Journal of Spatial Hydrology

Volume 6 Article 3

2006

Hydrologic modeling of the Upper Suriname River basin using WetSpa and ArcView GIS

Journal of Spatial Hydrology
Vol.6, No.1 Spring 2006

Hydrologic modeling of the Upper Suriname River basin using WetSpa and ArcView GIS

Nurmohamed. R[1], Naipal. S[1] and F. De Smedt[2]

Abstract

A grid-based distributed hydrological model WetSpa, compatible with ArcView Geographic Information Systems (GIS), was applied to the 7,860 km^2 Upper Suriname River basin. Model parameters were derived from a digital elevation model (DEM), land use and soil type map of the basin. These parameters and the observed daily meteorological data (1978-1983) were used (1) to tests the performance of the WetSpa model to a large tropical basin, (2) to simulate water balance and outflow hydrographs, (3) to identify the different flow components and (4) to study the most sensitive model parameters for the study catchment. The statistical model evaluation results indicated that the model has a relatively high confidence and can give a fair representation of the flow hydrographs and the water balance for a complex terrain. The use of daily observations instead of hourly observations and the lack of other measurements of the hydrological processes (e.g. groundwater flow, infiltration) to calibrate/validate the model may have caused the large errors in low flows and high flows. The deviations between the observed and simulated flows may also be caused by the lack of a good representation of the meteorological conditions in the study area. The WetSpa model also provided insight into the main flow processes during the year. The most sensitive parameters for this basin were the interflow scaling factor ki, the groundwater flow recession coefficient Kg, the initial soil moisture K_ss and the correction factor for potential evapotranspiration K_ep.

Keywords: Geographic Information Systems, Hydrologic modeling, Hydrology, Upper Suriname river basin, WetSpa.

Introduction

Nowadays, hydrological models are a powerful tool to understand and to approximate the hydrological responses of a basin (Perrin et al 2001). They are based upon the hydrological cycle and simulate part of this cycle. The main variables that influence the dominant processes of the hydrological cycle such as runoff and groundwater recharge, are precipitation, land use, soil texture, elevation and, to a lesser extent, potential evaporation (Booij 2002; Liu et al 2004; Seifu 2003). Rainfall-runoff modeling can be useful for water resources assessment, estimation of river flows, flood forecasting and design of engineering works. Models for these purposes can generally be classified in simple lumped models (e.g. Stanford model, HEC, TANK) and physically based spatial distributed models (e.g. IHD, TOPMODEL, MIKE-SHE, HBV, SWAT and Xinanjiang) (Booij 2002; Beven 2000; DeVries and Hromadka 1993; Feenstra and Short 1996; Maidment 1992; Perrin et al 2001, WMO/UNESCO 1997; WMO 1975). The main difference between these two groups of models

[1] PhD student, [2] Associated Professor, Department of Infrastructure, Faculty of Technology, University of Suriname, Leysweg, POB 9212, Paramaribo, Suriname, [3] Professor, Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
Corresponding author's email: r.nurmohamed@uvs.edu

is that the lumped models do not take account of the spatial distribution of physical data of the basin (e.g. soil, land use, topography) nor of the spatial variation of the climate (e.g. precipitation, evaporation), while distributed models do. The lumped models have the advantage that they are easier to operate and require less data than distributed models. However, they can only be applied to basins with measurements and require long-term historical data for calibration. Distributed models do require a great deal of detailed data of the basin and have, in general, a large number of parameters to optimize. The spatial variation of data in these types of models is represented by sub-basins or grids.

Rainfall-runoff modeling for medium to large catchments is complex due to the lack of complete understanding of the hydrological system and the stochastic behavior of the hydrological processes and variables (Beven 1989, 2000). Large catchments are characterized by a variety of topographic, soil, vegetation/land use and geological factors and the variation of climate in time and space that will affect the rainfall-runoff. For such catchments it is recommended to use a distributed hydrological model rather than a lumped model. The use of GIS in hydrological modeling allows us also to analyze a great amount of spatial-related physical data and to account for the spatial variation of model parameters and processes at the detailed resolution (Liu 1999; Beven 2000).

There are a few published studies known of large-scale hydrologic model applications in tropical regions. Perrin et al (2001) applied 19 daily lumped hydrological models on different basins in Brazil (up to 50,600 km^2), Andersen et al (2001) applied the MIKE SHE model to the 375,000 km^2 Senegal river basin in Senegal, Campling et al (2002) applied the TOPMODEL to the Ebonyi river basin (379 km^2) in Nigeria, Bormann (2005) applied a lump conceptual model UHP to the Queme river basin (14,000 km^2) in Benin and Molicova et al (1997) applied the TOPMODEL to a 15,000 m^2 Sinnamary river basin in La Guiana. The model performance in these studies was mainly influenced by the inadequacy of the model structure, errors in data and impaired river flow, the lack of high resolution topographic, soil and land use maps, the lack of sufficient rainfall stations and measurements of potential evapotranspiration, and information on soil hydraulic processes.

No application of hydrological models on large river basins in Suriname is known. This study is, therefore, a first attempt to apply a hydrological model, WetSpa, on daily time step in combination with GIS ArcView to the Upper Suriname River basin (7,860 km^2) in Suriname. The objectives are: (1) to tests the performance of a physical-based and spatial distributed hydrological model for a large tropical basin with coarse resolution physical data and insufficient hydrometeorological observations, (2) to simulate water balance and outflow hydrographs, (3) to identify the different flow components and (4) to study the most sensitive model parameters for the study catchment.

WetSpa Model

WetSpa is a continuous, distributed, physically-based hydrological model with variable time step (hourly, daily). This model is developed by the Vrije Universiteit Brussel, Belgium (Liu and De Smedt 2004) and has been applied to small and medium catchments (34-1,176 km^2) in Belgium, Luxembourg and France. Liu et al (2002, 2003, 2004) and Seifu (2003) have shown that the model is suitable for simulation of spatial distribution of hydrological processes and analysis of land use changes and climate change impacts of hydrological processes. In WetSpa, a basin is discretized in a number of grid cells and in the vertical direction in four layers. The model structure is shown in Fig. 1. The model considers the following hydrological processes: precipitation, evapotranspiration, overland flow and channel flow, surface runoff, interception, infiltration, percolation, subsurface storm flow (interflow), groundwater flow and water balance in the root zone and saturated zone (Liu 2004). For each grid the water balance in the root zone is calculated as:

$$D\frac{\Delta\theta}{\Delta t} = P - I - S - E - F - R \quad \text{(Equation 1)}$$

where D is the root depth (mm); $\Delta\theta$ is the change of soil moisture content (m^3/m^3), Δt is the time interval (hr), P is the precipitation (mm), I is the initial abstraction including interception and depression losses during the initial storm within time Δt (mm/hr), S is the surface runoff, E is the actual evapotranspiration (mm/hr), F is the interflow or subsurface flow (mm) and R is percolation out of the root zone or groundwater recharge (mm). Default parameters for interception and depression storage capacity are collected from literature (Liu 2004).

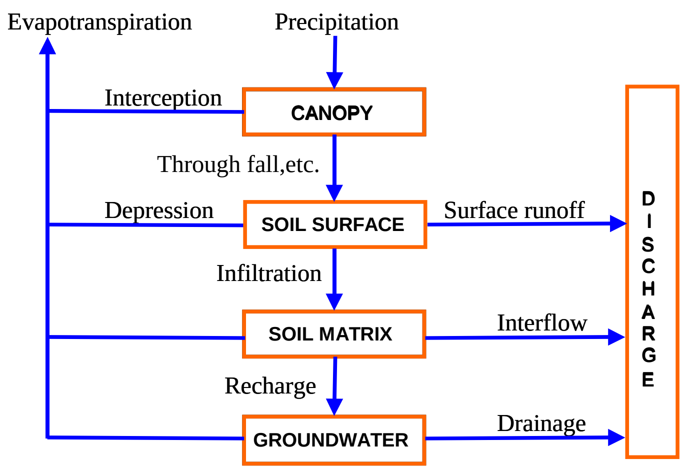


Figure 1: The WetSpa model structure at a grid level (Liu and De Smedt, 2004)

Surface runoff is calculated using a moisture-related runoff coefficient method:

$$S = c_r P_n \frac{\theta}{\theta_s} \quad \text{(Equation 2)}$$

where S is the surface runoff (L/T), P_n is the net precipitation P-I (L), θ is the average soil moisture content, θ_s is the saturated soil moisture content, c_r is the runoff coefficient and is mainly determined by the slope, land use and soil type. Default runoff coefficients are collected from literature (Liu 2004).

Interflow and percolation are very important components in the root zone water balance. They are assumed to occur when the soil moisture is higher than field capacity. The main factors that influence percolation are the hydraulic conductivity, root depth and water content of the soil. They are estimated based on Darcy's law and the kinematics approximation. Interflow is given by equation (3):

$$F = \frac{c_f D S_o K(\theta)}{W} \quad \text{(Equation 3)}$$

where D is the root depth (m), S_o is the slope (m/m), K(θ) is the unsaturated hydraulic conductivity (mm/h), W is the cell width (m), θ is the soil moisture content (m^3/m^3), c_f scaling parameter which is a function of land use and soil.
Percolation is calculated by:

$$R = K(\theta) = K_s \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^{(2+3B)/B} \quad \text{(Equation 4)}$$

where K(θ) is the unsaturated hydraulic conductivity (mm/hr), θ is the soil moisture content (mm/hr), θ_r is the residual soil moisture content (m^3/m^3), θ_s is the soil porosity (m^3/m^3), B is the cell pore size distribution index.

The total discharge at the catchment outlet is thus the sum of the overland flow, interflow and groundwater flow from all the grid cells and is given by equation 5:

$$Q(t) = \sum_{i=1}^{N_w} Q_s(t) + Q_f(t) + Q_g(t) \quad \text{(Equation 5)}$$

where Q(t) is the total discharge of the subcatchments at time t (m^3/s), Q_s is the overland flow of the subcatchments at time t (m^3/s), Q_f is the interflow (m^3/s), Q_g is the groundwater runoff of the subcatchments at time t (m^3/s), N_w is the number of cells over the entire catchment.

Groundwater runoff is estimated using a nonlinear relationship:

$$Q_g = K_g S_g^{\ 2} \quad \text{(Equation 6)}$$

where Q_g is the groundwater flow of the subcatchments (m^3/s), S_g is the groundwater storage (mm), K_g is the non linear groundwater flow recession coefficient (m^2/s or $m^{-1}s^{-1}$) and is mainly related to the sub basin area shape, slope, pore volume, transmissivity of the sub basin.

The main input data in the WetSpa model are digital spatial data (elevation, river network, land use and soil type), and hydrological and weather data (precipitation, evapotranspiration, discharges). For calibration of the model, nine global input parameters can be used for tropical areas. These are the interflow scaling factor ki, the groundwater flow recession coefficient Kg, the initial soil moisture K_ss, the initial groundwater storage go (mm), the maximum groundwater storage G_max in depth (mm), correction factor for potential evapotranspiration K_ep, the surface runoff exponent K_run (is an exponent reflecting the effect of rainfall intensity on the actual surface runoff coefficient when the rainfall intensity is very small) and a threshold of the rainfall intensity P_max (mm/day).

ki is generally greater than 1.0 and less than 10.0, and can be calibrated by comparing the recession part of the computed flood hydrograph with the observed hydrograph. The higher the ki the more amount of interflow. K_ep is in general close to 1.0 and can be calibrated by comparing the calculated and observed flow volume for a long-term series. Kg can be obtained from analyses of recession curves of the river flows or from observed base flow or by dividing the discharge volume over the area's constant value for the entire basin and should be less than 0.01 or ki. For example, Kg of 0.0001 means that the groundwater flow decreases with half of the amount over 1 month. Calibration of this parameter is done by comparing computed and observed low flow hydrographs. The lower the Kg the flatter the curves of groundwater flow. K_ss can be adjusted during calibration by analysis of the balance output and comparison between computed and observed flow hydrographs for the initial phase. For long term flow simulation, K_ss is less important. For short-term flow simulation, K_ss becomes one of the most important factors in runoff production. go can be adjusted during calibration by comparing computed and observed low flows for the initial phase. K_run is, in general, between 1 and 3. If K_run is 1, the actual runoff coefficient is then a linear function of the relative soil moisture content and the effect of rainfall intensity on the runoff coefficient is not taken into account. K_run and P_max can be adjusted based on the agreement between calculated and observed flows for small storms with lower rainfall intensity.

The main outputs of the WetSpa model are river flow hydrographs for the entire basin and sub basins (e.g. surface runoff, interflow, groundwater flow), water balance and spatial distributed hydrological characteristics for the entire basin at each time step (e.g. runoff, soil moisture, groundwater recharge, infiltration rates) (Liu et al 2004; Seifu 2003).

WetSpa uses five evaluation criteria. The model bias C1 shows the ability to reproduce water balance with best value of 0 and is given by equation 7:

$$CR1 = \frac{\sum_{i=1}^{N} Qs_i - Qo_i}{\sum_{i=1}^{N} Qo_i} \qquad \text{(Equation 7)}$$

where Qs_i and Qo_i are the simulated and observed river flows at time step i (m^3/s), N is the number of time steps.

C2 is the model determinant coefficient and represents the proportion of the variance in the observed river flows that are explained by the simulated river flows and varies between 0-1 with best value of 1 and is give by:

$$CR2 = \frac{\sum_{i=1}^{N} \left(Qs_i - \overline{Qo}\right)^2}{\sum_{i=1}^{N} \left(Qo_i - \overline{Qo}\right)^2} \qquad \text{(Equation 8)}$$

where $\overline{Qo}$ is the means observed river flows.

The Nash-Sutcliffe coefficient C3, with best value of 1, indicates how well the river flows are simulated by the model and is give by:

$$CR3 = 1 - \frac{\sum_{i=1}^{N} \left(Qs_i - Qo_i\right)^2}{\sum_{i=1}^{N} \left(Qo_i - \overline{Qo}\right)^2} \qquad \text{(Equation 9)}$$

C4 is the Logarithmic Nash-Sutcliffe efficiency and shows the ability to reproduce time evolution of low river flow with best value of 1 and is give by:

$$CR4 = 1 - \frac{\sum_{i=1}^{N} [\ln(Qs_i + \varepsilon) - \ln(Qo_i + \varepsilon)]^2}{\sum_{i=1}^{N} [\ln(Qo_i + \varepsilon) - \ln(\overline{Qo} + \varepsilon)]^2} \qquad \text{(Equation 10)}$$

C5 is an adapted version of the Nash-Sutcliffe criterion for evaluating the ability of reproducing the time evolution of high river flow with best value of 1 and is give by:

$$CR5 = 1 - \frac{\sum_{i=1}^{N}(Qs_i + \overline{Qo})(Qs_i - Qo_i)^2}{\sum_{i=1}^{N}(Qo_i + \overline{Qo})(\overline{Qo_i} - \overline{Qo})^2} \qquad \text{(Equation 11)}$$

Methodology

The study is conducted in the Upper Suriname river basin, which is situated in central Suriname. It is located between 3^o to 4.5^o NL and 55^o to 56.5^o LW and covers an area of about 7,860 km^2 up till Pokigron (Fig. 2). It is the main source of water for the Afobakka reservoir. This reservoir is used for hydropower generation and is, therefore, very important for the economy of Suriname. The elevation ranges from 75 m in the north to 809 m in the south of the basin above mean sea level (Fig. 3). The land is mainly covered with high tropical dense (Nurmohamed 1998). The different soil types in this basin (Fig. 4) are: sand (1.6%), silt (5.5%), silt clay loam (48.2%), clay loam (27.9%) and clay (16.8%). The Upper Suriname river basin is characterized by a tropical humid climate. The annual precipitation in the study area ranges from 2,300 mm for the lower part of the basin to 2,800 mm for the upper part of the basin. The annual evaporation is around 1,850 mm. The mean annual temperature varies between 24.8^o and 26.4^{o}C (Lenselink and van der Weert 1970; Nurmohamed and Naipal 2004).

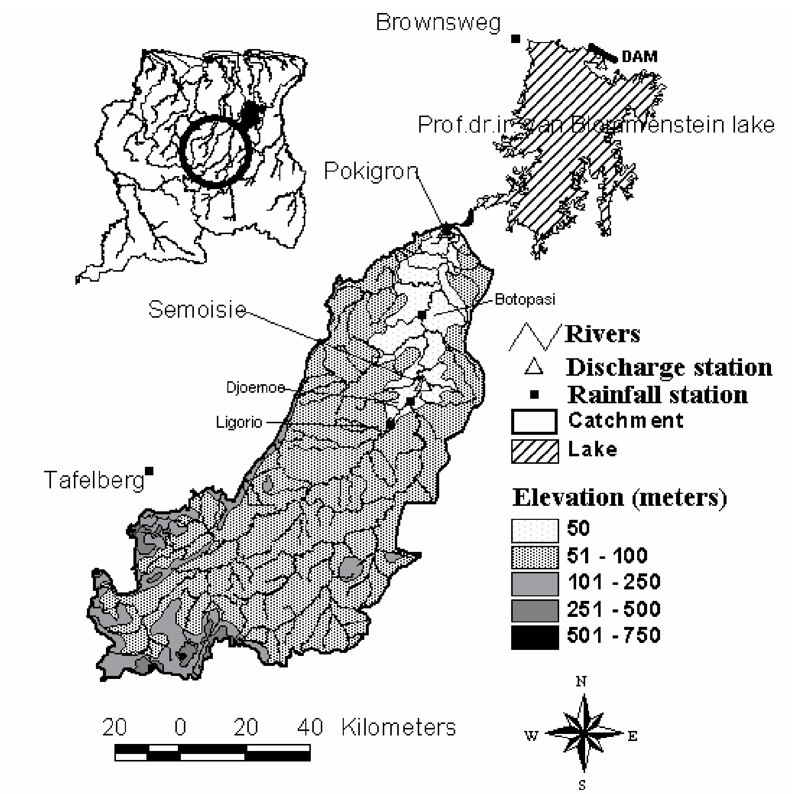


Figure 2: Study area and measuring networks

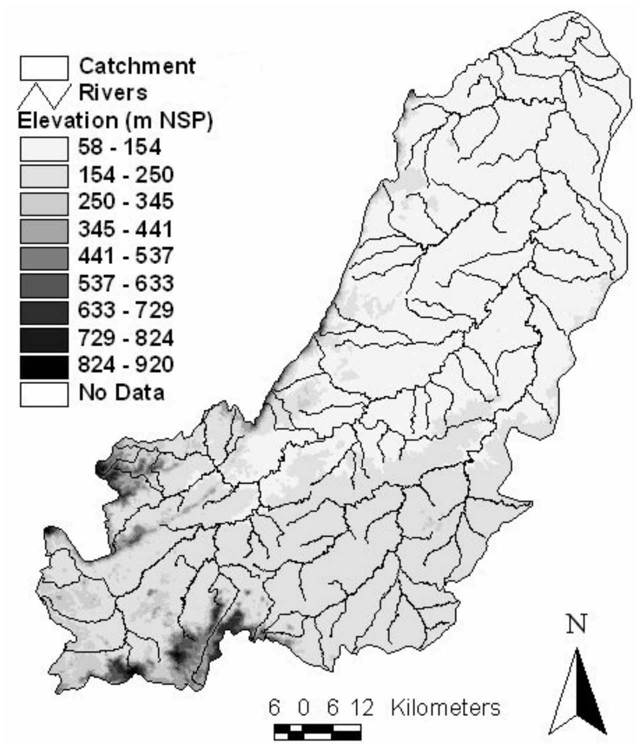


Figure 3: Topography of the Upper Suriname river basin (in m above mean sea level)

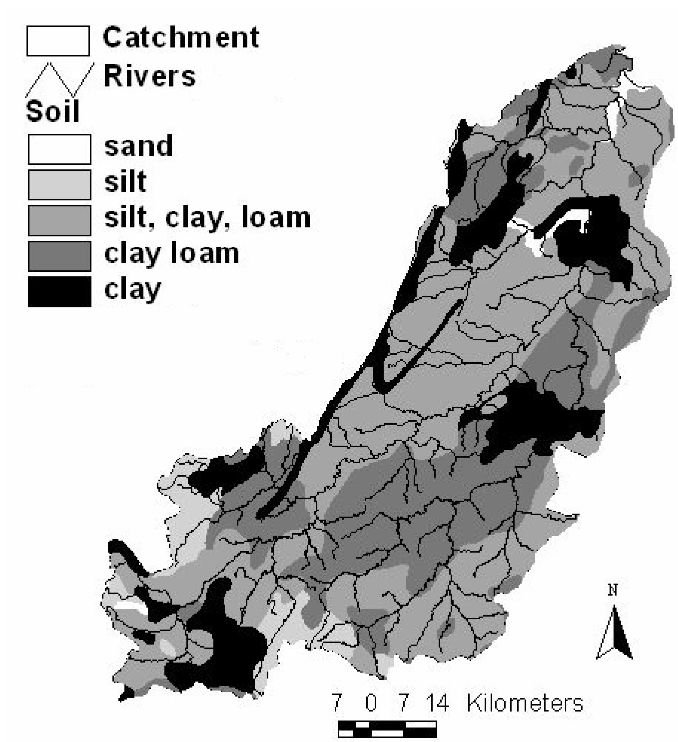


Figure 4: Soil map of the Upper Suriname river basin

A total of six rainfall stations in or close to the study area (Brownsweg, Pokigron, Botopasi, Djoemoe, Ligorio and Tafelberg) and two river discharge stations (Pokigron and Semoisie) were found suitable for use in this study in terms of data length and continuity. The different stations are shown in Fig. 2. Pan-evaporation (Eo) data is very scarce in this area and, therefore, mean evaporation data (1975-1983) at Pokigron has been interpolated from station Coeroeni and Sipaliwini and evaporation data at Semoisie has been interpolated from station Stoelmanseiland. Potential evapotranspiration (PET) is estimated from the long-term water balance in this basin, PET = Q-P = kEo, and the Eo values are corrected by the factor k. Q is the river discharge and P is the precipitation.

Daily precipitation and evaporation data (1961-1983) are received from the Meteorological Service Suriname and the daily discharges (1952-1985) data are obtained from the Hydraulic Research Division Suriname and the Bureau for Hydroelectric Power Works. Only the period 1975-1983 covers a spatial coverage efficient to use for hydrological modeling purposes. To complete missing data of precipitation and discharge, artificial linear interpolating is carried out. The correlation coefficient between the monthly rainfall data of the stations ranges from 0.51 to 0.82 (lag 0). The river flows at Semoisie and Pokigron show a high consistency with a cross correlation coefficient of 0.95 for lag 0 and 0.71 for lag 1 month.

A digital 50 m interval topographic contour map and river network (scale 1:100,000) from the year 1963 was obtained from the Center of Natural Resources and Assessment (NARENA). From this map, a 10 m resolution elevation contour map with grid size 50 m (slope factor 0.5, threshold factor 1.0) was first created from a 50 m elevation contour map using the ArcView Contour Gridder extension. Different resolution DEM were created (50 m, 100 m, 200 m, 500 m) using the TOPOGRID function in Arc/Info. From visual comparison of the actual river network and the generated river network and because of computation time and computer memory, the 100 m DEM was accepted for further model simulation. From the DEM, the following physical parameters for each grid cell were created by ArcView: stream orders and network, slope of overland flow and river channels, flow direction, flow accumulation, subwatersheds based on stream links and the hydraulic radius according to a flood frequency of 2 years. From these results it is found that the majority of the basin has a slope of up to 7% and the mountainous area a slope of up to 14%.

A soil map (scale 1:100,000) from 1963 was obtained from NARENA. The soil information was first reclassified according to the 12 U.S. Department of Agriculture (USDA) soil texture classes used in WetSpa and then also converted to a 100 m grid map. From the soil map and the default parameters characterizing the soil of the study as shown in Table 1, different maps of physical properties such as porosity, hydraulic conductivity, residual moisture, pore index field capacity and wilting point were created.

Table 1: Default parameters characterizing the soil in the study area (Liu and de Smedt, 2004)

Texture class	Hydraulic conductivity (mm/h)	Porosity (m^3/m^3)	Field capacity (m^3/m^3)	Wilting point (m^3/m^3)	Residual moisture (m^3/m^3)	Pore size distribution index
Clay loam	1.51	0.464	0.310	0.187	0.075	8.32
Sand	208.80	0.437	0.062	0.024	0.020	3.39
Silt clay loam	4.32	0.398	0.244	0.136	0.068	7.20
Clay	0.60	0.475	0.378	0.251	0.090	12.13
Silt	6.84	0.482	0.258	0.126	0.015	3.71

A land use map (scale 1:100,000) from 1963 was obtained from NARENA. The land use information was also converted to six land use classes used in WetSpa and then also converted to a 100 m grid. From this map and the default parameters characterizing the land use of the study, as shown in Table 2, different maps of physical properties such as root depth, Manning's coefficient and interception capacity were created.

Table 2: Default parameters characterizing the land use in the study area

Land use class	Vegetated fraction (%)	Leaf area index	Root depth (m)	Manning's coefficient ($m^{-1/3}$ s)	Interception capacity (mm)
Evergreen broad leaf tree	90	5-6	1.5	0.60	0.15-2.00
Tall grass	80	0.5-6.0	1.0	0.40	0.10-1.50

Based on the combination of DEM, soil and land use map, the potential runoff coefficient (Fig. 5) and depression storage capacity maps were created. The flow routing parameters are calculated with ArcView GIS using the slope, hydraulic radius and Manning coefficient maps. Fig. 6 shows the travel time from the flow to the basin outlet. From these figures we can conclude that the majority of the basin has an average annual velocity of up to 0.7 m s^{-1} and an average annual travel time to the basin outlet of up to 93 hrs (3.9 days). In the lower part of the basin, travel times are up to 185 hrs (7.7 days). The average annual runoff coefficient is mainly between 0.2 and 0.4, while in the mountainous area values of up to 0.7 are reached. This is due to the steeper slopes in the mountainous area.

The point rainfall data of six stations are used to create aerial rainfall distribution, using the ArcView Thiessen polygon extension. For potential evapotranspiration, a Thiessen polygon map was also created based on time series at two locations. The WetSpa model is finally run using observed daily rainfall, potential evapotranspiration and the derived physical parameters in ArcView GIS for both the semi-distributed and fully distributed model. In WetSpa the fully distributed model operates on cell scale and a variable time step and the semi-distributed model on small subwatershed scale.

Results and Discussion

For calibration of the WetSpa model, we used daily flows for the period January 1975 to December 1981, while for model validation the period January 1982 to December 1983 was used. To determine how well the observed hydrographs are reproduced by the model, a visual comparison and the five model efficiencies (C1, C2, C3, C4, C5) are used. The global input parameters are adjusted till a satisfactory performance of the model is obtained. Table 3 shows the comparison in model evaluation criteria for the semi-distributed and fully distributed model. The first three years (1975-1977) were needed as warming up periods and are ignored to obtain better model evaluation results. The model performance is found satisfactory for both models. From the results, we can see that for such a large basin, the semi-distributed model produces slightly better evaluation results than the fully distributed model. It is also found that the most sensitive global input parameters are ki, Kg, K_ss and go.

Table 3: Model performance for the calibration/validation period (1975-1983) for the Upper Suriname river basin at station Pokigron. The years 1975-1977 are used as the warming up period. Global parameters are set as follows: ki = 1.0, Kg = 0.01, K_ss = 1.0, K_ep = 1.0, go = 30 mm, g_max = 400 mm, K_run = 1.5, Pmax = 300 mm/day. C1 to C5 are the model evaluation criteria.

Model	**Model evaluation**				
Semi-distributed model	***C1***	***C2***	***C3***	***C4***	***C5***
Calibration (1978-1981)	-0.011	0.839	0.543	0.555	0.643
Validation (1982-1983)	0.194	0.875	0.768	0.633	0.850
Total (1978-1983)	0.046	0.833	0.622	0.609	0.715
Fully distributed model					
Calibration (1978-1981)	-0.219	0.726	0.552	0.493	0.585
Validation (1982-1983)	-0.029	0.794	0.779	0.779	0.804
Total (1978-1983)	-0.166	0.727	0.631	0.659	0.662

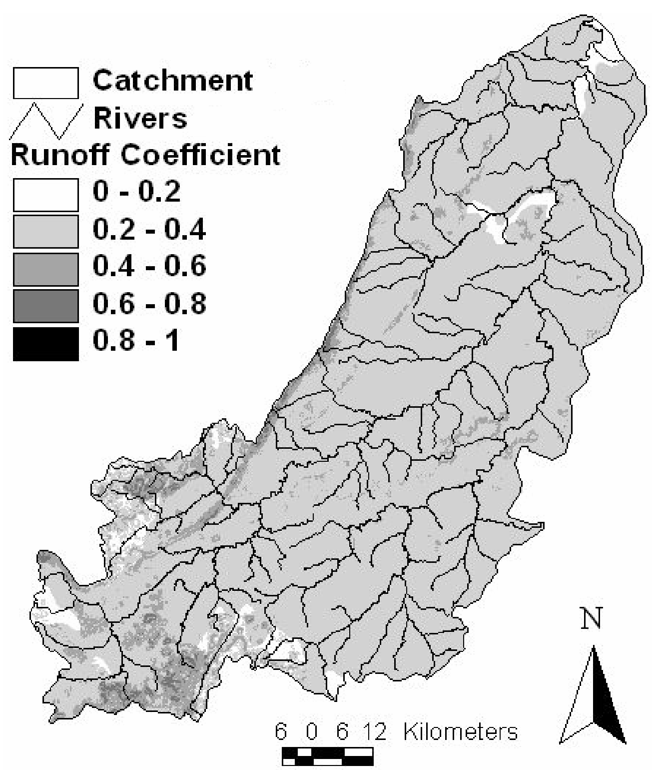


Figure 5: Potential runoff coefficients of the basin

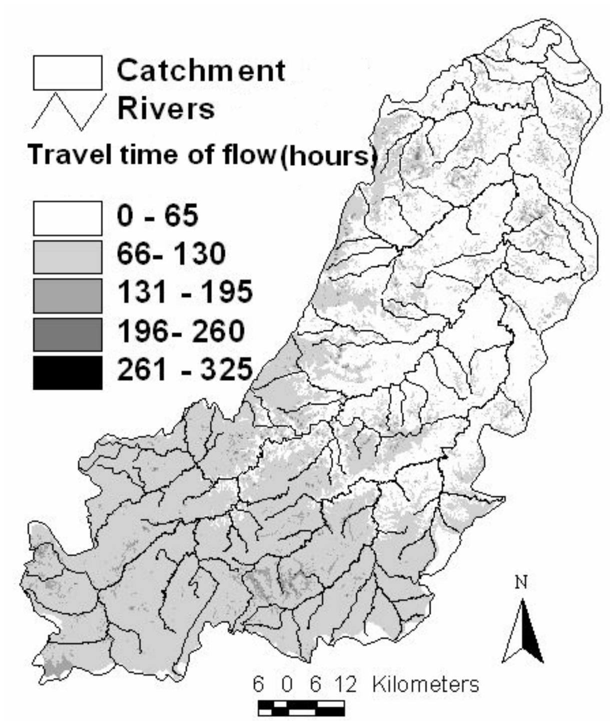
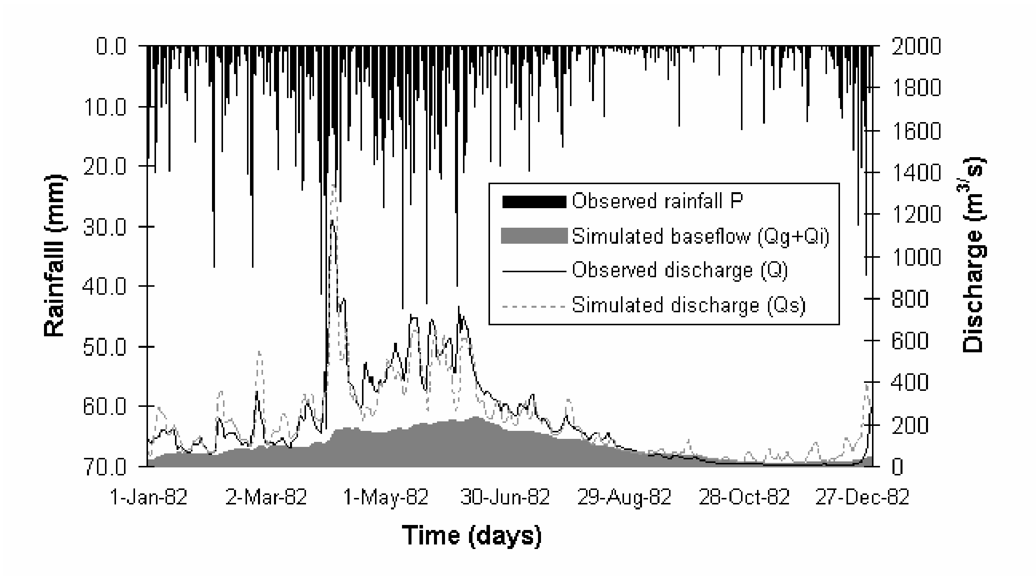


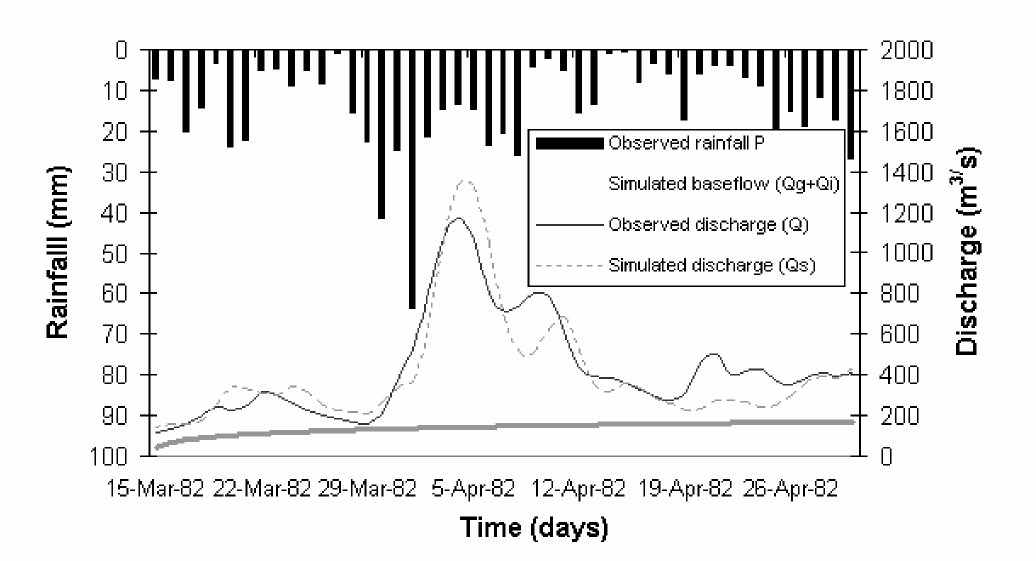
Figure 6: Travel time of flow (hours) to the basin outlet

Figure 7a shows a typical calibration result for year 1982, corresponding to the global input parameters: ki = 1.0, Kg = 0.01, K_ss = 1.0, K_ep = 1.0, go = 30 mm, g_max = 400 mm, K_run = 1.5 and Pmax = 300 mm day^{-1}. During 1982, seven big rainfall storms occurred: February 4, 36.7 mm, February 23, 36.7 mm, April 1, 63.7 mm, May 10, 43.7 mm, May 22, 42.8 mm, June 6, 40.8 mm, December 29, 38.1 mm. The storm of April 1 (Fig. 7b) produced the largest runoff (1170 m^3 s^{-1}). The increase in river flow can be explained by the heavy rainfall events and the increase in base flow (interflow and groundwater flow) during January - mid-June. The decrease in flow after mid-June can be explained by the decrease in rainfall events and the base flow. The peak discharge on April 4, 1982 is a result of the amount of rainfall, the previous rainfalls (2-7 days before) and the soil moisture. During these days, soils were getting saturated leading to an increase in base flow. From the ranked value of the observed and simulated flows (Fig. 8), we may conclude that there are some obvious deviations for low flows (Q < 160 m^3 s^{-1}) and for high flows (Q > 220 m^3 s^{-1}). The error for small flows is up to 436%, especially flows smaller than 30 m^3 s^{-1}, and for large flows up to 23%. The large errors for small flows are caused due to lack of observations, especially during the dry seasons (September-November) and the ability of the model to simulate low flows (< 1 m^3 s^{-1}). The errors for large flows are caused by the use of daily observations, which cannot capture storm events of rainfall causing floods. The lack of other measurements of the hydrological processes (e.g. groundwater flow, infiltration) makes it also difficult to estimate the base flow recession coefficient, and the surface runoff coefficient and the maximum groundwater storage, and may also contribute to the large errors in low flows and high flows respectively. The deviations between the observed and simulated flows may also be caused by the lack of a good representation of the meteorological conditions in the study area (Xiaohua et al 2005). Rainfall and evaporation stations are very scarce and the stations are generally located along the river. Other reasons are deficiency of model structure (Liu

2004), errors in the elevation, soil and land use maps including the low resolution of these maps and the default input parameters used in the model.



(a)



(b)

Figure 7: (a) Observed and calculated river discharges at Pokigron for 1982 (semi-distributed model), (b) observed and calculated river discharges at Pokigron for the peak river flows in April 1982 (semi-distributed model). Note: Qs is the river flow, Qg is de groundwater flow and Qi is the interflow.

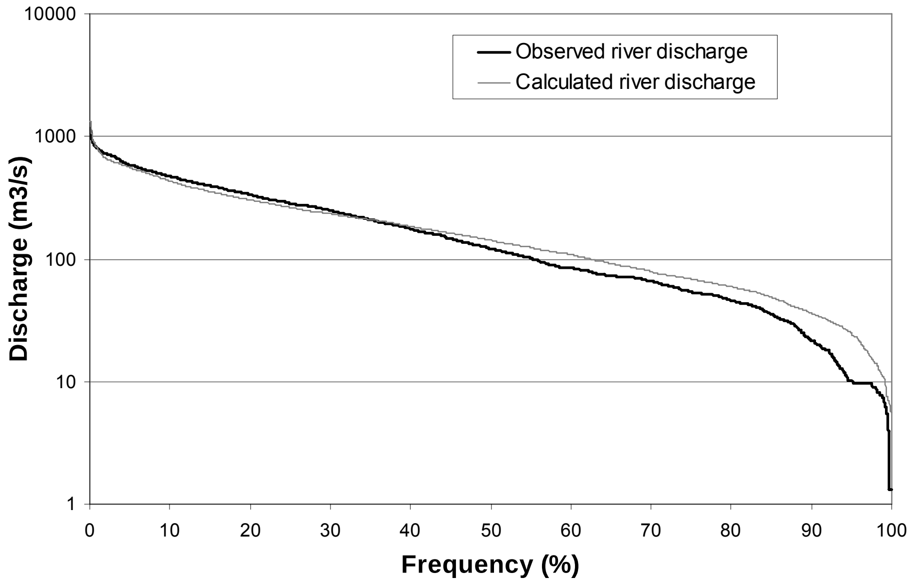


Figure 8: Comparison of the ranked value of the daily observed and simulated mean flows at Pokigron (1978-1983)

Table 4 summarizes the observed and simulated water balance for the period 1978-1983 and for 1982. It is evident that, except for the evapotranspiration component, the observed and simulated precipitation and total runoff water balance components do not differ much from each other. The large difference in the evapotranspiration component is mainly caused by the K_ep coefficient. The best statistical evaluation is found for the year 1982 (Table 5) and similar simulation results are obtained for other hydrological years. The simulated water balance (1978-1983) shows that the total runoff of the Upper Suriname River basin is composed of 57% surface runoff and 43% base flow (groundwater flow and interflow). About 8% of the total precipitation that falls on the surface is captured by vegetation (interception), 67% infiltrates into the soil (infiltration) and 19% runs off the land surface. The missing 6% is due to the soil moisture difference and the groundwater storage at the beginning and end of the simulation period. About 53% of the infiltrated part of the rainfall is percolated further as groundwater flow, about 1% moves laterally as interflow and 47% returns to the atmosphere as evapotranspiration from the root zone. The seasonal water balance analyses shows that when the river discharge increases in the Upper Suriname river in December-February and March-May (see Fig. 7a), the amount of surface runoff is about 60% and base flow about 40% of the total runoff and does not change significantly in both periods. When the discharge decreases (see Fig. 7a), base flow dominates and is about 67% of the total runoff in June-August and 74% of the total runoff in September-November. Surface runoff is about 33% and 26% of the total runoff in June-August and September-November respectively. It is also concluded that during the low flow period, the model evaluation results are the lowest.

Table 4: Observed and simulated water balance of the Upper Suriname river basin for the period (a) 1978-1983 and (b) 1982. Global parameters are set as follows: ki = 1.0, Kg = 0.01, K_ss = 1.0, K_ep = 1.0, go = 30 mm, g_max = 400 mm, K_run = 1.5, Pmax = 300 mm/day (semi-distributed model).

Component	**Observed (mm)**	**Percentage of precipitation (%)**	**Simulated (mm)**	**Percentage of precipitation (%)**
Precipitation	14173	**100**	14052	***100***
Interception			1162	8.3
Infiltration			9453	67.3
Evapotranspiration	12256	**86.5**	8528	**60.7**
Percolation			5053	35.9
Surface runoff			2667	19.1
Interflow			112	0.8
Groundwater flow			2177	13.9
Total runoff	4736	**33.4**	4956	**35.3**
Soil moisture difference			-28	-0.2
Groundwater storage			-51	-0.3

(a)

Component	**Observed (mm)**	**Percentage of P (%)**	**Simulated (mm)**	**Percentage of P (%)**
Precipitation	2524	**100**	2503	***100***
Interception			196	1.7
Infiltration			1692	67.6
Evapotranspiration	1762	**69.8**	1421	**56.8**
Percolation			967	38.7
Surface runoff			479	19.1
Interflow			21	0.8
Groundwater flow			379	15.1
Total runoff	841	**33.3**	878	**35.1**
Soil moisture difference			41	67.6
Groundwater storage			41	1.7

(b)

Table 5: Comparison of model evaluation for the year 1982 using the semi-distributed and fully distributed models. Global parameters are set as follows: ki = 1.0, Kg = 0.01, K_ss = 1.0, K_ep = 1.0, go = 30 mm, g_max = 400 mm, K_run = 1.5, Pmax = 300 mm/day. C1 to C5 are the model evaluation criteria.

Model	**Model evaluation**				
	C1	***C2***	***C3***	***C4***	***C5***
Semi-distributed model	0.078	0.815	0.854	0.700	0.878
Full distributed model	-0.099	0.789	0.808	0.845	0.804

Conclusions

A spatial distributed hydrological model WetSpa in combination with GIS has been applied to the Upper Suriname River basin (7,860 km^2). The fully and semi-distributed models were used to simulate water balance and river flows using digital elevation, soil and land use data, and 9 years of observed daily precipitation and evapotranspiration data. From the results, we may conclude that the model has a relatively high confidence and gives a good representation of the water balance and outflow hydrographs at the basin outlet. The model performance (1978-1983) for reproducing river flows is about 62%, the model determination coefficient is 83%, the Nash-Sutcliffe efficiency is 62% and the ability to reproduce low and high flows is 61% and 71% respectively. The water balance was overestimated by 4.6%. The fact that the optimal evaluation results have not been achieved is due to the model assumptions and some uncertainties in the WetSpa model (Liu 2004), the limited global input parameters, but also the complexity of optimization of some of these parameters. The lack of high resolution DEM, land use and soil maps for the Upper Suriname River basin and the lack of a dense network of precipitation and evapotranspiration stations in the study area also contributed to the obtained model evaluation results. The WetSpa model provided insight in the main flow processes during the year. It is also found that the most sensitive parameters are the interflow scaling factor ki, the groundwater flow recession coefficient Kg, the initial soil moisture K_ss and the correction factor for potential evapotranspiration K_ep. The model appears to be suitable for application to large tropical river basins. The use of ArcView GIS with the WetSpa model enabled us to perform quicker hydrological analyses, especially for large basins, using the semi-distributed model.

ACKNOWLEDGEMENTS

This research is financially supported by the Research and Development Fund of the University of Suriname under project No. Bv/FB/sw-520. The provision of the WetSpa model by Y. B. Liu is gratefully acknowledged. We are thankful for the constructive and valuable review comments by two anonymous reviewers.

References

Andersen, J., Refsgaard, J.C. and Jensen, K.H. (2001). Distributed hydrological modeling of the Senegal River Basin – model construction and validation. pp. 200-214. Journal of Hydrology 247.

Beven, K. (1989) Changing ideas in hydrology – the case of physically based models, pp. 157-172. Journal of Hydrology 105.

Beven, K. J. (2000) Rainfall-runoff modeling, pp. 1-200. John Willey and Sons Ltd, England.

Booij, M.J. (2002) Appropriate modeling of climate change impacts of river flooding (PhD thesis), pp. 1-179. Universiteit Twente, Nederland

Bormann, H. (2005) Regional hydrological modeling in Benin (West Africa): Uncertainty issues versus scenarios of expected future environmental change. pp 472-484. Physics and Chemistry of the Earth 30.

Campling, P., Gobin, Q., Beven, K. and Feyen, J. (2002) Rainfall-runoff modeling of a humid tropical catchment: the TOPMODEL approach, pp 231-253. Hydrological Processes 16.

DeVries, J. J. and Hromadka, T. V. (1993) Computer models for surface water, in: Handbook of Hydrology, Maidment, D.R. (eds), pp. 21.1-21.37. McGraw-Hill, USA.

Feenstra, J. and Short, M. (1996) Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, Draft Version 3, pp. 1-1 - 4-36. United Nations Environment Program (UNDP) and Institute for Environmental Studies, Vrije Universiteit Amsterdam, Netherlands.

Lenselink, K. and van der Weert, R. (1970) Estimating free water evaporation in Suriname, Surinaamse landbouw, pp. 70-79. Suriname.

Liu, Y.B, Gebremeskel, S., De Smedt, F., Hoffman, L and Pfister, L. (2002) Flood prediction with the WetSpa model on catchment scale, eds. Wu et al, pp. 499-507, Flood Defense 2002, Science Press, New York Ltd.

Liu, Y.B, Gebremeskel, S., De Smedt, F., Hoffman, L and Pfister, L. (2003) A diffusive approach for flow routing in GIS based food modeling, J. Hydrol, 283, 91-106.

Liu, Y.B. and De Smedt, F. (2004) WetSpa extension, a GIS based hydrologic model for flood prediction and watershed management, pp. 1-108. Vrije Universiteit Brussel, Belgium.

Liu, Y. (2004) Development and application of a GIS based hydrological model for flood prediction and watershed management (PhD thesis), pp. 1-307. Vrije Universiteit Brussel, Belgium.

Liu, Y.B., De Smedt, F., Hoffmann, L. and Pfister, L. (2004) Parameterization using Arcview GIS in medium and large watershed modeling, GIS and RS in hydrology, water resources and environment, Volume 1, Chen et al (eds).

Liu, Y. (1999) GIS-based spatially distributed hydrological modeling of the Barebeek catchment (MSc thesis), pp. 1-85. Vrije Universiteit Brussel, Belgium.

Maidment, D. (1992) Handbook of Hydrology. 1.3 -23.1. McGrawHill Inc, United States of America.

Molicova, H., Grimaldi, M.m Bonell, M and Hubert, P. (1997) Using topmodel towards identifying and modeling the hydrological patterns within a headwater, humid, tropical catchment, pp. 1169-1196. Hydrological Processes, vol 11.

Nurmohamed, R. (1998) Een methode voor systematisch onderzoek naar het micro-miniwaterkracht potentieel in het binnenland van Suriname (BSc thesis), pp. 58-147. Faculteit der Technologische Wetenschappen, Universiteit van Suriname.

Nurmohamed, R. and Naipal, S. (2004) Trends and Variation in Monthly Rainfall and Temperature in Suriname. Proceedings of the BALWOIS Conference on Water

Observation and Information System for Decision Support. 3. Ohrid, FY Republic of Macedonia on 25-29 May 2000, pp. 3.

Perrin, C., Michel, C. and Andreassian, V. (2001). Does a large number of parameters enhance model performance? Comparative assessment of common catchment model structures on 429 catchments, pp. 275-301. Journal of Hydrology 242.

Seifu, G. (2003) Modeling the effect of climate and land-use changes on the hydrological processes: an integrated GIS and distributed modeling approach (PhD thesis), pp. 22-345. Vrije Universiteit Brussel, Belgium.

WMO/UNESCO (1997) Water Resources Assessment - Handbook for Review of National Capabilities, pp. 1-113. United States of America.

WMO (1975) Inter comparison of hydrological models, WMO publ. Geneva.

Xiaohua, D., Dohmen-Janssen, M and Booij, M. (2005). Appropriate spatial sampling of rainfall for flow simulation, pp. 279-298. Hydrological Sciences Journal 50 (2).