APPLICATION OF IIS DISTRIBUTED HYDROLOGICAL MODEL (IISDHM) IN NAKHON SAWAN CATCHMENT, THAILAND

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A physically based distributed mathematical hydrological model has been developed and applied into two moderate size catchments, Ping river basin in Thailand [1)] and Agno river basin in the Philippines [2)] of catchment areas 3300 km^2 and 1600 km^2 respectively. The model performed well in simulating the behavior of different hydrologic components in these two river basins. In this research, the model has been applied in the Chao Phraya river basin upto Nakhon Sawan, comparatively large river basin with 62,716 km^2 of catchment area. The simulation of hydrographs are better in the mountainous side of the catchment than the relatively flat side of the catchment. This is because the DEM in the mountainous side is better and generated rivers match the actual rivers. On the other hand, DEM of flat area is not good and generated rivers are not matching with actual rivers.

Key Words : *Distributed Hydrological Model, Large Catchment, Chao Phraya, Thailand*

1. INTRODUCTION

Numerous distributed and lumped hydrological models have been developed in the past, but traditional models are lumped, i.e., they refer to spatially averaged conditions of the basin. Furthermore, their parameters have no direct physical meaning and cannot be easily derived from measurable properties of the basin. In these circumstances, traditional models can be applied only as long as the river basin remains unchanged. Therefore, they cannot be used to predict the effects of changes in land use, such as deforestation, cultivation and irrigation. On the other hand a physically distributed model can predict hydrological effects by manmade changes to land use and other water use. These models are thought to have an advantage over simple black box or even lumped physically based models in that, through their use of spatially distributed parameters which have physical significance, they do not require long term hydrological records for their calibration.

Due to rapidly increasing computational power and also the developments of the geographical information system (GIS) and availability of digital terrain map (DTM), development and application of physically distributed model are becoming easy. There are now a number of such models, that are being used regularly, such as Systeme Hydrologique Europeen (SHE [3)], [4)]), Institute of Hydrology Distributed Hydrological Model (IHDM [5)]). Due to one dimensional treatment of unsaturated flow, SHE model cannot be used to simulate the hilly terrain properly [6)]. Also this model does not give good results in large catchments. The IISDHM treats unsaturated zone 3-dimensionally, therefore, this model can be applied in any type of catchment. This model also solves the overland flow by two dimensional St. Venant equation by diffusion approximation, and thus can be used to simulate irrigation and floods.

2. MODEL DESCRIPTION

The model consists of four main components, e.g., interception, surface and river flow, subsurface flow and ground water, as presented in Figure 1. Spatial distributions of catchment parameters, rainfall input and hydrological response are represented in the horizontal plane by an orthogonal grid network and in the vertical plane by a column of horizontal layers at each grid. The modeling algorithms of different hydrological processes are described else where [1].

3. CATCHMENT DESCRIPTION

The Chao Phraya river basin, located between longitude $90^0 00'E$ and $101^0 30'E$ and latitude $15^0 00'N$ to $20^0 00'N$, is the largest river basin in Thailand with a total drainage area of 178,000 km^2 (17.8 million ha) or one third of the country area (Figure 2). The headwater region of the basin is in the north in which the four main tributaries of the Chao Phraya river originated namely: Ping, Wang, Yom and Nan. They merge to become the Chao Phraya river at Nakhon Sawan. The Chao Phraya river flows southward passing Chainat province where the Chao Phraya diversion dam is located. Downstream of dam, the river flows southward through the vast central plain of the country and finally discharges to the Gulf of Thailand. The length of the Chao Phraya river from Nakhon Sawan to the Gulf of Thailand is about 360 km. On the eastern rim of the river basin, the Pasak river is originated in steep mountain ranges draining southward to the Chao Phraya river near Ayutthaya province which is about 150km from the Gulf of Thailand. The Chao Phraya river divides into the Tha Chin river (Suphan river) at about 275km from the river mouth.

The simulated area in this research is taken up to Nakhon Sawan and the drainage area of river basin at this point is 110,569 km^2. Two intermediate gauging stations, i.e., P.7A in Ping basin and N.14 in Nan basin are also used to compare the results. The catchment area at P.7A and N.14 are 42,700km^2 and 33,120km^2 respectively. The actual drainage area of the simulation is 62,716 km^2. Due to computational limitation, a 1km grid size resolution is not possible to use in the simulation at present and hence, 2km size grids are used in the simulation.

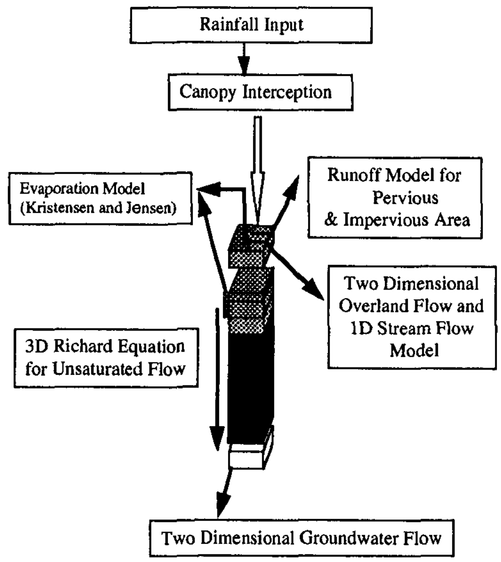

Fig. 1 Schematic Diagram of the Model Structure

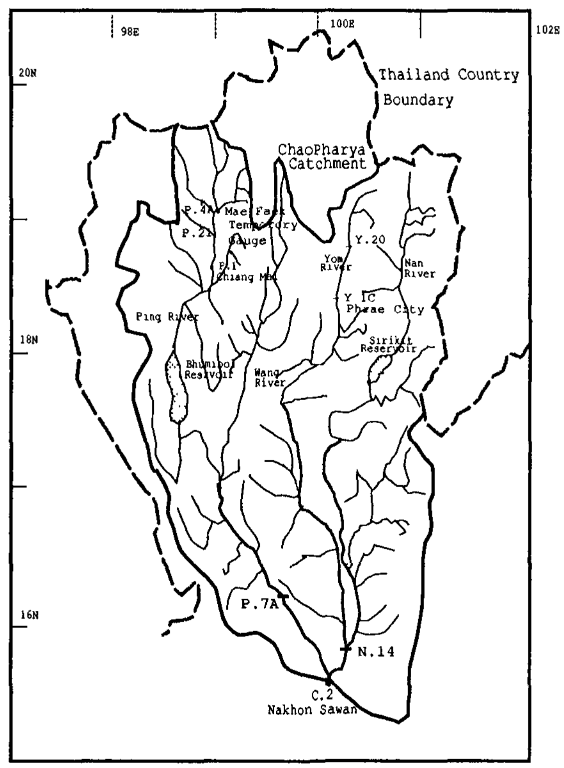

Fig. 2 Location Map of the Upper Chao Phraya River Basin

(1) Upstream Boundary Condition

There are two major reservoirs in this catchment namely, Bhumibol and Sirikit, which are located at the Ping river basin in Tak Province and Nan river basin in Nan province respectively. The capacity of Bhumibol reservoir is 13,462 MCM and the drainage area is 26,386 km^2, whereas the capacity of the Sirikit reservoir is 10,500 MCM and the drainage area is 13,130 km^2. The daily release from Bhumibol and Sirikit reservoirs are considered as the upstream boundary conditions of the model. There is one small reservoir Ku Lom dam in the Wang river basin and the release

Table 1 Types of Landuse and their Contributions (%)

S. No.	Landuse	Area (%)
1	Irrigated Paddy Field	3.27
2	Non-Irrigated Paddy Field	18.13
3	Upland Crop	28.25
4	Orchards	1.21
5	Forest	49.14

from this reservoir is not available. Therefore the discharge at a downstream gauging station (W.3A) is considered as the upstream boundary condition. The upstream conditions for rest of the rivers are taken as no flow condition.

(2) River Network

DEM for the study area was down loaded from United State Geological Survey (USGS) ftp site (http:// edcwww.cr.usgs.gov/landdaac/ 30asdcwdem/ 30asdcw dem.html). The resolution of the DEM was 30 arc seconds, which is equivalent to 922 m in the study area. It was resampled to 2000 m and used to delineate the catchment boundary and to generate rivers using ARC/INFO, GIS software. The generated river matches well in the Ping river basin, however, the matching is not good in the lower part of the Nan and Yom river basin. This is because, the lower part of the Nan basin is relatively flat which makes the generation of rivers difficult. There are 26 river channels and 742 total computational points in the river network system.

(3) Irrigation Area

There are eight irrigation projects in the simulated area, namely, Phitsanulok irrigation project left bank and right bank, Khamphang Khet irrigation projects (four phases) and two Sukothai groundwater irrigation projects (Zone1 and Zone2). Total command area of these irrigation projects is 2047 km^2 (204,700 ha). The daily irrigation diversion data of surface irrigation projects and daily pumping data from the ground irrigation projects are available from Royal Irrigation Department (RID), Thailand. The daily irrigation diversion is deducted from the river discharge while calculating the river routing and the pumping from ground water are introduced as sink terms to the groundwater solution.

(4) Groundwater

The saturated flow domain is used as the information available from Sukhothai groundwater irrigation project. The available lithology is simplified as a horizontal aquitard overlaid by an unconfined aquifer and followed by a deeper confined aquifer. The thickness of the aquitard is considered as 8m and the thickness of the deep aquifer is assumed as 40m. The hydraulic conductivity and storage coefficient of unconfined and confined aquifers are 1.0X10-6 m/s, 0.15 and 1.0X10-6 m/s, 0.0001 respectively. Initial groundwater levels in unconfined and confined aquifers were assumed to be 4m and 10m below the ground surface elevation respectively.

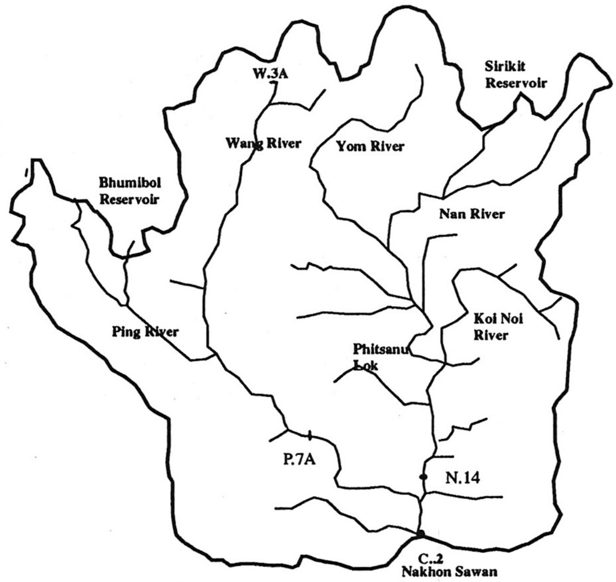

Fig. 3 Generated River Network

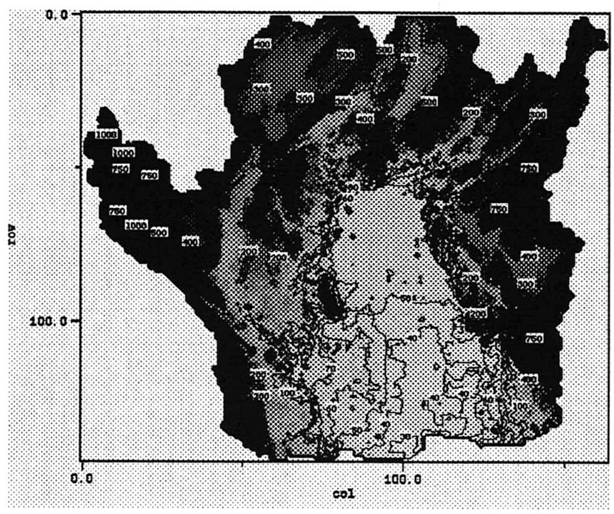

Fig. 4 Contour Map of the Catchment

(5) Soil and Landuse

There are seven categories of landuse in the study area. Due to less representation of some types of landuse and due to similar hydrologic behavior of some other kinds of landuse, the landuse has been reclassified into 5 representative classes as shown in Table 1. There are more than 23 categories of soil in the study area. But the soil parameters of only five types of soil are available, which corresponds the landuse type. Therefore, only five types of soils are used in the simulation. Monthly surface storage and leaf area index were collected during field visits and are shown in Table 2.

Table 2 Surface Storage and Leaf Area Index (LAI) of Different Crops in Different Months

Month	Storage (mm)		LAI	
	Paddy (irrigated/ non-irri.)	Forest (Upland/ Orchard)	Pad dy	For est
Jan.	40	25	0.5	4.5
Feb.	100	25	1.0	4.5
Mar.	100	25	1.5	4.5
Apr.	100	25	2.5	4.5
May.	20	25	1.0	4.5
June.	60	25	0.5	4.5
July.	100	25	1.0	4.5
Aug.	100	25	2.0	4.5
Sep.	100	25	2.5	4.5
Oct.	100	25	2.5	4.5
Non.	60	25	1.5	4.5
Dec.	20	25	0.5	4.5

(6) Rainfall and Evapotranspiration

The average rainfall of this catchment is about 1390mm. Daily rainfalls at 69 rain gauge stations are available and out of the 69 stations, hourly rainfall data were available at 12 stations which were collected from RID on special request. However, it was found that the hourly data are not dependable. They were not used in the simulation. The daily rainfall at each station was equally distributed to 24 hours to convert into hourly rainfall. Theissen polygon is used to find out the spatial distribution of these rainfall stations. The potential evapotranspiration is calculated from pan evaporation data and distributed equally to 24 hours. The pan evaporation data for 14 locations in the study area are available. Theissen polygon has been used to find out the spatial distribution of the potential evaporation.

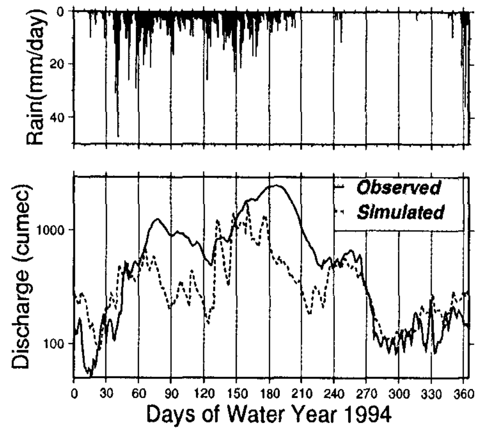

Fig. 5 Observed and Simulated Hydrographs at C.2 (Nakhon Sawan)

4. RESULTS

The hourly simulation has been carried out for 1994 from January to December. The simulated and observed hydrographs at C. 2 gauging station, Nakhon Sawan, N.14 station in Nan river basin and P.7A station in the Ping river basin (shown in Figure 3) are presented in Figures 5, 6 and 7 respectively. The simulated hydrograph is matching well with observed hydrograph in the dry season from January to June at C.2 station, however, the matching is not so good in the wet season. The observed and simulated hydrographs are matching well at P.7A station in both seasons, however, the hydrographs at N.14 stations are matching in the dry season and not matching in the wet season. There are mainly two reasons behind this. (a) More than 60% land in the Nan

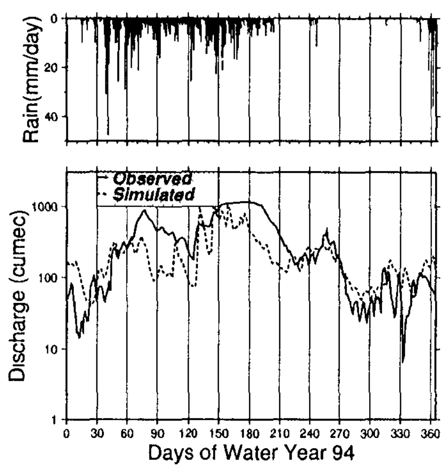

Fig. 6 Observed and Simulated Hydrographs at N.14

and Yom catchments are irrigated, non-irrigated

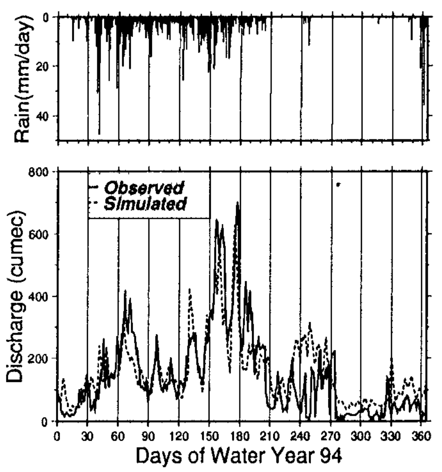

Fig. 7 Observed and Simulated Hydrographs at P.7A

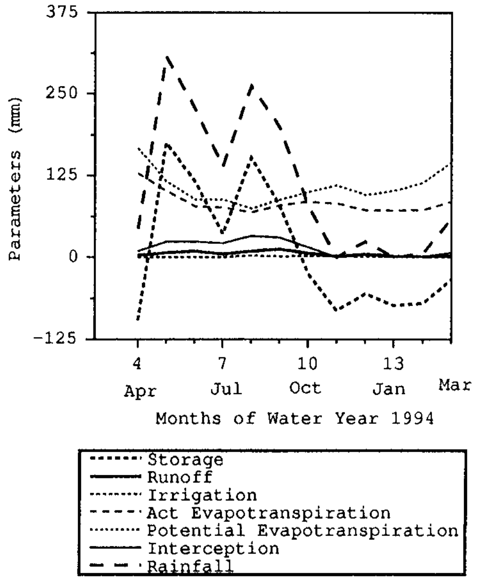

Fig. 8 Monthly Water Balance in the Whole Catchment

paddy and upland crop. The wet season crop in these area are paddy and paddy crop needs a different storage of water during its growth period. The farmers store and release water according to their own feeling, i.e., there are no standard rules to simulate the storage in the paddy field. In the model, the surface storage at each grid and any temporal resolution can be input, but this information is not available and is also not easy to collect. So, some standard maximum storage has been adopted in the simulation, which may not represent the actual one. The daily/monthly storage has to be improved to obtain better result in the wet season. However, in the ping river catchment up to P.7A gauging station only 15% of total landuse is used as paddy field in the wet season and rest of the land is either forest or other landuse, where the surface storage is not much affected by the human activities and can be simulated easily.

(b) The digital elevation model downloaded from ftp site is good in the mountainous catchment but not so good in the flat terrain as it is generated from larger contour intervals (Figure 4). DEM is used to generate the river as well as to route the surface overland flow. The river is generated after filling the depressions in the DEM. When the depressions are filled, large areas in the catchment are assigned the same elevations creating reservoirs at different locations in the flat regions. The generated and actual rivers match well in the Ping catchment, whereas they do not match well in the Nan river basin because the Nan catchment is relatively flatter than Ping catchment. The surface routing also does not simulate properly in the flat area. The energy gradient in these same elevation regions becomes very small (only due to head difference), which does not allow the water to move and thus water started to accumulate in these grids. This phenomenon also affects the water balance, as it increases the infiltration and evaporation and decreases the surface flow. So, a higher resolution DEM is needed to obtain good results in the flat areas.

IISDHM is a distributed hydrological model, which can be applied in a catchment to simulate temporal and spatial distributions of all hydrological parameters such as actual evaporation, ground water elevation in different aquifers, moisture contents in any layer of unsaturated zone. The spatial distributions of the total actual evapotranspiration in the two months, April and October are presented in Figures 9 and 10 respectively. Actual transpiration depends upon the soil moisture content, leaf area index and potential evapotranspiration. The total actual evapotranspiration in April is higher than that in October. This is because the potential evapotranspiration is higher in April than that in October (Figure 8). However, the average moisture content in April is lower than in October.

It is clear from Figure 8 that the ratio of the actual evapotranspiration to potential evapotranspiration in April is lesser than that in October. The actual evapotranspiration in the wet season is nearly equal to the potential evapotranspiration, because the moisture content in wet season is near to saturation.

Monthly water balance is shown in Figure 8 and yearly water balance has been presented in

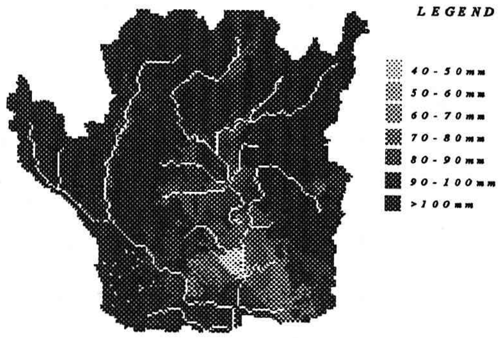

Fig. 9 Variation Monthly Total Actual Evapotranspiration in April

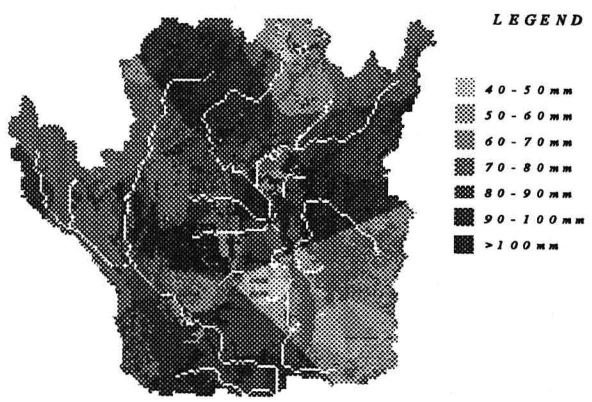

Fig. 10 Variation Monthly Total Actual Evapotranspiration in October

Table 3 Yearly Water Balance in the Whole Catchment

Rain fall	Intercept-ion	Actual Evapotra-piration	Irrig ation Input	Run off	Catch. Stor-age
1392	172	936	12	66	229

Table 3. Table 3 shows that the irrigation water in the catchment is nearly 12.14mm which is less than 1% of the total rainfall. The interception and evaporation are high, 172.52mm and 936.29mm, which are 12.4% and 67.2% respectively. The surface flow is only 5% of total input water.

5. DISCUSSIONS

The IISDHM can be successfully applied in any kind of the catchment, The total computational time taken for the simulating 62,716km^2 catchment at 2km grid size and one hour time resolution for one year is 24.5 hours in a DEC ALPHA vt-433 running windows NT. The total memory required is 15833 KB. The computation available currently shows that application of distributed hydrological model for large catchments is possible operationally. The result in the flat area can be improved by using higher resolution DEM and improved other input data.

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(Received September 30, 1997)