Tatha watersheds were then compared to that of streamflow measurements at the outlets of the two watersheds. If adjustments were needed, the values of the streamflow ratio were changed until runoff values from the model were approximately equal to that of measured discharges.

DISCUSSION OF RESULTS

Rainfall

The average annual rainfall for the study area was computed from the data collected from MWRS by applying the Thiessen Method. The location of the rainfall gaging stations and the Thiessen polygons created are shown on the GIS map on Fig. 5. A summary of the results, including the areas of the polygons and the elevation of each station, is shown on Table 1. The average rainfall for Ni Khu Hu is 1,747.17 mm, for Tatha is 1,748.86 mm , and for the whole watershed is 1748.03 mm.



Where :

P = RAINFALL MAP

PET = POTENTIAL EVAPOTRANSPIRATION MAP

SOIL = SOIL MAP

SLP CLASS = SLOPE CLASS MAP

LAND COV = LAND USE MAP

EXMOIST = EXCESS MOISTURE MAP

RMAP = STREAMFLOW RATIO MAP

RUNOFF = RUNOFF MAP

Fig. 4 GIS Map Overlays

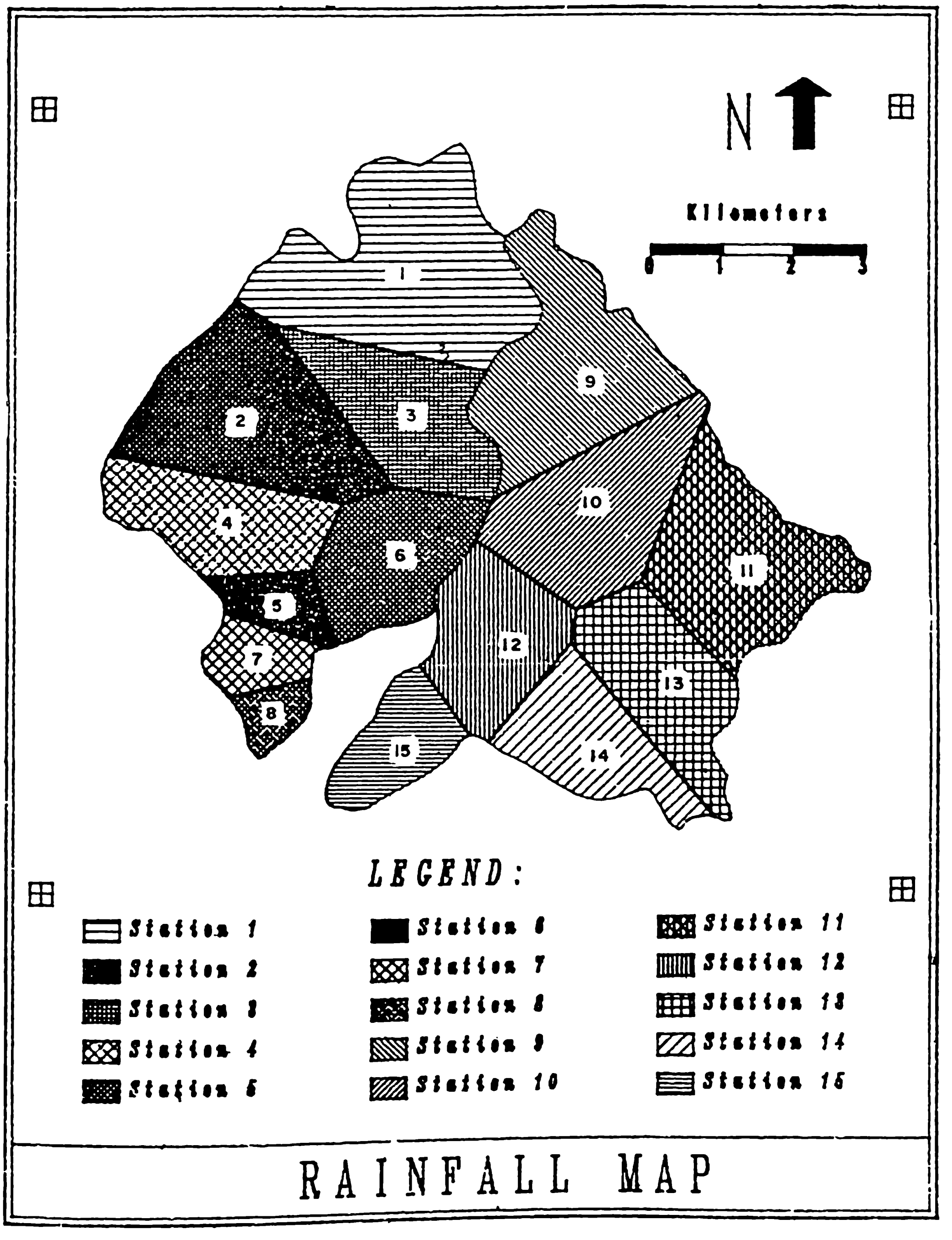


Fig. 5 Rainfall Map

Table 1 - *Annual Rainfall Data of Ni Khu Hu and Tatha*

Sta. No.	Eastings (m)	Northings (m)	Tributary Area (sq. km.)	Rainfall (mm)	Elev (m)
1	484,648	1,615,270	7.66	1765.05	800
2	487,687	1,615,678	5.92	1740.13	400
3	485,896	1,617,126	4.02	1752.45	600
4	485,638	1,615,999	3.52	1741.34	420
5	484,337	1,613,811	3.47	1735.84	340
6	485,248	1,613,382	1.12	1733.95	300
7	484,260	1,611,515	1.21	1727.05	180
8	484,096	1,612,234	0.74	1723.35	120
	NI KHU HU	Subtotal	27.66	1747.17	Ave.
9	484,381	1,613,095	5.87	1757.92	800
10	489,300	1,612,145	4.91	1755.05	700
11	488,490	1,614,107	5.27	1763.72	800
12	490,501	1,613,331	3.51	1734.28	500
13	488,491	1,611,485	3.77	1744.45	600
14	487,366	1,612,442	3.32	1743.81	600
15	485,632	1,611,208	2.11	1712.35	240
	TATHA	Subtotal	28.76	1748.86	Ave.
		Total	56.42	1748.03	Ave.

Potential Evapotranspiration

The potential evapotranspiration was computed from the annual pan evaporation data collected from the climatic stations located at Ni Khu Hu and Tatha . The annual pan evaporation measured at Ni Khu Hu was 1,447.15 mm., while that of Tatha was 1,530.48 mm. As a result of the following equation ,

$$PET = 0.70 * \text{Pan Evaporation}$$

the annual potential evapotranspiration of Ni Khu Hu is 1013.00 mm. and for Tatha is 1071.34 mm.

Soil Type and Land Use

After the land use classification, the resulting land use map (**LANDCOV**) is shown on Fig. 6. From the map, the study area can be described as a forest area mostly covered by

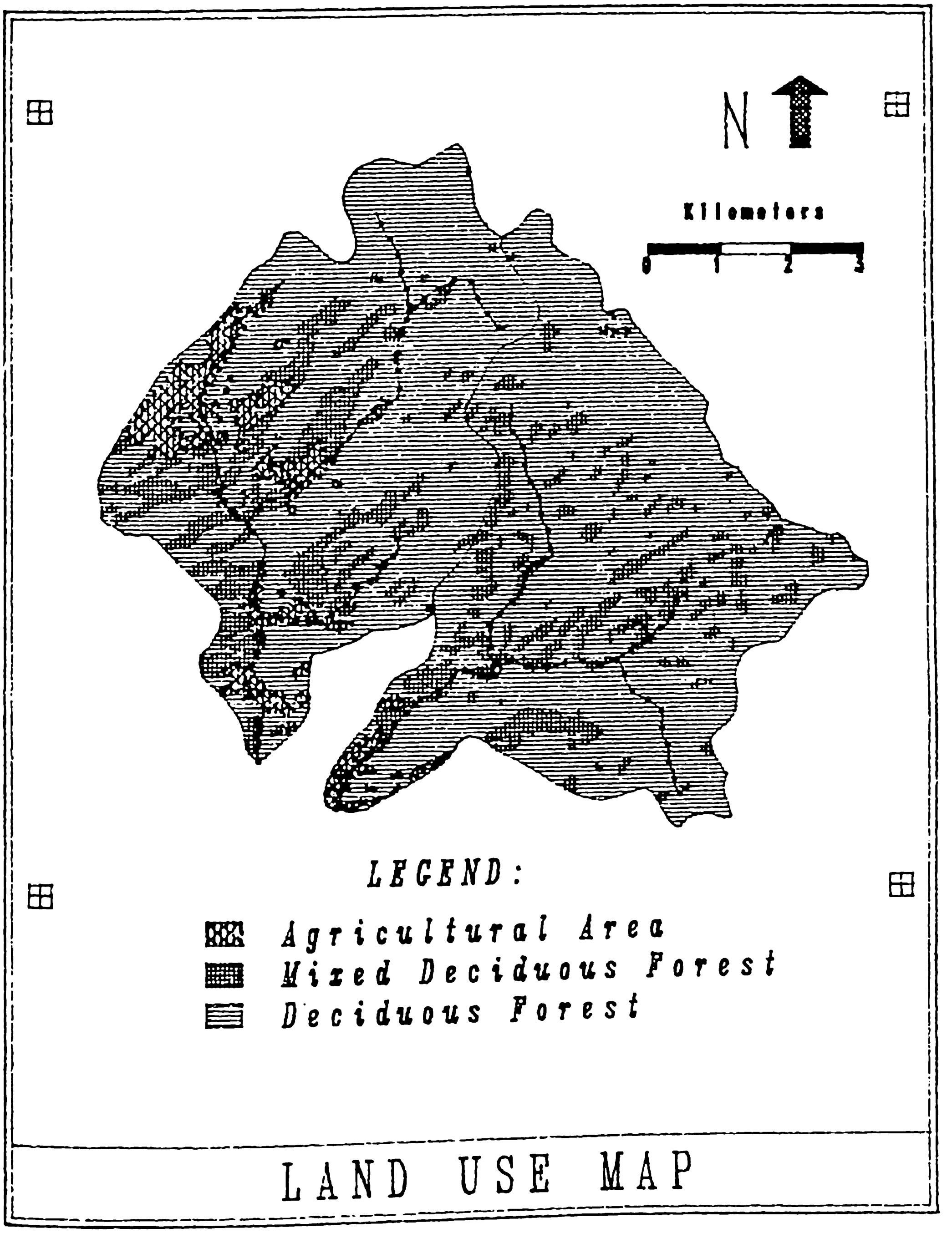


Fig. 6 Land Use Map

deciduous forest. The land use was classified into three (3); agricultural area (class 1), mixed deciduous forest (class 2), and deciduous forest (class 3). Ninety four percent (94%) of the total area is forest, six percent (6%) is used for shifting agriculture, for crops such as rice, cotton, tobacco, ginger, and rubber while fourteen percent (14%) is forest mixed with wild bananas and different varieties of bamboo. The agricultural area is concentrated on the western portion of Ni Khu Hu and near the outlets of the two watersheds. Areas with forest mixed with bananas are located near the river banks because of the needed soil moisture content.

Due to the lack of available information on the soil type in the area from the provided soil map, the different classes; clay (class 1), sandy clay (class 2), and sandy clay loam (class 3), were determined from field observations.

The maximum soil moisture storage S_m for different combinations of vegetation and soil types can be determined. The values of S_m are 75 mm for shallow rooted crops in clay, 400 mm for mature forest in sandy clay, and 300 mm for forest in sandy clay loam. Knowing the water holding capacities of the different soil types, it was assumed that the initial soil moisture storage S_1 for clay is 60 % of its maximum soil moisture storage, 50 % for sandy clay, and 40 % for sandy clay loam.

Actual Evapotranspiration and Final Soil Moisture Storage

With the computed rainfall **P**, maximum soil moisture storage $\mathbf{S_m}$ and initial soil moisture storage $\mathbf{S_1}$, the actual evapotranspiration **AET** and final soil moisture storage $\mathbf{S_2}$ can be computed by applying the following equations :

$$AET = \mathrm{Min}\{ PET, S_1 + P, P + (PET - P) * S_1/S_m \}$$

$$S_2 = \mathrm{Min}\{ S_m, S_1 + (P - AET) * (1 - M) \}$$

$$M = 2 * (S_1/S_m)^2 \quad \text{for } 0 < S_1/S_m \leq 0.5 \text{ and } P > AET$$

$$= 1 - 2 * (S_1/S_m)^2 \quad \text{for } 0.5 < S_1/S_m \leq 1 \text{ and } P > AET$$

$$= 0 \quad \text{for } P \leq AET$$

Excess Moisture

The excess moisture can be computed from the water balance equation and the result is shown on the map on Fig. 7. The map was classified into six (6) groups depending on the excess moisture value. Almost sixty percent (60%) of the available water is lost through evapotranspiration and ten percent (10%) to change in soil moisture content. Only thirty percent (30%) of the rainfall in the watershed contributed to runoff and groundwater recharge.

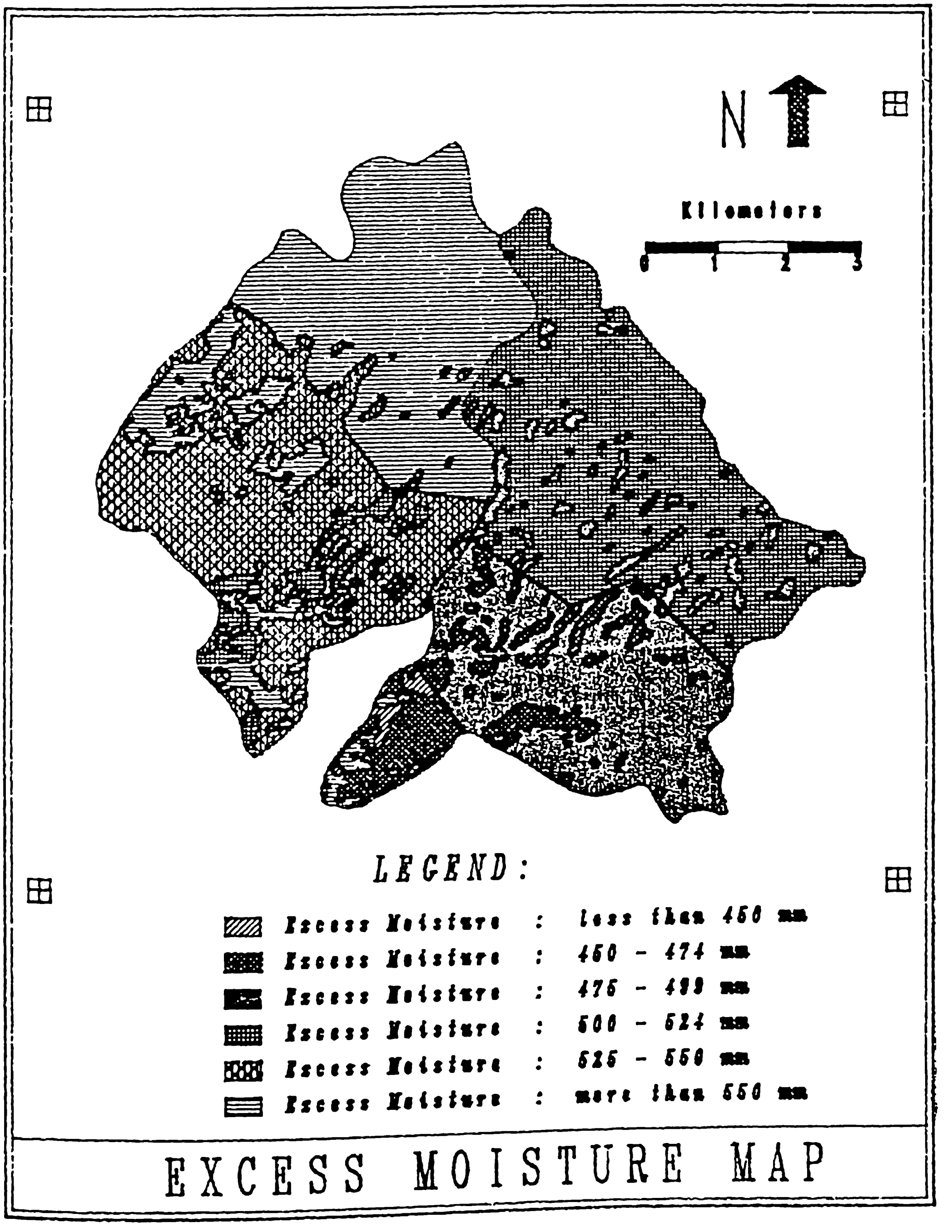


Fig. 7 Excess Rainfall Map

Slope Classes

Four (4) slope classes were formed as shown in the table below. The average slope of the study area is 22 %. Almost sixty percent (60%) of the area is class 2, 27.51 % is class 1, 11.16 % is class 3, and 1.67 % is class 4.

Slope Class	Slope Range	Description
1	0 - 10 %	Flat to Gentle
2	11 - 35 %	Rolling to Moderately Steep
3	36 - 60 %	Steep Slope
4	> 60 %	Very Steep Slope

Streamflow Ratio

The streamflow ratio map RMAP was produced by overlaying the slope class map, land use map, and the soil map. Twelve (12) streamflow ratio classes RCLASS were formed from different classes of slope , land cover, and soil as shown on the following table :

Slope Class	Land Use	Soil Class	RCLASS
1	1	1	1
2	1	1	2
3	1	1	3
4	1	1	4
1	2	2	5
2	2	2	6
3	2	2	7
4	2	2	8
1	3	3	9
2	3	3	10
3	3	3	11
4	3	3	12

Runoff

The streamflow ratio map **RMAP** was overlayed with the excess moisture map **EXMOIST** to produce the runoff map **RUNOFF**. Initial values of streamflow ratio were used for

Table. 2 Streamflow Ratio Values for Model Calibration

SLPCLS	LCOV/ SOILCLS	RCLASS	STREAMFLOW RATIO VALUE							
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	1	1	0.40	0.55	0.62	0.64	0.66	0.65	0.65	0.65
2	1	2	0.50	0.10	0.73	0.72	0.77	0.78	0.78	0.78
3	1	3	0.60	0.75	0.77	0.75	0.79	0.80	0.80	0.80
4	1	4	0.70	0.80	0.80	0.80	0.81	0.81	0.81	0.81
1	2	5	0.45	0.55	0.58	0.59	0.59	0.58	0.58	0.58
2	2	6	0.55	0.60	0.63	0.70	0.72	0.74	0.74	0.74
3	2	7	0.65	0.70	0.74	0.76	0.79	0.80	0.80	0.80
4	2	8	0.75	0.80	0.78	0.80	0.82	0.82	0.82	0.82
1	3	9	0.50	0.45	0.44	0.44	0.44	0.43	0.43	0.42
2	3	10	0.60	0.60	0.59	0.60	0.59	0.61	0.59	0.59
3	3	11	0.70	0.75	0.78	0.82	0.80	0.81	0.80	0.80
4	3	12	0.80	0.90	0.88	0.80	0.88	0.88	0.85	0.85
NI KHU HU										
Measured Runnoff (mm)			365.50	365.50	365.50	365.50	365.50	365.50	365.50	365.50
Runoff from Model (mm)			324.80	337.85	343.74	352.58	352.89	358.89	352.94	351.99
TATHA										
Measured Runnoff (mm)			285.80	285.80	285.80	285.80	285.80	285.80	285.80	285.80
Runoff from Model (mm)			284.74	285.87	285.54	292.35	290.36	295.09	289.47	288.14

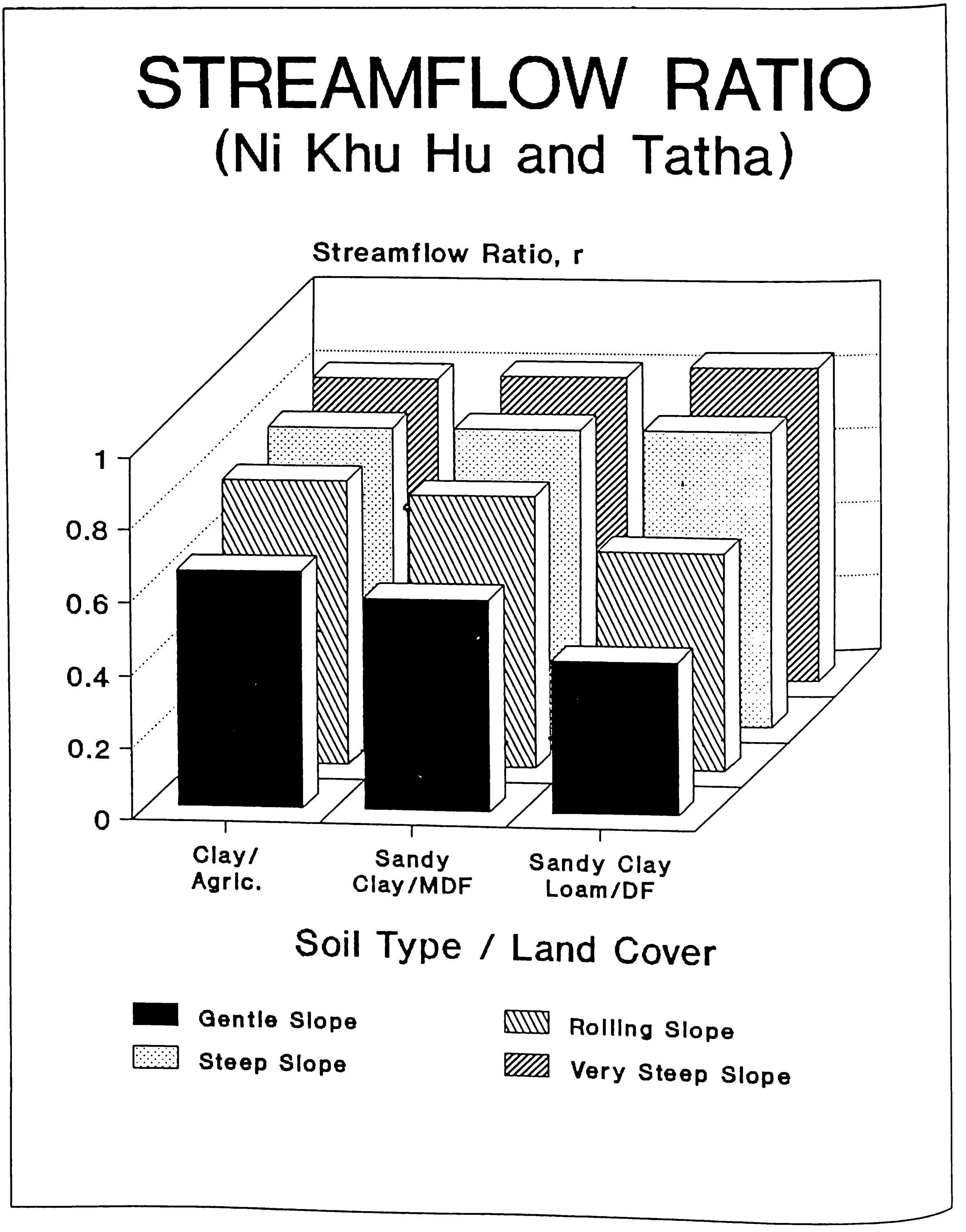


Fig. 8 Final Streamflow Ratio Values

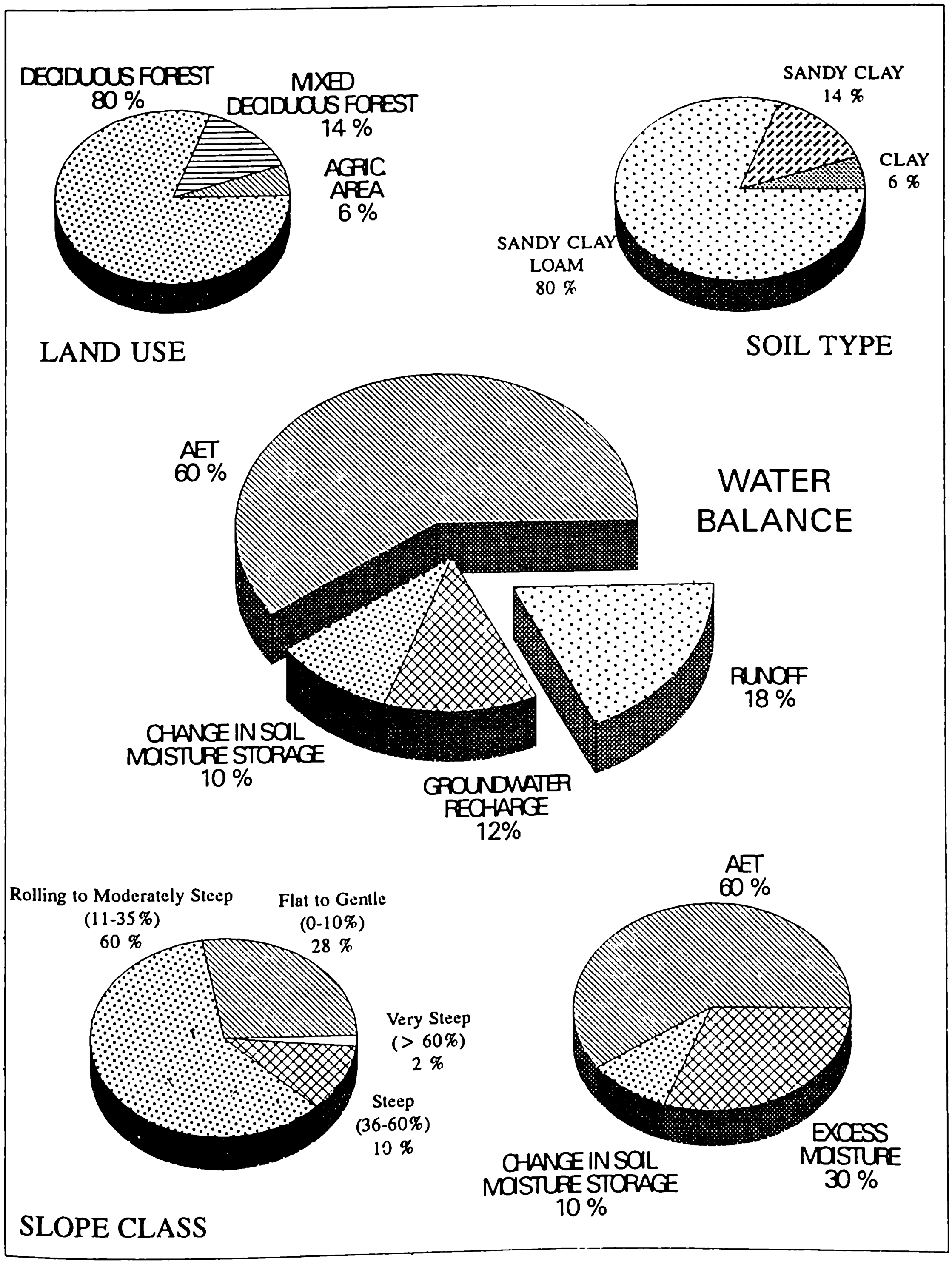


Fig. 9 Water Balance for Ni Khu Hu and Tatha

the first calibration and the streamflow discharge was computed by multiplying the streamflow ratio with the excess moisture value. From the result, the total discharge from the **RUNOFF** map was compared to the streamflow discharges measured at Ni Khu Hu which is 365.5 mm and at Tatha which is 285.8 mm.

Adjustments on the values of the streamflow ratio had to be made for the next calibration runs until the values from the model and the measured quantities were approximately the same. The effect of each ratio class on the total runoff for each watershed was determined before the streamflow values were adjusted. The effects of the classes were computed by getting the contribution of each class on the total runoff in terms of percentages.

A total of eight (8) calibration runs were made. The streamflow ratio for each run are tabulated on Table 2 and the final streamflow ratio values shown on Fig. 8. Analyzing the streamflow ratio graph, it can be seen that for gentle to rolling slopes (classes 1 and 2), the streamflow ratio for clay is the highest and lowest for sandy clay loam. For steep to very steep slopes (classes 3 and 4), the ratio doesn't vary much. This suggests that the ratio is not affected by the type of soil or by land cover for the particular slope range. It can also be seen that for the different soil types and land cover, the ratio increases with slope.

The final water balance for the watersheds is shown on Fig. 9. Runoff accounted for eighteen percent (18%), sixty percent (60%) was lost through evapotranspiration, ten percent (10%) was retained on the soil, and twelve percent (12%) of the rainfall was added to groundwater.

CONCLUSION

The output of the study was a GIS model of the water balance in the Ni Khu Hu and Tatha watersheds. The model will provide additional useful information to researchers of the Mae Klong Watershed Research Station. The study produced a calibrated GIS map of the streamflow ratio needed in determining the discharges at the outlets of the two watersheds.

The study showed that GIS can be integrated with remote sensing for hydrologic and other engineering studies. It showed that the available water in a watershed can be determined at pixel level by applying the water balance equations and RS/GIS. The application of these new techniques provided a facility in solving engineering problems and can be very useful to watershed management.

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