HYDROLOGIC MODEL OF SMALL WATERSHED FILLING WITH WEIRS AND PADDY LAND

by

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ABSTRACT

A mathematical model was developed to represent the hydrologic system of a small watershed in rural areas of Thailand typically filling with weirs and paddy land. Emphases were made in modelling on the unique characteristics of land use as paddy land with supplementary irrigation from diversion weirs built along the streams and also on the use of commonly available input data.

A watershed is divided into smaller catchment areas, one foreach weir. Each catchment area consists of natural land and paddy land. The paddy area is further divided into command area receiving diverted water from weir and noncommand area which is rainfed. The Curve Number method is used to determine the runoff from the natural land. The Water Balance method is used for the paddy area. There are four model parameters that can be optimize dusing observed rainfall-runoff data for the best of representation of watershed characteristics. The model inputs are : daily rainfall, daily pan evaporation, areas of different land uses andsoil types, number of weirs, depth-width-length-slope of stream at each weir, and other watershed characteristic parameters. The model output is runoff hydrograph at the watershed outlet and other interested quantities.

Sensitivity analysis indicated that the runoff hydrograph was most sensitive to the surface and subsurface water routing times. The model was used to simulate the hydrologic system of asmall watershed of 143 square kilometers in Northeast Thailand. The best estimates of model parameters for the watershed were obtained and then used in the prediction of runoff hydrograph in1989. The predicted runoff hydrographs agree well with the observed data with the exception that the predicted runoff are lower than the observed values during the early rice growing period. Nevertheless, the model serves as a useful tool for small watershed management.

บทคัดย่อ

แบบจำลองอุทกวิทยาที่สร้างขึ้น เป็นแบบจำลองทางคณิตศาสตร์ของลุ่มน้ำขนาดเล็กของพื้นที่ชนบทในประเทศไทย ซึ่งส่วนใหญ่ประกอบด้วยฝายและพื้นที่นา การสร้างแบบจำลองได้เน้นลักษณะพิเศษของพื้นที่นาที่มีการผันน้ำจากฝายที่สร้างตามแนวลำน้ำ และเน้นการใช้ข้อมูลที่มีอยู่โดยทั่วไป

พื้นที่ลุ่มน้ำแบ่งย่อยออกเป็นพื้นที่รับน้ำของฝายแต่ละตัว ภายในพื้นที่รับน้ำย่อยแบ่งออกเป็นพื้นที่ตามธรรมชาติและพื้นที่นา ซึ่งแบ่งย่อยออกเป็นพื้นที่นาที่ได้รับน้ำผันจากฝายและพื้นที่นาส่วนที่อาศัยน้ำฝนอย่างเดียว การไหลออกจากพื้นที่รับน้ำธรรมชาติหาได้โดยวิธีของ SCS ส่วนการไหลออกจากพื้นที่นาคำนวณจากสมการงบดุลน้ำ แบบจำลองสามารถจำลองขบวนการอุทกวิทยาของน้ำผิวดิน น้ำใต้ผิวดินและในลำน้ำ เพื่อให้แบบจำลองขบวนการอุทกวิทยาของน้ำผิวดิน น้ำใต้ผิวดิน และในลำน้ำ เพื่อให้แบบจำลองสามารถจำลองสภาพลุ่มน้ำได้ใกล้เคียงความเป็นจริงมากที่สุดจึงกำหนดให้มีพารามิเตอร์ 4 ตัว ซึ่งเป็นคุณสมบัติเฉลี่ยของระบบลุ่มน้ำที่สามารถปรับเทียบหาค่าที่ดีที่สุดโดยใช้ข้อมูลน้ำฝนและค่าการไหลออกจากลุ่มน้ำที่บันทึกไว้ ข้อมูลที่ใช้สำหรับแบบจำลองได้แก่ ฝนรายวัน การระเหยจากถาดรายวัน จำนวนฝาย ความกว้าง-ลึก-ยาว-ความลาดชันของลำน้ำที่ฝายแต่ละตัวลักษณะพื้นที่และชนิดดินของพื้นที่รับน้ำย่อยสำหรับฝายแต่ละตัว และค่าเริ่มแรกของพารามิเตอร์ของแบบจำลอง ผลที่ออกจากแบบจำลองคือชลภาพของการไหลผ่านฝายแต่ละตัว

ผลการศึกษาความไวของแบบจำลองต่อการเปลี่ยนแปลงค่าพารามิเตอร์พบว่า ชลภาพของการไหลออกมีความไวต่อค่าเวลาของการไหลหลากของน้ำผิวดินและน้ำใต้ผิวดินมากที่สุด จากการเลียนสภาพระบบลุ่มน้ำห้วยคุมมุมในจังหวัดขอนแก่น ซึ่งมีขนาดพื้นที่รับน้ำ 143 ตารางกิโลเมตร โดยใช้ข้อมูลน้ำฝนและน้ำท่าที่บันทึกในช่วงเดือนกรกฎาคม ถึงเดือนตุลาคม 2531 ในการปรับเทียบหาค่าพารามิเตอร์ที่ดีที่สุดสำหรับแบบจำลอง ซึ่งใช้เป็นค่าคุณสมบัติของลุ่มน้ำในการทำนายชลภาพน้ำท่าในช่วงเดือนสิงหาคมถึงตุลาคมของปี 2532 ผลการทำนายให้ค่าชลภาพน้ำท่าใกล้เคียงกับค่าที่วัดได้ทั้งสองกรณี ยกเว้นในต้นฤดูฝนช่วงที่เริ่มปลูกข้าวที่ค่าทำนายมักจะต่ำกว่าที่วัดได้ แต่ถึงอย่างไรก็ตามแบบจำลองระบบลุ่มน้ำที่พัฒนาขึ้น นับว่าเป็นเครื่องมือที่มีประโยชน์อย่างมากเพื่อการวางแผนพัฒนาและการจัดการลุ่มน้ำ

THE MODEL WATERSHED SYSTEM

The watershed system to be modelled in this study is a smallrural watershed typically consisting of paddy land and diversion weirs. Figure 1 illustrates such a watershed system consisting ofweirs built along the streams to divert runoff water into the paddy land on both sides of the streams. The whole watershed is divided into sub-catchment areas of each weir which can be classified into paddy land and natural land. The natural land is further classified into forest, agricultural land, residential area, and water surface. The paddy is divided into command area being able to receive diverted water from weir and noncommand area of typical rainfed paddy land.

The hydrologic processes of the system is illustrated inFigure 2. Precipitation is system input. Within a sub-catchment area of each weir, excess rainfall from the naturalland flows as local runoff into the noncommand paddy area. Some water is stored within paddy bunds during the rice growing season at an average depth of about 150 mm. Water spilled from the noncommand area will flow into the command paddy land in which the same depth of water is stored during the rice growing season. If the daily water depth in the command area is less than the desirable depth (150 mm.), parts of the inflow from the noncommand area will be stored while the excess flows into the stream.

During the period when there is no rainfall input or when th water depth in the command paddy area is less than the desirable depth, stream water will be diverted by the weir intothe command area. If the water volume left in the stream exceeds themaximum storage capacity after diverting into the commandarea, the excess water becomes spillage over the weir or otherwise there will be no spillage.

Infiltration water from the natura land replenishes the soil moisture and flows by gravity to the stream at a rate dependingon the underground characteristics of the watershed. Flow ofpercolating water from the paddy land takes place in two forms : seepages from the noncommand area to the command area and fromthe command area to the stream. The seepage rate is governed by Darcy's law. Evapotranspiration from the natural land, consumptive use of rice from the paddy land, and evaporation from the watersurface are considered major losses from the watershed system.

HYDROLOGIC PROCESSES AND THE MATHEMATICAL MODELS

Rinfret (1986) developed a model of catchment area of asmall diversion weir in order to study the amount of water that can be diverted from a weir and the depth of storage water in the command paddy area [1,2]. Given the number of days rice can withstand the inadequate water conditions, the appropriate ratio of catchment to command area (c/c ratio) can be estimated using the model. Aryupong (1988) developed a watershed simulation model using the SCS concept for the natural land and the water balance concept for the paddy land. Appropriate number an location of weirs in a watershed can be determined [3]. The basic concepts used in these two models are applied with some modifications for better representation of the real system in this study.

The hydrologic processes within the watershed system and then mathematical models describing the processes are presented as follows. All the quantity give are depths of water which when multiplied by the areas will be the volume of water stored orflow in one day.

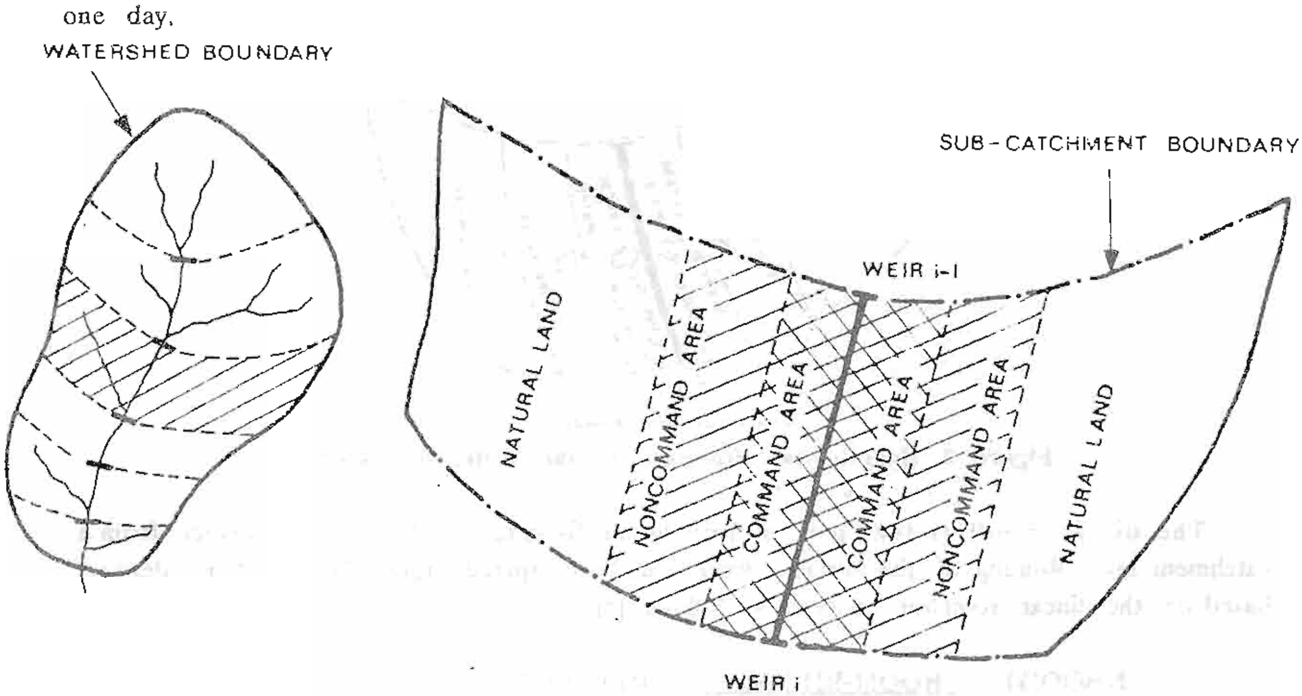

Figure 1 The Model System of Watershed with Weirs and Paddy Land

Natural Land

The natural land is runoff producing land which can be one of the following : forest and range land, agricultural land, residential area, and water surface. The SCS method is applied for the estimation of direct runoff and infiltration from the natural land catchment as follows [4].

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

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

where P is cumulative rainfall, mm.
Q is cumulative direct runoff, mm.
F is cumulative infiltration, mm.
I_a is initial losses, mm.
S is potential maximum retention of the soil mass, mm.

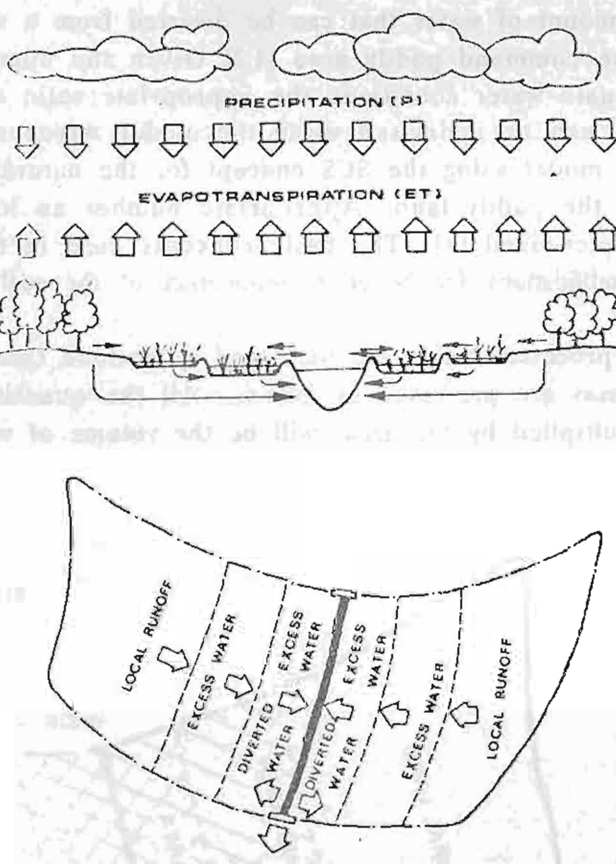

Figure 2 Hydrological Processes of the Watershed System

The direct runoff is that part of rain water flowing on the ground surface from a catchment area. Routing of the surface water can be computed from the equation derived based on the linear reservoir concept as follows [5]

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

Where

RHOQ(k) and RHOQ(k-1) are lumped outflows from the surface water storage of the natural land into the noncommand area in days k and k-1, mm.

HOQM is average local runoff in days k and k-1, mm.

TQ surface water storage routing time , a model parameter to be calibrated, day

The infiltration water will replenish the underground soil moisture storage which can be represented by a mathematical expression as

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

Where HSM(k) is soil moisture storoge level in day k, mm.

HSM(k-1) soil moisture storoge level in day k-1, mm.

FF(k) infiltation depth in day k, mm

ET(k) evapotranspiration in day ,kmm.

SMR(k) outflow from the soil moisture storage into the stream in day k, mm.

The daily infiltration depth is computed from the cumulative infiltration of the SCS method (Eq.2). The daily evapotranspiration depth is estimated from the pan evaporation data and the potential maximum retention value(S) as suggested by Kohler [6]. Flow of water from the soil moisture storage intothe stream in each day is given based on the linear reservoir concept as [5]

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

where SMR(k) and SMR(k-1) are lumped outflows the soil moisture storage into the stream in days k and k-1, mm.

HSMM is average soil moisture storage in day k, and k-1, mm.

TS soil moisture routing time, a model parameter to be calibrated, day.

Paddy Land

From the law of conservation of mass, the water balanceequations for the noncommand and command paddy land are given as

$$WDN(k) = WDN(k-1) + P(k) + DQL(k) - ETr(k) - DQN(k) \qquad ....(6)$$

and

$$WDC(k) = WDC(k-1) + P(k) + DQN(k) + DQD(k) - ETr(k) - DQC(k) \qquad ....(7)$$

where

WDN(k) and WDN(k-1) are water depth in the noncommand area in days k and k-1, mm.

DQL(k) is local runoff from natural land into the noncommand area in day k and k-1, mm.

DQN(k) excess water overflowing from the noncommand area onto the command area, mm

WDC(k) and WDC(k-1) are water depth in the command area in days k and k-1, mm

DQC(k) excess water overflowing from the command area to the stream, mm.

AL natural land area, sq.km.

AN noncommand paddy area, sq.km.

The evapotranspiration from rice paddy is calculated from the daily pan evaporation data using the method given by Rinfret[1]. Percolation and seepage loss through the paddy ground can becalculated using Darcy's law. Preliminary model investigation indicated that the seepage loss to the stream does not have any effect on the runoff hydrograph. From the sensitivity analysis, atenfolds increase of the seepage loss coefficient of the model did not make any change on the computed runoff hydrograph. The process of percolation and seepage loss from the paddy area is therefore neglected [7].

Stream Flow and Storage

The desirable water depth in the rice paddy is taken as 150 mm. If the water depth in the command area is less than the desirable depth, the stream water will be diverted into the command area of the amount depending on the availibity of stream water and the shortage of water in the command area. The amount of supplementary water needed in the command area is actuallyless than the amount of water diverted from the stream because of losses and return flow. A parameter called "Diversion Efficiency, DE was introduced to account for the difference.

Spillage of water over each weir depends on the incoming flow, the stream storage volume, and the diversion flow. If the stored volume in the stream is greater than the maximum storage capacity after the diversion, the excess water will be spilled over the weir. Otherwise there will be no spillage.

Computer Simulation Model

The hydrologic processes of the model watershed system is summarized in Figure 3. A computer program "HYMOST" was written in FORTRAN 77 for use in the watershed hydrologic simulation. The computer inputs consist of the hydrological data and watershed characteristics such as: daily rainfall, daily pan evaporation, areas of different land uses and soil types, number of weirs, depth-width-length-slope of stream at each weir, and other watershed characteristic parameters. The computer outputs is the runoff hydrograph at the watershed outlet and other interested quantities [7].

For the best representation of the watershed hydrologic characteristics, 4 parameters can be calibrated using recorded rainfall-runoff data. They are:

1. Soil moisture storage routing time (TS)
2. Surface water routing time (TQ)
3. Percentage of command area (PCA)
4. Diversion efficiency (DE)

The percentage of command area, PCA, is the ration of thecommand area to total paddy land area. The parameter is introduced because the actual size of paddy land that can be supplied with diverted stream water is usually not certainly known. The parameter DE is also introduced because the actual amount of water diverted in practice by the farmer can never be assessed.

STUDY OF SMALL WATERSHED HYDROLOGY

Simulated Watershed

The study watershed is Huay Kum Mum in Khon Kaen Province, Thailand, with a catchment area of 143 sq.km of which about 16 sq.km is paddy land and the rest is mainly forest. The watershed was divided into 14 sub-catchment for each of the 14 weirs in the watershed as shown in Figure 4.

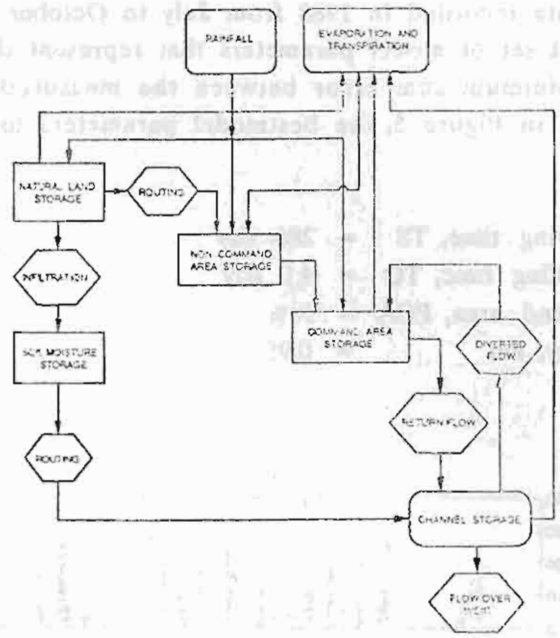

Figure 3 Hydrologic Processes of Small Watershed with Weir and Paddy Land

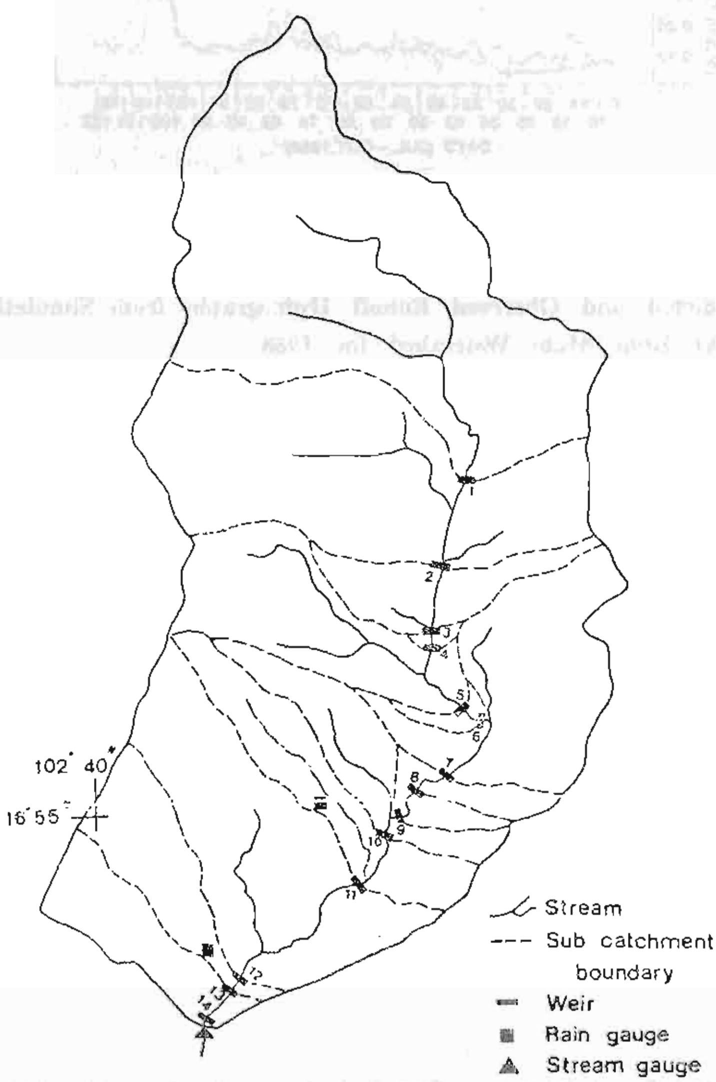

Figure 4 Huay Kum Mum Watershed, Khon Kaen, Thailand

Calibration of Model Parameters

Rainfall and runoff data recorded in 1988 from July to October [8] was used to calibrate the model for the best set of model parameters that represent the watershed hydrological properties. With the minimum sum error between the measured andthe predicted runoff hydrographs as shown in Figure 5, the bestmodel parameters for Huay Kum Mun Watershed are as follows

Soil moisture routing time, TS = 286 day
Surface water routing time, TQ = 4.1 day
Percent of command area, PCA = 10%
Diversion efficiency, DE = 0.95

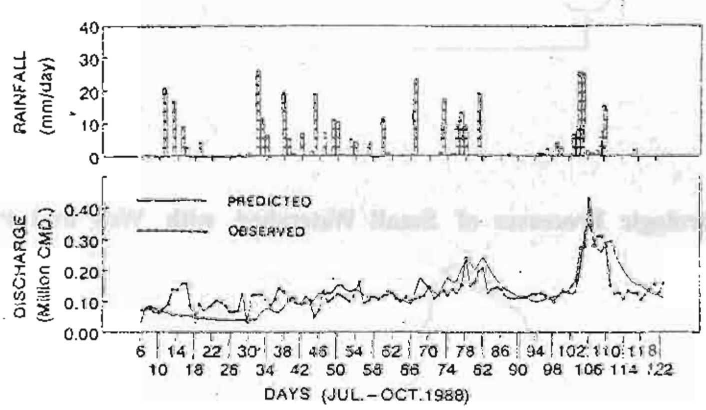

Figure 5 **Predicted and Observed Runoff Hydrographs from Simulation of Huay Kum Mum Watershed for 1988**

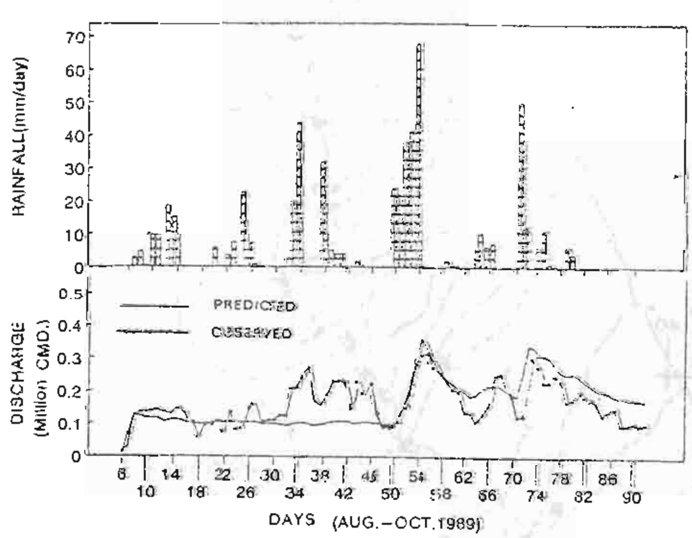

Figure 6 **Predicted and Observed Runoff Hydrographs from Simulation of Huay Kum Mum Watershed for 1989**

Runoff Hydrograph Prediction

Using the best model parameters in the simulation of HuayKum Mum Watershed during the period from August to October 1989, the predicted runoff hydrograph compares fairly well with the recorded runoff hydrograph as shown in Figure 6. Comparisons of the predicted and the measured hydrographs in Figure 5 and 6 indicated that the predicted hydrograph is smoother in the early period in which the predicted runoff is about half of the measured value. This might be due to the difference of the model paddy land storage from the actual field condition. In reality, the paddy land storage might be much less due to the fact that farmers did not store or divert as much water into the paddy landas assumed in the model. On the other hand, the predicted runoff is higher than the measured value toward the end of the rainy season, especially in October, which implies that there is more surface water storage in reality. This is probably due to thefact that farmers try to store more surface runoff water inactual practice for use in the dry season but the model did not account for such field conditions. Nevertheless the predicted volume of direct runoff over the whole period of 4 months in1988, which is 14,458,160 cubic meter, is almost the same as themeasured value of 14,308,580 cubic meter. The model can accurately predict the direct runoff volume over a long period using recorded rainfall data.

Hydrology of Small Watershed with Weir and Paddy Land

From the analyses of the watershed simulation results, followin conclusions can be drawn on the hydrological characteristics of small paddy land watershed with weirs.

For Huay Kum Mum Watershed having a catchment area of 143 sq.km of which 15.8 sq.km is paddy land and 1.58 sq.km of the paddy land is command area, the amount of water diverted into thecommand area is very little compared to the available water flowi ng over each weir. On a monthly average, the volume of diverted water is about 0.93, 0.64, 0.18 and 0.16 percent of the flow over a weir in July, August, September and October respectively. The declining percentage is probably because of the increasing rainfall and runoff in the later months. The total volume of diverted water in 4 months is 2.6 percent of the direct runoff from the watershed or about 250 mm. of water onto the command area. Should there be more weirs in the watershed such that the catchment to command area ratio is at the minimum limit of 50 for the dry zone as suggested by Rinfret [2] or the command area in the watershed is 2.86 sq.km, the diverted water will be about 4.7 percent of the runoff volume from the watershed which is still a small portion.

The monthly runoff coefficient values computed from the simulation results are 0.17, 0.15, 0.34 and 0.40 for July, August, September and October respectively with a four month average of 0.27. The low runoff coefficients values for July and August comform with the higher percentage of diverted water in these two months as previously mentioned.

CONCLUSIONS

Small watershed filling with paddy land and small diversion weirs is a common hydrologic system of rural areas in Southeast Asian Countries. Such system is the basic production unit that provides livelihood for the rural population. The watershed simulation model developed in this study serves as a useful tool for watershed management. Model simulation of watershed conditions will provide better understandings of existing water resource conditions and watershed responses to future development such as to answer the questions of how much more paddy land canbe irrigated, what is the maximum number of weirs that can be built without significant effect on downstream water use, etc.

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