PN-ABQ-123 C7-187

FINAL REPORT

HYDROLOGY OF RAINFED PADDY LAND

A Research Project

Grant No. 936-5544-G-00-7017-00

C7-187

Submitted by

Amnat Apichatvullop

Acting Project Leader

Water Resources and Environment Institute

Faculty of Engineering

Khon Kaen University

REC'D IN R&D/R
JUN 0 1 1995

May 1995

CC:BOSTID

PROJECT PROFILE

Country	: Thailand
Grant No.	: 936-5544-G-00-7017-00
Program	: U.S.-Israel CDR
Project Title	: Hydrology of Rainfed Paddy Land
Project Leader	: Sacha Sethaputra
Acting Project Leader	: Amnat Apichatvullop
Organization	: Water Resources and Environment Institute Faculty of Engineering Khon Kaen University
Collaborators	: Isaac Shainberg and Rami Keren Institute of Soils and Water Agricultural Research Organization The Volcani Center
Project Consultants	: Charat Mongkolsawat Yongyuth Sukwanachaikul
Total Budget	: US $ 150,000
Project Duration	: May 1987 to December 1990

CONTENTS

1. Executive Summary 4

2. Research Objectives 4

    2.1 Overall Objectives 4

    2.2 Specific Objectives 5

3. Methods and Results 5

    3.1 Watershed Survey 5

    3.2 Selection of Watersheds for Study 5

    3.3 Instrumentation and Monitoring of Hydrologic Data 5

    3.4 Soil Moisture Tension 5

    3.5 Infiltration and Soil Loss Study 6

    3.6 Mathemetical Model of Paddy Land Watershed 6

4. Impact, Relevance and Technology Transfer 9

5. Project Activities/Outputs 9

6. Future Work 10

7. References 10

Figures 11

Tables 22

1. Executive Summary

The overall objective of the project was to develop a mathematical model capable of predicting streamflow for watersheds containing predominantly paddy land. Related components in the process of model develop to be studied were infiltration characteristic of the soil and erosion and sedimentation of the watershed.

Six watersheds of varying land use and topography in Northeast Thailand were selected for monitoring rainfall, streamflow and groundwater movement. Four rainy seasons of data were collected, compiled and published (Progress Report Nos. 4, 5, 9 and 10).

Soil samples from runoff-contributing land were collected and shipped to collaborators in Israel for infiltration study. The soils were found to form crust when exposed to rain, preventinginfiltration and causing high runoff and erosion. Mulching was effective in preventing crust formation (Progress Report No. 8). On-site experiments using ring infiltrometers also showed that the infiltration rates drop sharply which suggests that the soils are susceptible to crust formation (Progress Report No. 7). On-site small plot experiments showed that mulching with rice straws was effective in preventing crust formation and reducing runoff and erosion.

A mathematical model was developed to represent the hydrologic processes in paddy land watersheds. The model incorporates the unique characteristics of paddy land with bunds to store water and weirs to divert stream water to irrigate the paddy. The watershed is divided into sub-catchments, one for each weir. Each sub-catchment consists of runoff-contributing land (forest and upland) and paddy land. Paddy land is further divided into command area which receives diverted water from the weir and non-command area which is rain-fed. An approach similar to the Curve Number method was used to determine the runoff and infiltration from runoff-contributing land. The water balance method was used for the paddy land. Four model parameters need to be calibrated. Model inputs include: daily rainfall, daily pan evaporation, land use and soil type, number of weirs and their location and stream dimensions.

The model was used for the Huai Khummum watershed in Khon Kaen province. The data of 1988 rainy season were used to calibrate the four model parameters. The model was then used to predict the streamflow of 1989 rainy season. The prediction agrees well with the observed streamflow. The model can become a useful tool for small watershed management.

2. Research Objectives

2.1 Overall Objectives

The project aims at developing a mathematical model capable of simulating the streamflow for watersheds containing paddy land. The model should take into account the unique characteristics of paddy land and small weirs which divert streamflow as supplementary irrigation for paddy. Such land and water use is practised in the paddy culture countries of Asia. The model for paddy land will be useful in planning and management of water utilization. This project is a component in the overall research framework aiming at large-scale implementation of small diversion weirs for supplementary irrigation of rain-fed paddy land. Figure 1 presents the overall research framework.

The model is to provide answers relevant to many important development issues. These include: How much water is available in a stream as a result

of a certain land use pattern? How much of this water can be used for supplementary irrigation of paddy land? How many diversion weirs should be built for such irrigation? How to minimize soil erosion and sediment depositionat the weirs?

2.2 Specific Objectives

Related specific objectives of the project are:

1) to study the infiltration characteristics of the soils

2) to develop simple measures to reduce soil erosion and deposition at the diversion weirs.

3. Methods and Results

3.1 Watershed Survey

A typical watershed, Huai Yang in Udorn Thani province, was surveyed for land use stream characteristics, water resource facilities, water management practice and social and economic conditions.

It was found that paddy farmers make extensive use of water control stuctures made from earth, timber or concrete to harvest surface water for supplementary irrigation of paddy. Fig. 2 shows the extent of water control structures employed by farmers in Huai Yang watershed.

3.2 Selection of Watersheds for Study

Northeast Thailand was chosen as a target study area due to development priority. The region also contains several types of topograhpy ranging from mountainous areas to alluvial plains. Fig. 3 and table 1 show the location of the selected watershed and the relevant characteristics.

3.3 Instrumentation and Monitoring of Hydrologic Data

The six watersheds were installed with standard and recording rain gages, staff and recording stream gages and groundwater observation wells. Local farmers were hired to attend the instruments and record readings or change recording papers. Monthly site visits by project personnel were made to collect the recordings and pay the attendants. Data were examined, cross-checked wherever possible, compiled and published. Published data include: daily rainfall, rainfall by storm, daily streamgage and rating curve, daily groundwater level. Four rainy seasons of data are available (1987 to 1990) as published in Progress Report Nos. 4, 5, 9 and 10.

3.4 Soil Moisture Tension

Twenty seven soil samples in 9 different soil types from the watersheds were collected using core samplers (undisturbed). The samples were tested to determine moisture tension (water content of soil when subject to different suction pressure) for tension ranging from 1 cm of water to 15 bars.

It was found that most of the soils have relatively low available moisture (3 to 9 % by weight).

3.5 Infiltration and Soil Loss Study

Soil samples representing 5 dominant soils from runoff contributing land in the selected watersheds were collected and shipped to Israel for study. Physical and chemical analyses were carried out. Table 2 summarizes the results. The five soils are sandy in texture with clay content ranging from 1.4 to 3.6 %. Fine sand is the predominant size (73 - 87 %). The cation exchange capacity of the soils range from 1.4 to 5.1 meq/100g and the percent saturation bases 45 - 75 %. Of these, sodium ranges from 1.4 to 10.5 %, potassium 5.5 to 8.6 %. The moderate concentration of exchangeable sodium and potassium causes the soil to be dispersive when exposed to rain.

Soil samples were packed in 30 x 50 cm x 2 cm thick perforated metal trays over 8 cm of coarse sand. The trays were subjected to rain from a rain simulator with instensity of 37 mm/h. Samples of runoff water were taken and electrical conductivity and sediment concentration were measured and soil losses calculated. The volume of runoff was measured during the rain and the infiltration rate calculated.

The effect of rain depth on the infiltration rate of the five soils is presented in Fig. 4 and 5. The infiltration rates drop sharply with rain depth for all five soils which implies that the soils form crust. When impact of the raindrops was reduced by mulching the infiltration rates do not drop as the rain depth increases. This means impact of the raindrops causes fromation of the crust.

Phospho gypsum was spread on the soil to increase electrolyte into the soil solution. It was found that the electrolyte concentration prevents the dispersion of the soil clays and stops crust formation. This is very pronounced in the Slope Complex soils and less pronounced in the other soils.

Infiltration curves of Fig. 4 and 5 were fitted with the Horton's equation:

$$I_t = I_f + (I_i - I_f)\exp(-p\gamma t)$$

where I_t = infiltration rate at time t

I_f = final infiltration rate

I_i = initial infiltration rate

p = rainfall intensity (mm/h)

γ (gamma) = a constant

The parameters for each soil are presented in Table 3.

Soil losses are presented in Fig. 6. Korat soil, being highest in fine sand content, was most erosive at 8.6 ton/ha. for 80 mm rain storm.

3.6 Mathemetical Model of Paddy Land Watershed

The paddy land watershed is schematized as follows. The watershed is divided into sub-catchments, one for each weir at the outflow point. Each sub-catchment is divided into runoff-contrubuting land and paddy land. Runoff-contributing land includes natural forest and upland where farmers grow cash crops such as cassava and kenaf without water control. The paddy land is further divided into command area and non-command area. Command area receives supplementary irrigation diverted by the weir while non-command area is rain-fed paddy land. Fig. 7 shows the schematization of the paddy land watershed.

The hydrologic processes in the model are depicted in Fig. 8. Precipitation and evapotranspiration are the model inputs. Portion of the water on the runoff-contributing land becomes runoff into the non-command paddy land while

another portion becomes infiltration. Water is stored within the paddy bunds and the excess spills into the command paddy land. The commmand paddy land also receives stream water diverted by the weir. Infiltrated water replenishes the soil moisture and flows by gravity to the stream. Water on paddy land is also subject to seepage governed by Darcy's law. These processes are also presented in diagram form as shown in Fig. 9.

An approach similar to that used by the US Soil Conservation Service is employed to calculate the runoff and infiltration from the runoff-contributing land. Thus

$$Q = (P - I_a)^2 / (P - I_a + S) \qquad \text{..... (1)}$$

$$F = (P - I_a) S / (P - I_a + S) \qquad \text{..... (2)}$$

where
- P is cumulative rainfall, mm
- Q cumulative runoff, mm
- F cumulative infiltration, mm
- I_a initial losses, mm
- S storage capacity of the soil mass, mm

Routing of the surface water can be computed using the linear reservoir concept:

$$RHOQ(k) = \{HOQM-RHOQ(k-1)\}/(TQ+1/2) + RHOQ(k-1) \qquad \text{..... (3)}$$

where RHOQ(k) and RHOQ(k-1) are lumped outflows on days k and k-I
HOQM is average local runoff on days k and k-1
TQ is surface waer storage routing time, a model parameter

Soil moisture balance can be expressed as:

$$HSM(k) = HSM(k-1) + FF(k) - ET(k) - SMR(k) \qquad \text{..... (4)}$$

where HSM(k) and HSM(k-1) are soil moisture storage on day k
FF(k) infiltration depth on day k
ET(k) evapotranspiration on day k
SMR(k) outflow from soil moisture storage into stream on day k

The daily infiltration depth is computed from the cumulative infiltration (equation 2). The daily evapotranspiration is estimated from pan evaporation and the soil moisture storage as suggested by Kohler. Flow from soil moisture storage into the stream is computed using the linear reservoir concept:

$$SMR(k) = \{HSMM-SMR(k-1)\}/(TS+1/2) + SMR(k-1) \qquad \text{.....(5)}$$

where SMR(k) and SMR(k-1) are lumped outflows from soil moisture storage on days k and k-1
HSMM average soil moisture storage on days k and k-1
TS soil moisture routing time, a model parameter

Water balance on the paddy land can be written as:

$$WDN(k) = WDN(k-1) + P(k) + DQL(k) - ETR(k) - DQN(k) \qquad \text{..... (6)}$$

$$WDC(k) = WDC(k-1) + P(k) + DQN(k) + DQD(k) - ETR(k) - DQC(k) \qquad \text{.. (7)}$$

where WDN are water depth in noncommand area

DQL local runoff from runoff-contributing land = RHOQ(k).AL/AN

AL , AN areas of runoff-contributing land and noncommand

ETR consumptive use of paddy

DQN excess water from noncommand into command paddy land

WDC water depth in command paddy land

DQC excess water from command paddy land

The consumptive use for paddy is calculated from pan evaporation using the method given by Rinfret [1]. Percolation and seepage through paddy land can be calculated by Darcy's equation. It was found that percolation and seepage were negligible.

The desirable water depth in paddy land is taken at 150 mm. When the depth is less than this, farmers will divert stream water if possible, into the command area. The amount of supplementary irrigation needed is less than that actually diverted due to losses and return flow. A parameter called diversion efficiency, DE, was introduced to account for the difference.

Overflow from each weir depends on the incoming flow, the stream storage capacity and the diversion. If the stored volume after diversion is greater than the capacity the excess will overflow, otherwise there will be no overflow.

The size of the command paddy land is usually not certain depending on topography and control structures. Therefore another parameter is introduced: the percent command area, PCA.

A computer program was written in FORTRAN 77 for the mathematical model. Model inputs consist of daily rainfall, daily pan evaporation, land use and soil type, number of weirs, stream dimensions and the four model parameters.

A typical watershed, Huai Khummum in Khon Kaen province, is used to calibrate and verify the model. Fig. 10 shows the map of the watershed. The data of 1988 rainy season were used to calibrate the model parameters. Fig. 11 shows the calibrated and the observed streamflow. The parameters were:

Surface water routing time, TQ = 4.1

Soil moisture routing time, TS = 286

Percent of command area, PCA = 10 %

Diversion efficiency, DE = 0.95

The model was then used to simulate the streamflow of 1989 rainy season. The predicted flow agrees reasonably well with the observed flow as shown in Fig. 12. The predicted volume of overflow for the 1988 rainy season agrees very well with the observed value (14.458 cf 14.308 million cubic meters).

For the irrigation season (July to October) the monthly diversions are 0.93, 0.64, 0.18, 0.16 % of the streamflow. The total volume of diversion is 2.6 % of the streamflow or about 250 mm of water on the command area of 1.6 sq.km.

The model serves as a useful tool for the planning and management of the watershed. It has provided better understanding of the existing water resource

conditions. Future development issue of increasing the command area can be answered with such model.

4. Impact, Relevance and Technology Transfer

The overall objective of developing a mathematical model to predict streamflow in paddy land watershed was fulfilled. The overall research framework aim of large-scale implementation of weir program was also realized. The Department of Local Administration (DOLA) of the Royal Thai Government took up the weir program and implemented it extensively both in the northeastern and the northern regions. DOLA personnel at the district level were trained to plan and manage surface water in the context of watershed.

The research project also triggered a morphological study and survey of small watersheds in northeast Thailand, the resulting information and conclusion were very useful in water resource planning at the district level.

5. Project Activities/Outputs

Two papers were presented at conferences, namely:

1) Hydrology of Rainfed Paddy Land, presented at His Majesty Fifth Commemorative Conference of USAID Science Award Grantees, 24-26 July 1987, Nakorn Pathom, Thailand.

2) Water for Agriculture in Small Watersheds, presented at Conference on Crop Production in Problem Soils in Northeast Thailand, 23-27 May, 1987, Agricultural Development Research Center, Khon Kaen, Thailand.

A research paper was being submitted for publication in an internation journal: Hydrologic model of small watershed filling with weirs and paddy land, by Wirojanagud, P., A. Apichatvullop, and A. Watana-Udomchai.

Ten progress reports were submitted to USAID.

Seven Masters theses related to the project were produced, three of these received direct funding from the project.

1) Water Balance Study of Weir Dominated Small Watershes in Norhteast Thailand, by Chuchoke Aryupong, Faculty of Engineeing, Khon Kaen University, 1987.

2) Transplant Dates and Water Depth Control for Maximum Yield: A Case Study of Paddy Land in Northeast Thailand, by Manus Chaiprasert, Faculty of Engineeing, Khon Kaen University, 1988.

3) A Hydrologic Network Model for Runoff Prediction in Northeast Thailand, by Chalermchai Pawatana, Faculty of Engineeing, Khon Kaen University, 1988.

4) Sediment Transport: A Test Case of Small Watersheds in Northeast Thailand, by Pratchaya Jittpratchaya, Faculty of Engineeing, Khon Kaen University, 1989.

5) Spatial-Temporal Heterogeneity Based Hydrologic Model, by Vikul Lohamongkol, Faculty of Engineeing, Khon Kaen University, 1990.

6) A Hydrologic Model of Small Watershed in Northeast Thailand, by Adirek Watana-Udomchai, Faculty of Engineeing, Khon Kaen University, 1990.

7) Daily Water Budget in Paddy Land, by Udom Jaiyong, Faculty of Engineeing, Khon Kaen University, 1991.

More theses related to paddy land watersheds are expected to be produced over the next few years.

6. Future Work

The Faculty of Engineering intends to continue with small watershed modeling through its Water Resources and Environment Institute and its graduate program in Water Resources Engineering for several years. It will continue to support the weir program and the water resources planning at the district level now being undertaken nationwide by the Department of Local Administration.

7. References

1. Rinfret, J.R., "Diversion Weir for Small Scale Supplemental Irrigation in Northeast Thailand," Master thesis, Asian Institute of Technology, Bangkok, 1986.

2. Soil Conservation Service, "National Engineering Handbook Section 4, Hydrology," Washington, D.C., U.S. Government Printing Office, 1972.

3. Kohler, M.A., "Meteorological Aspects of Evaporation," Int. Asso. Sci. Hydr. Trans., vol. III, General Assembly, Toronto, 1958, pp. 423-436.

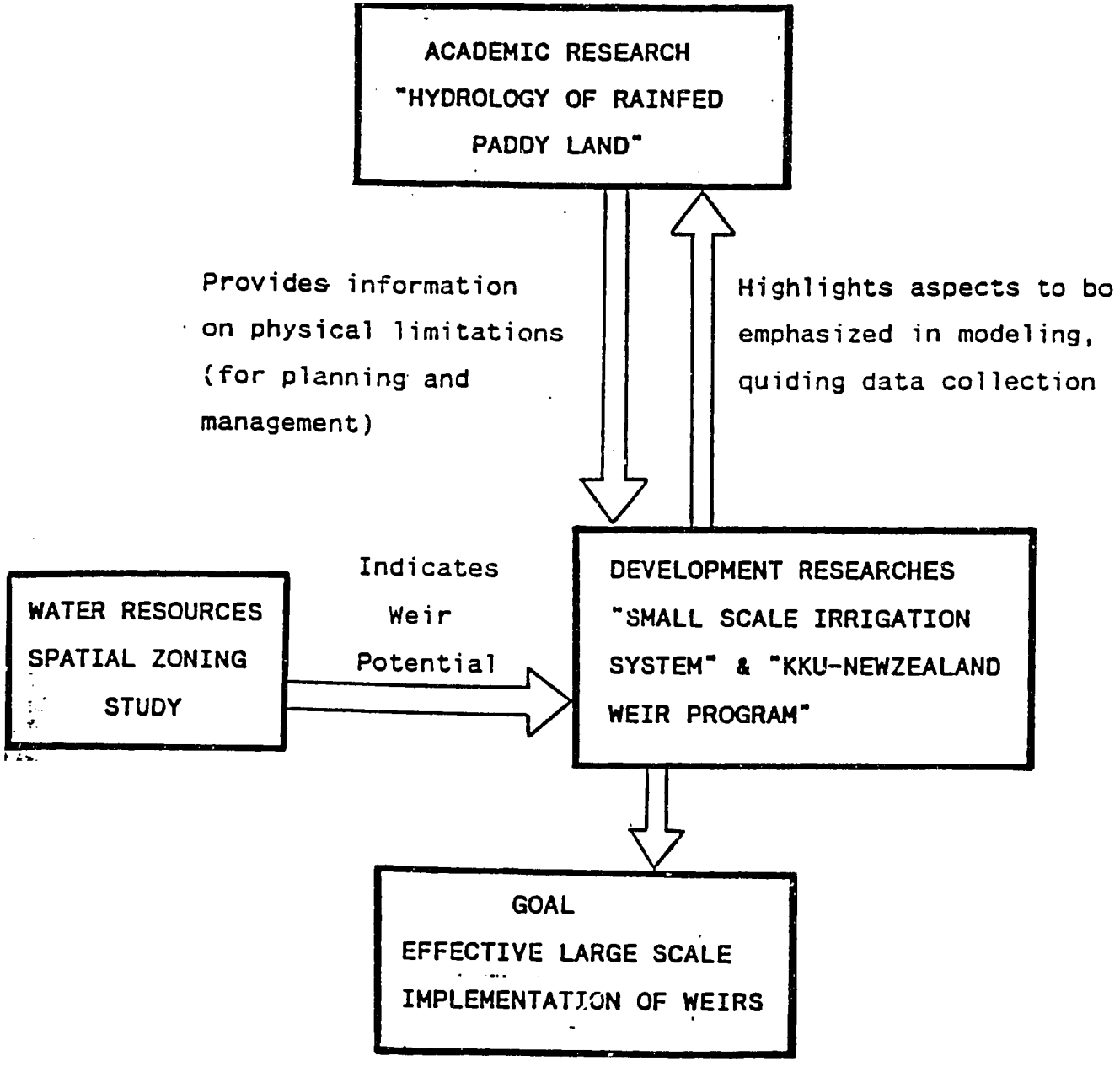


FIGURE 1 - RESEARCH FRAMEWORK FOR AGRICULTURAL WATER

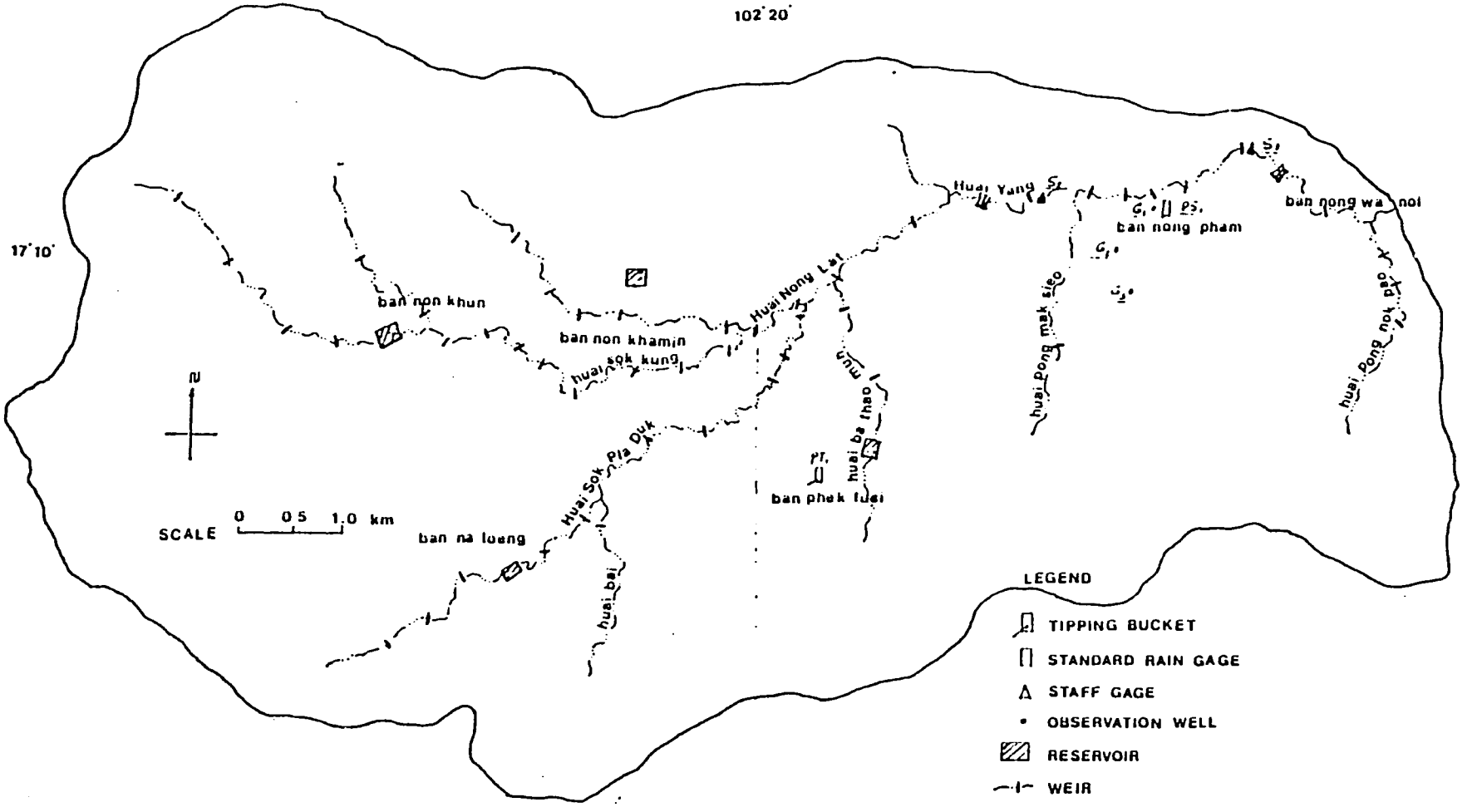


FIGURE 2 HUAI YANG WATERSHED

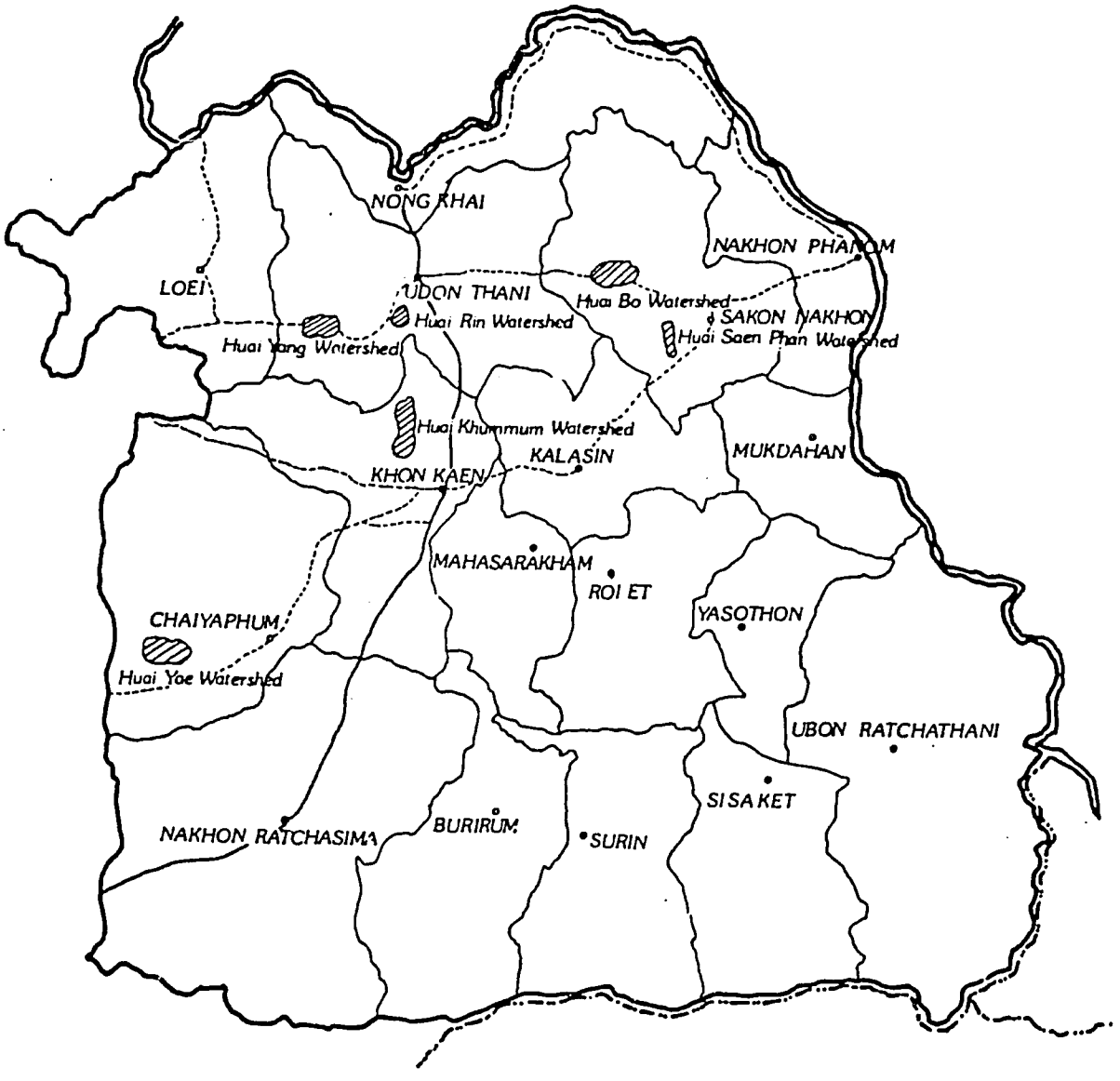
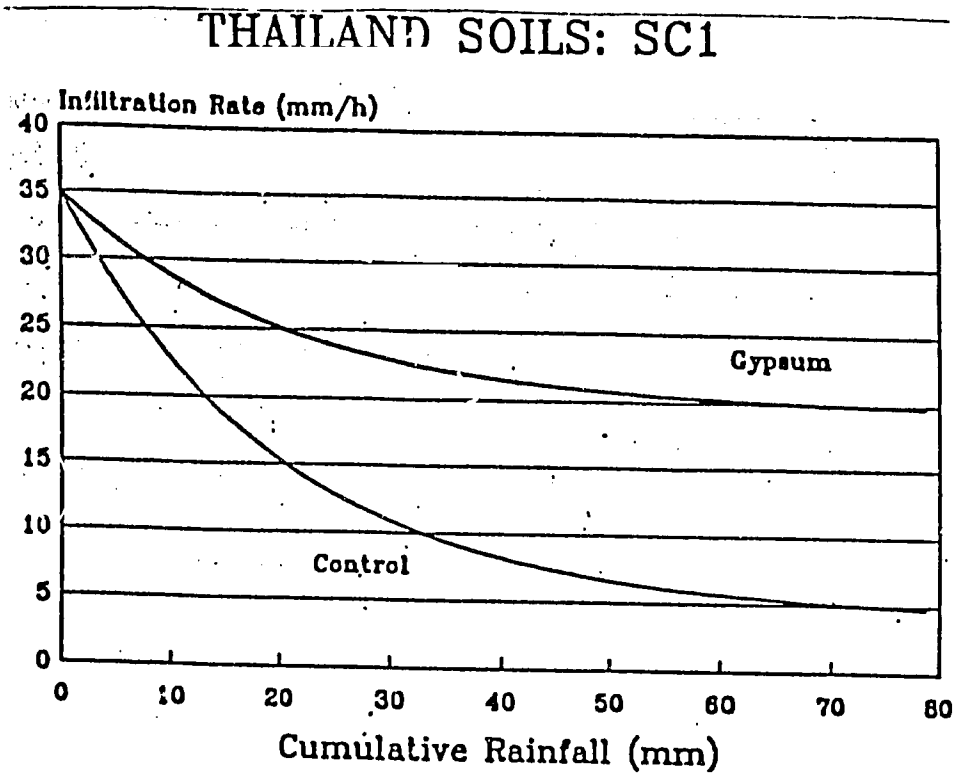


Figure 3 Location of Selected Watersheds



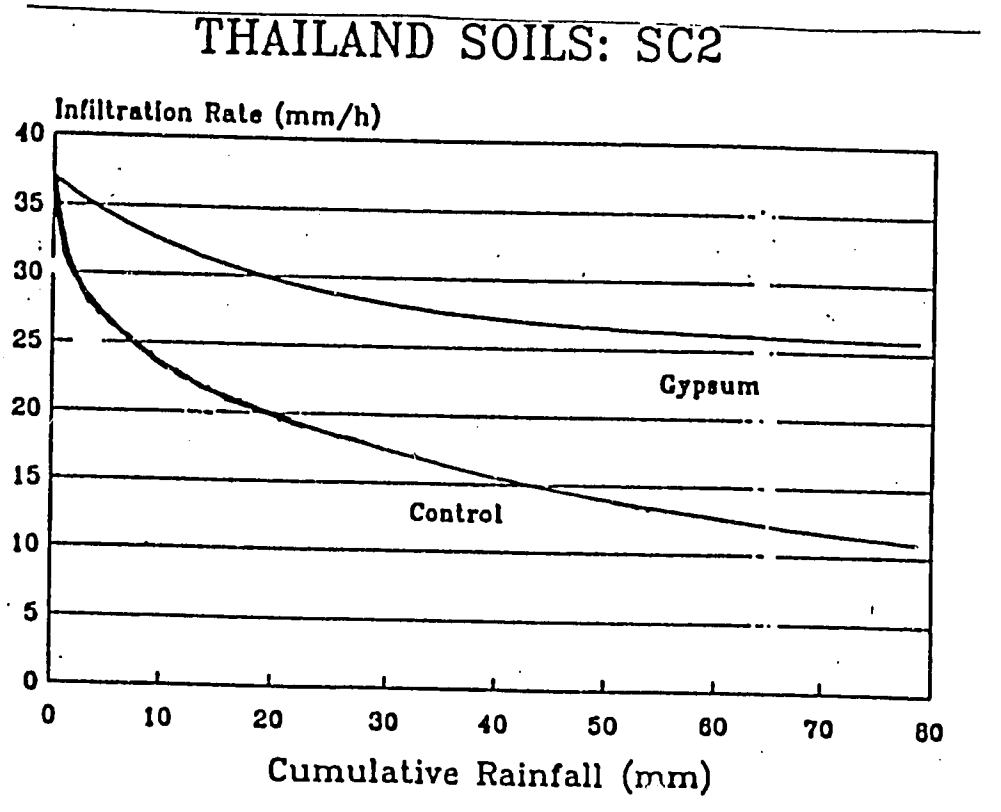
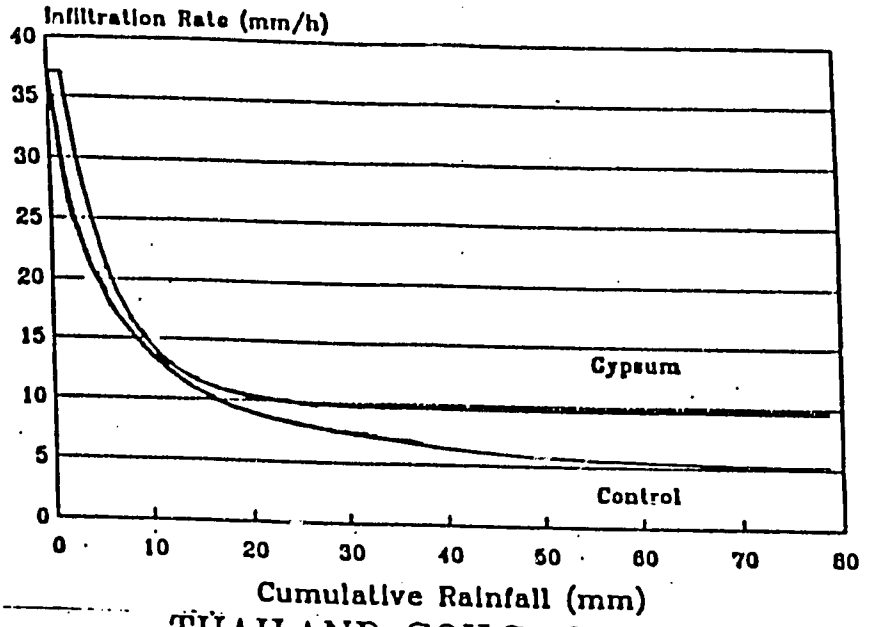
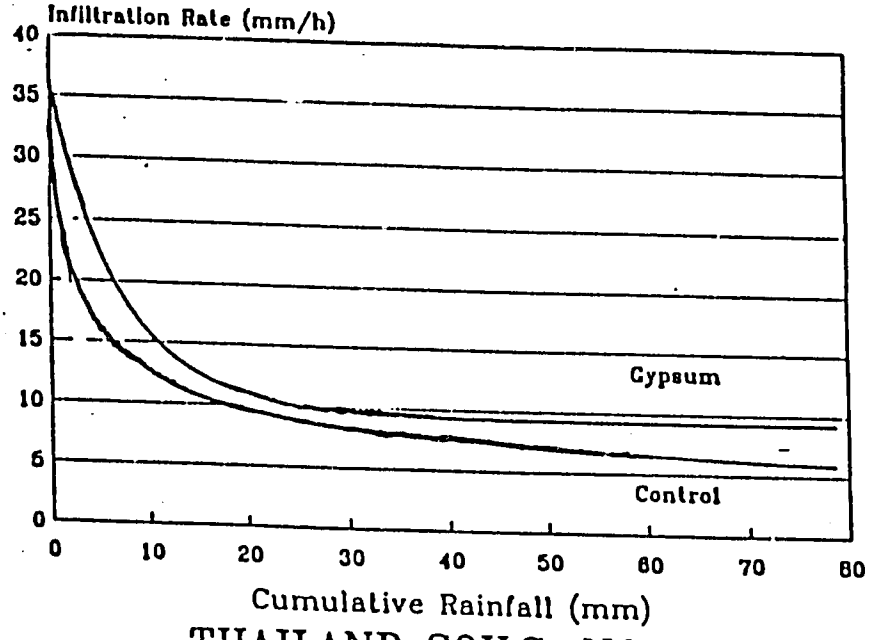


Fig. 4 Effect of cumulative rainfall on the infiltration rate of SC1 and SC2 soils. (Phosphogypsum was applied at the rate of 5 ton.ha^{-1}.)

THAILAND SOILS: KT



THAILAND SOILS: SUK



THAILAND SOILS: NG

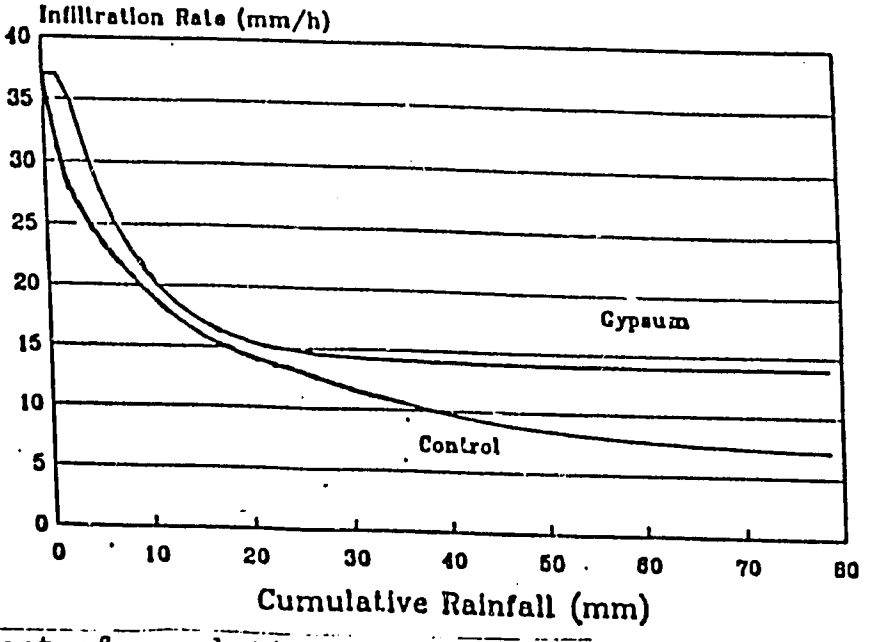


Fig. 5 Effect of cumulative rainfall on the infiltration of three uplan soils. (Phosphogypsum was applied at the rate of 5 ton.ha^{-1}.)

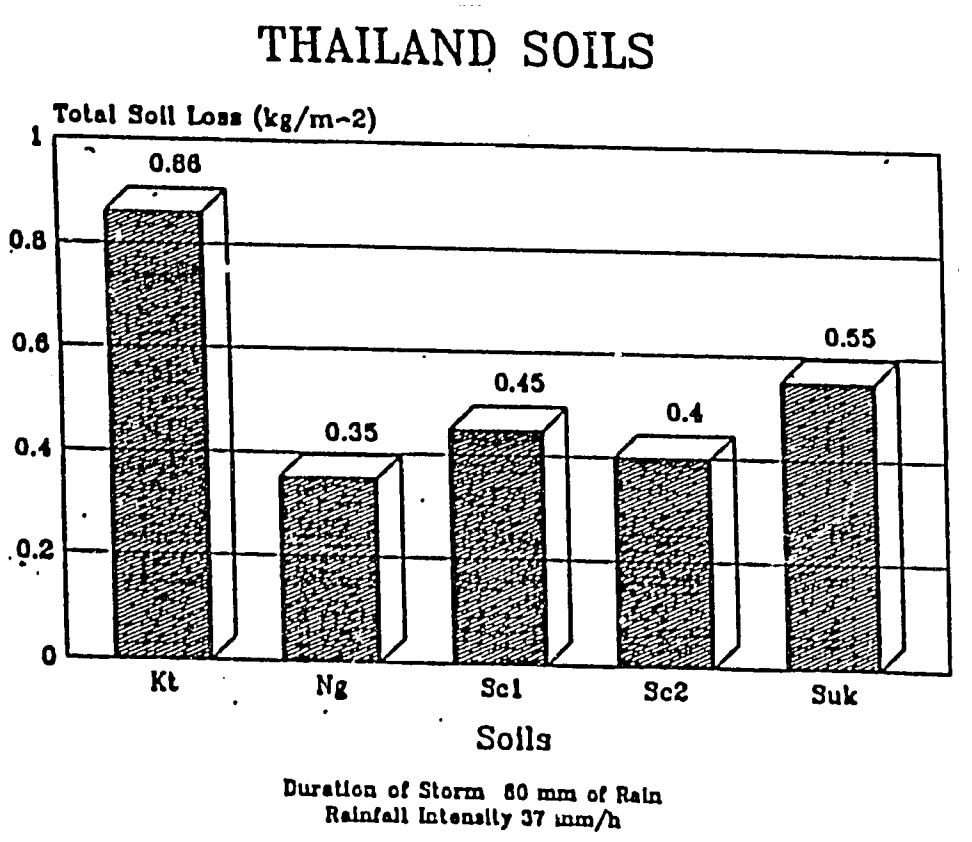


Fig. 6 Soil losses from the five soils from Thailand.

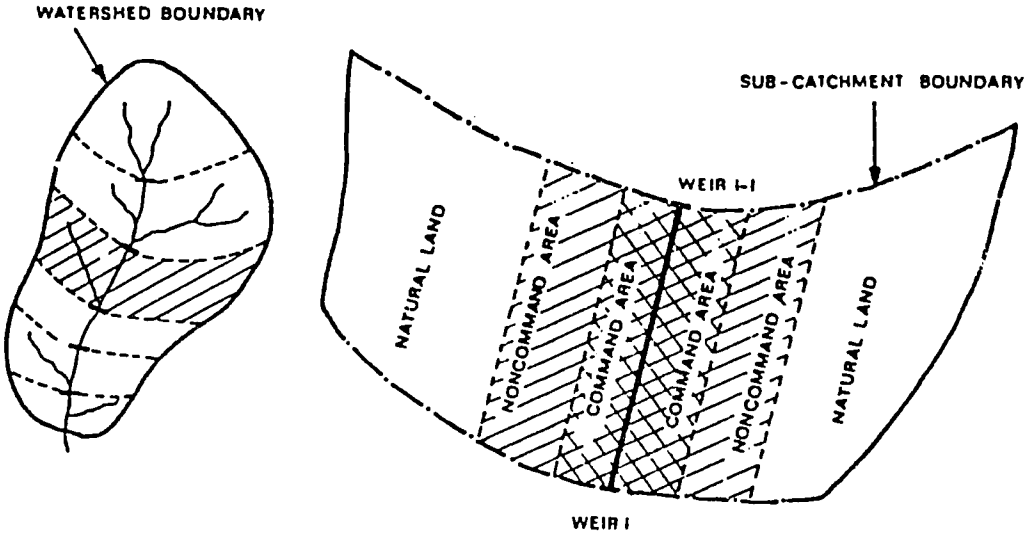


Figure 7 The Model System of Watershed with Weirs and Paddy Land

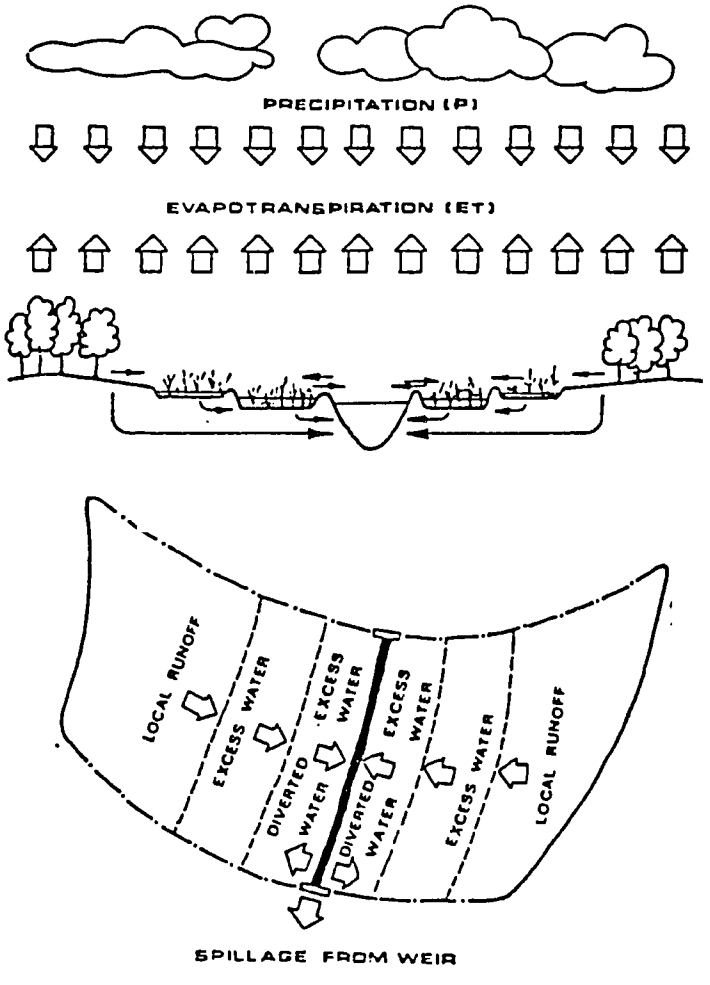


Figure 8 Hydrological Processes of the Watershed System

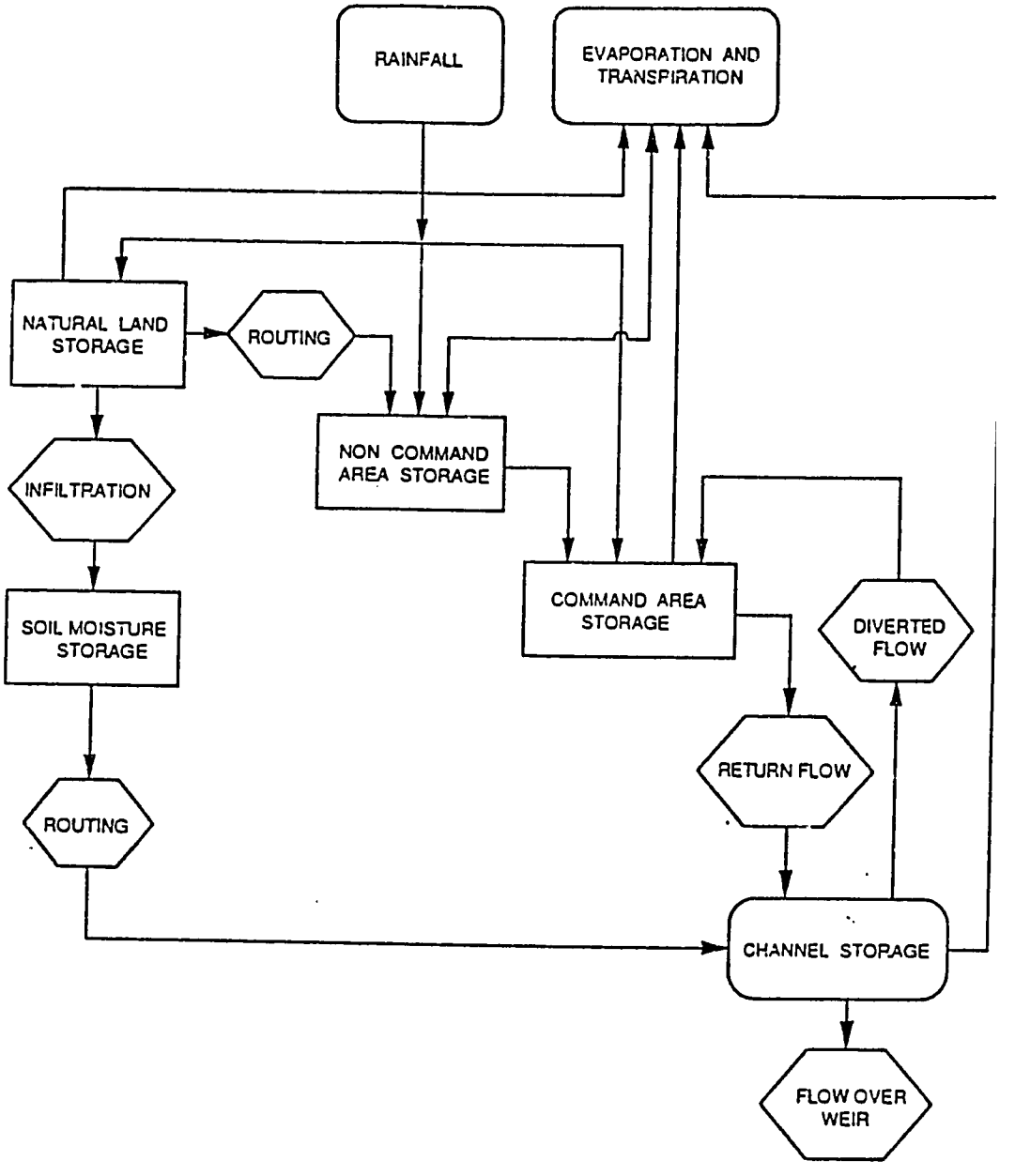


Figure 9 Hydrologic Processes of Small Watershed with Weir and Paddy Land

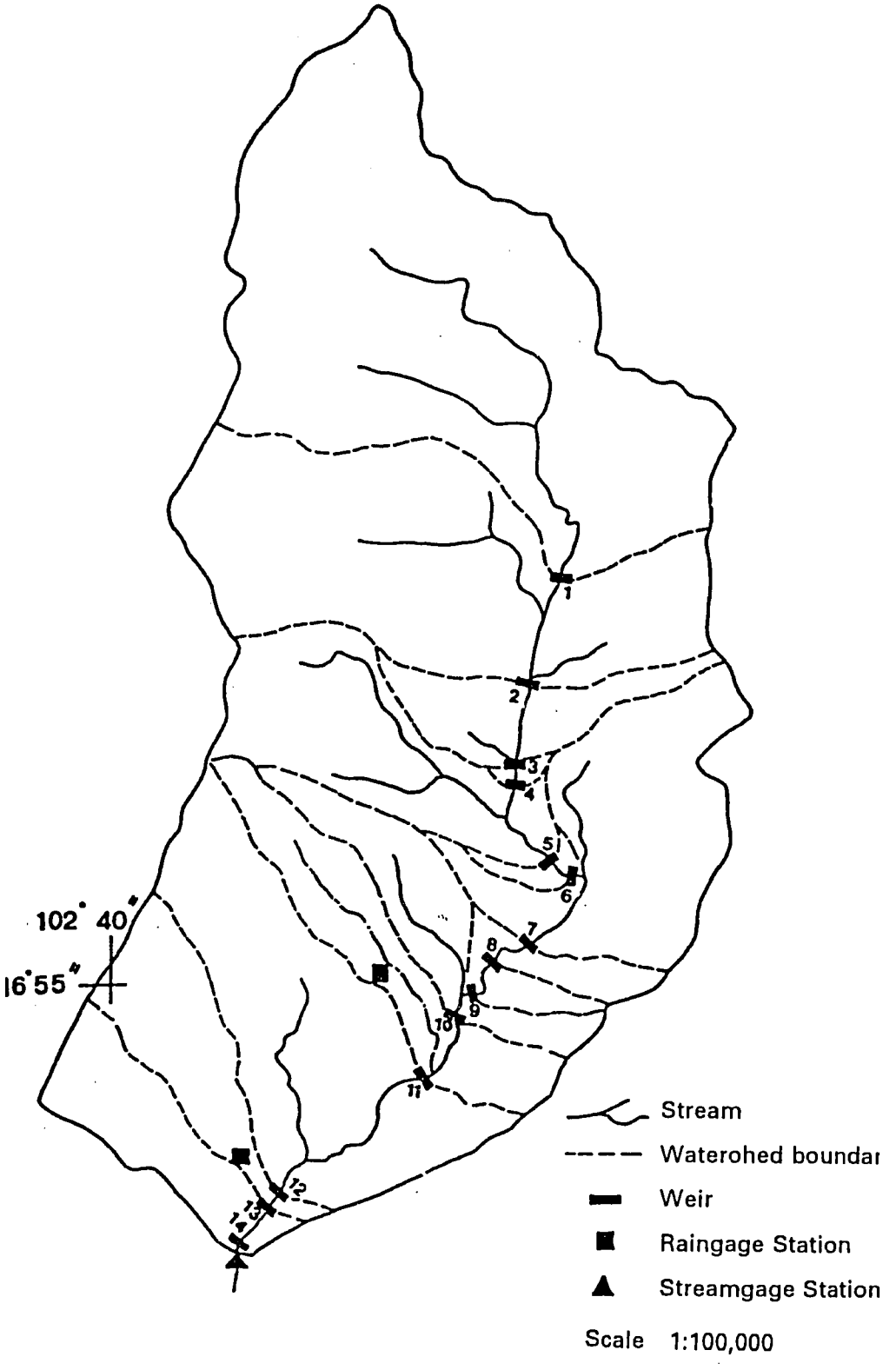


Figure 10 Map of Huai Khummum, Khon Kaen Province

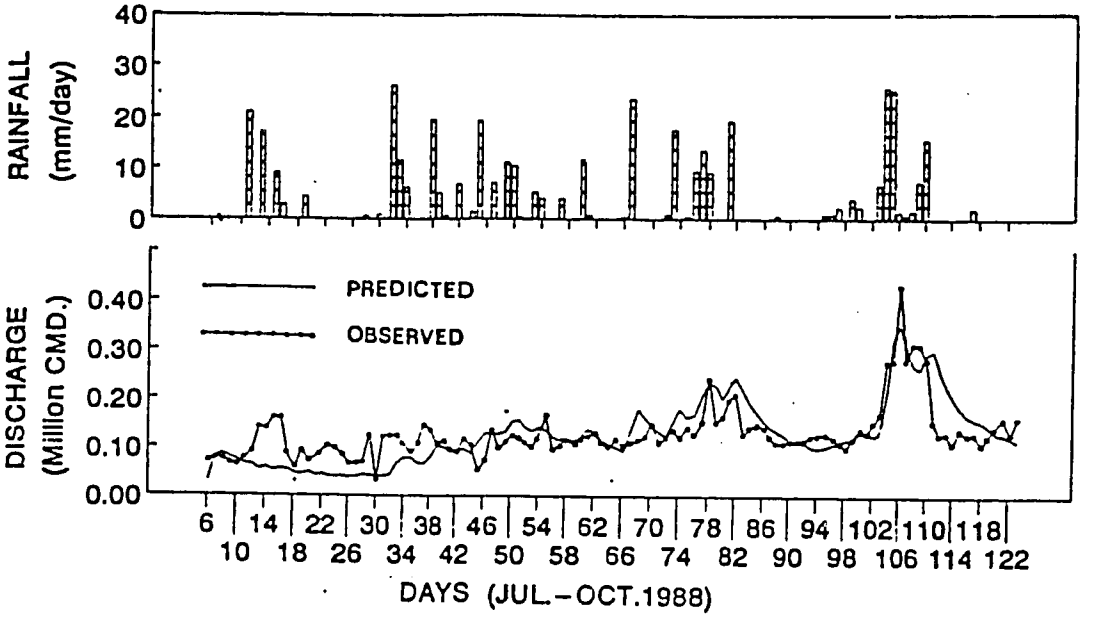


Figure 11 Predicted and Observed Runoff Hydrographs from Simulation of Huay Kum Mum Watershed for 1988

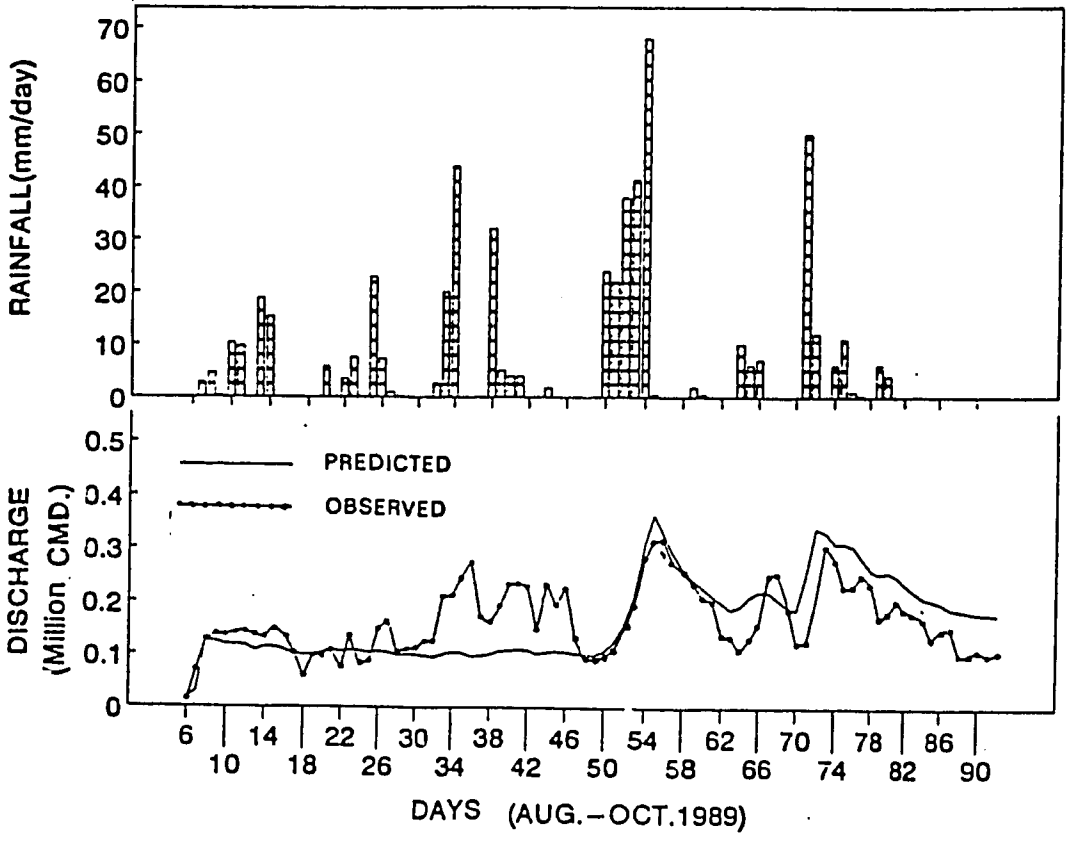


Figure 12 Predicted and Observed Runoff Hydrographs from Simulation of Huay Kum Mum Watershed for 1989

Table 1 Characteristics of Selected Watersheds

No.	Name	Terrain Type	Area (km2)	Length of Main Stream (km)	Slope (%)	Land Use (%)			Dominant Soil Type
						Forest	Upland	Paddy Land	
1	Huai Yae	Foothill	187	25.4	0.24	50	30	20	Slope Complex Soil (SC)
2	Huai Yang	Rolling	75	15	0.14	-	25	75	Korat Series (Kt)
3	Huai Rin	Rolling	40	12	0.96	40	50	10	Sicpe Complex Soil (SC)
4	Huai Khummum	Foothill to Rolling	180	30	0.13	40	40	20	Slope Complex Soil (SC)
5	Huai Bo	Plain	82	15.4	0.026	-	20	80	Korat Series (Kt)
6	Huai Saen Phan	Foothill	40	11.5	0.38	-	30	70	Korat Series (Kt)

Table 2 : Some physical and chemical properties of Thailand soils.

SOIL	Texture %				CEC meq/ 100g	Bases meq/ 100g	% satur- ation	cation/Na+Ca+Mg+K				1:5 extract	
	clay	silt	sand	fine sand				ESP	EPP	EMgP	ECaP	EC ds/m	pH
								%					
1 Kt	1.4	1.78	9.9	86.9	1.4	0.91	64.7	4.7	7.41	42.3	45.5	0.015	5.9
2 Ng					1.84	0.64	47.9	10.5	9.4	34.4	46.0	0.025	5.23
3 Sc1	1.4	3.5	21.88	43.22	2.1	0.95	45.2	4.5	5.5	34.2	55.8	0.012	5.41
4 Sc2					5.12	3.848	75.1	1.4	5.0	37.3	66.3	0.026	6.2
5 Suk	3.6	4.86	7.64	83.9	1.62	1.087	67.1	3.9	8.6	45.9	41.4	0.011	5.68

Note : Local Soil Series

Kt = Korat
Ng = Nam Phong
Sc1 = Slope Complex 1
Sc2 = Slope Complex 2
Suk = Satuk

Table 3 : Parameter for Hortonian-type infiltration curves.

Soil	Parameter	Kt	Ng	Sc1	Sc2	Suk
Untreated Soil	If	5.1	6.7	4.2	7.0	4.9
	Ii	25.0	29.0	35.0	26.0	15.0
	Gamma	0.07	0.05	0.05	0.02	0.03
PG treatment	If	9.7	14.0	19.5	25.6	9.3
	Ii	45.0	45.0	35.0	37.0	36.0
	Gamma	0.20	0.15	0.05	0.05	0.14

If Final Infiltration Rate
Ii "Initial Infiltration Rate"
PG Phosphogypsum applied at the rate of 5 t/ha

INFILTRATION DATA

Soil		Kt	Ng	Sc1	Sc2	Suk
Untreated Soil	Ts (mins)	0.0	0.0	0.0	0.0	0.0
	CI (mm)	19.0	26.7	25.4	36.2	19.2
	CI (%)	23.7	33.4	31.7	45.2	24.0
	% Runoff	76.3	66.6	68.3	54.8	76.0
PG treatment	Ts (mins)	3.2	3.7	0.0	0.0	0.0
	CI (mm)	26.1	36.4	51.3	62.8	25.7
	CI (%)	32.6	45.5	64.1	78.5	32.1
	% Runoff	67.4	54.5	35.9	21.5	67.9

Ts Time to ponding
CI Cumulative Infiltration after 80 mm of rainfall