

# IS INTERCEPTION INFORMATION IMPORTANT FOR RAINFALL-RUNOFF MODELING?

Pedro Luiz Borges CHAFFE<sup>1</sup>, Masato KOBAYAMA<sup>2</sup>, Yosuke YAMASHIKI<sup>3</sup>, Kaoru TAKARA<sup>4</sup>

<sup>1</sup>Student Member of JSCE, Graduate student, Dept. of Urban and Environmental Engineering, Kyoto University (Kyoto 615-8540, Japan) Email: pedrochaffe@flood.dpri.kyoto-u.ac.jp

<sup>2</sup>Non-member, D. Eng., Associate Professor, Federal University of Santa Catarina (Florianopolis 88040-900, Brazil)

<sup>3</sup>Member of JSCE, Dr. Eng., Associate Professor, DPRI, Kyoto University (Uji 611-0011, Japan)

<sup>4</sup>Fellow of JSCE, Dr. Eng., Professor, DPRI, Kyoto University (Uji 611-0011, Japan)

So far, it is not known to what extent modeling interception process influences rainfall-runoff modeling. Therefore, the objective of the present work was to investigate whether interception information is important for simulating rainfall-runoff or not. Interception and discharge data from the Saci River Catchment was used. Three different model formulations were used for the analysis of the effects of interception information in rainfall-runoff modeling (Tank Model using gross rainfall as input; using net rainfall as input; and coupled with the Sparse Rutter Model using gross rainfall as input) Model comparison was done through the use of the GLUE method. The results permit to conclude that: (i) the interception information is more important to study the rainfall-runoff processes in dry condition than in wet condition; and (ii) the consideration of the interception information in the hydrological models results better performance in any situation.

*Key Words : Interception, rainfall-runoff, modeling, uncertainty, Saci River Catchment*

## 1. INTRODUCTION

Interception is the first process of the land part of the hydrological cycle and water losses due to it might account for as much as 60% of the annual water budget<sup>1),2),3)</sup>. Despite this fact, interception has been one of the most underrated processes in rainfall-runoff analysis<sup>4)</sup>, especially in rainfall-runoff modeling.

The common approach in hydrological studies is either of the following: (i) to measure and model interception at the plot scale; or (ii) to model rainfall-runoff processes at the catchment scale but only by considering total rainfall and catchment discharge. This difference might be due to the different background of hydrologists that mainly come from agricultural and forestry sciences or civil engineering. Some might be more concerned with long-term water budget for crop production, meanwhile others might be concerned with event-based flooding simulation for example.

Many widely-used hydrological models, such as

TOPMODEL<sup>5)</sup> and Tank Model<sup>6),7)</sup>, simply ignore interception process or consider that it is accounted implicitly in calibrating the model. This might be problematic and disregarding interception might introduce errors in the calibration of subsequent processes<sup>4)</sup>. The HYCYMODEL<sup>8)</sup> is a case of a hydrological model that considers interception process through the use of a interception model developed by Suzuki *et al*<sup>9)</sup>. However, it is not well understood neither to what extent modeling or neglecting interception is relevant in rainfall-runoff analysis nor in which conditions it should be considered.

The objective of the present work was, therefore, to investigate whether interception information is important for rainfall-runoff processes modeling. Both the approaches that usually are used separately were performed by investigating interception process at the plot scale and its influence on rainfall-runoff modeling at the catchment scale.

## 2. SUDY SITE

The Saci River catchment is located in the north of Santa Catarina State, Southern Brazil. This region is characterized by moderate elevation and Subtropical climate. The Saci River catchment area is approximately 10.2 ha, in which around 8.7 ha are *Pinus taeda* afforestation while 1.5 ha is considered to be native forest (Subtropical Ombrophilous Forest) (Fig. 1). The pine forest is very uniform with average height of 30 m and its density of 673 trees/ha.

This catchment is a headwater of the Parana River Basin, which is considered one of the most important ones in the South America due to its rich natural resources and biodiversity and also to its high hydropower generation capacity. The Saci River catchment is a part of the school-catchment network implemented by Kobiyama *et al.*<sup>10</sup> in order to answer the questions: what is the influence of different land cover on the rainfall-runoff processes?; and what kind of land-use is better for the water resources management in the region?

## 3. HYDROLOGICAL DATA

We estimated rainfall interception by measuring gross rainfall, throughfall and stemflow (Fig. 1). Gross rainfall was measured with a tipping bucket at a cleared area beside the catchment. Throughfall

was measured by using pairs of steel troughs connected to tipping buckets in two points in the catchment; the value of throughfall was then averaged to represent catchment throughfall. Stemflow was measured with rubber hoses around four different stems and connected to a tipping bucket; therefore the value of stemflow was an average of 4 trees. Net rainfall was considered to be the sum of throughfall and stemflow and interception the difference between gross rainfall and net rainfall. A data series from 23/Aug/2008 to the 17/Nov/2008 with 10-min time interval was obtained (Fig. 2). The total amount of gross rainfall during this period was 665 mm and throughfall, stemflow and interception corresponded to 71.2%, 7.4% and 21.4% of the gross rainfall, respectively.

A discharge time series of the same period and temporal resolution as rainfall was obtained (Fig. 2). It was measured by using a Parshall flume coupled with a weir system and with a water level gauge connected to a datalogger. Potential evapotranspiration was calculated by using the modified Penman method<sup>11</sup> and INMET (Brazilian National Institute of Meteorology) data.

Despite a relatively short time series of hydrological data, this series represents different climatic conditions. It covers from the end of the winter to the end of the spring in the Southern Hemisphere.

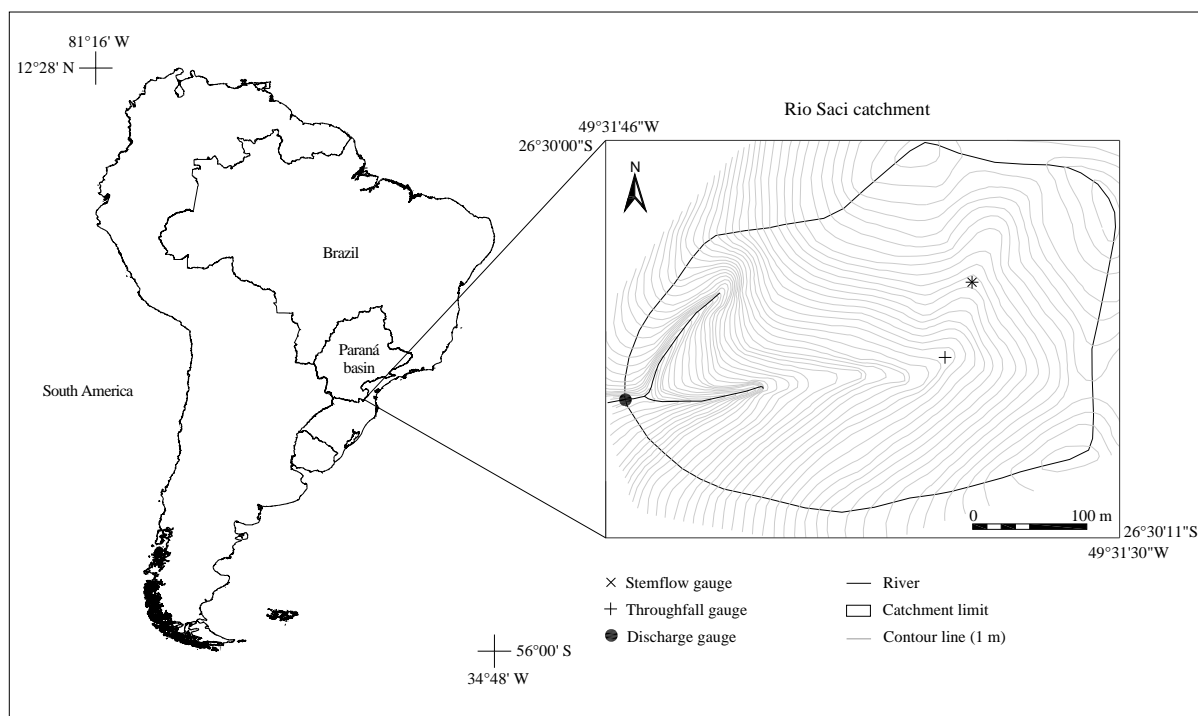
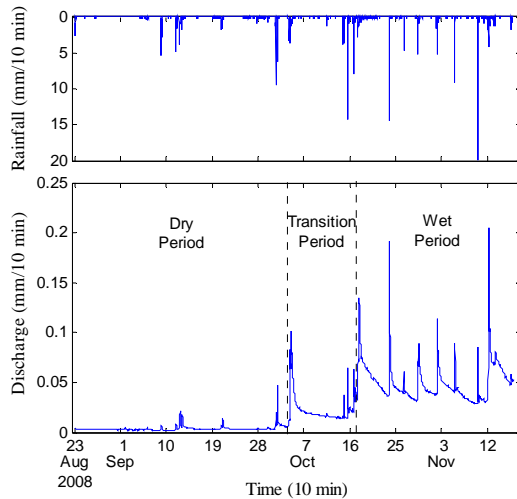


Fig.1 Location of the Saci River Catchment and gauging stations.

Discharge was very low at the beginning and total rainfall towards the end was very higher if compared to the same seasons in previous years. Therefore, the present study divided the series into three distinct periods: The first one (Dry Period) comprehends the time from 23/Aug/2008 at 4h20min to 3/Oct/2008 at 20h10min; the second (Transition Period) from 03/Oct/2008 at 20h10min to 17/Oct/2008 at 14h10min; the third (Wet Period) from 17/10/2008 at 14h10min to 17/Nov/2008 at 6h20min (**Fig. 2**).



**Fig.2** Time series of gross rainfall and discharge used for the study.

#### 4. MODELING PROCEDURE

The models used in this study were the Tank Model<sup>(6,7)</sup> and the Sparse Rutter Model<sup>(12)</sup>. The former one was used for rainfall-runoff modeling, it has the advantage of being simple to implement and its four tanks structure can represent different humidity conditions of the catchment. The latter one is a generalization of the widely-used<sup>(13)</sup> Rutter Model<sup>(14)</sup>. Chaffe<sup>(15)</sup> showed that the Sparse Rutter Model simulated the interception process in a continuous way rather than an event-based approach, and produced good results for the interception simulation for the Saci River catchment well.

Basically, the approach taken for modeling was to use the Tank Model by itself and the Tank Model coupled with the Sparse Rutter Model.

##### (1) Tank Model

The Tank Model with four tanks was utilized (**Fig. 3**). This structure was considered a good initial model<sup>(6,7)</sup> and had satisfactory performance in previous simulations<sup>(15)</sup>. Basically, rainfall water is input to the first tank and it is consequently

discharged by the outlets following the equation:

$$q(t) = \lambda \cdot h(t) \quad (1)$$

where  $q(t)$  is the discharge at time  $t$ ,  $\lambda$  is a constant representing the size of the outlet and  $h(t)$  is the amount of water above the orifice at time  $t$ . Total discharge is the sum of all the side-outlet discharges. Evapotranspiration is initially taken out from the first tank. In the case where the amount of water in the first tank is less than potential evapotranspiration, the remaining potential evapotranspiration is subsequently taken from the second, third or fourth tank.

The used model has 12 parameters (**Fig. 3**) and their feasible interval were determined from previous studies<sup>(6,7)</sup>. The parameters started by  $H$  mean the height of the side outlet above the bottom of each tank. The parameters started by  $C$  are the constant representing the size of the outlet.

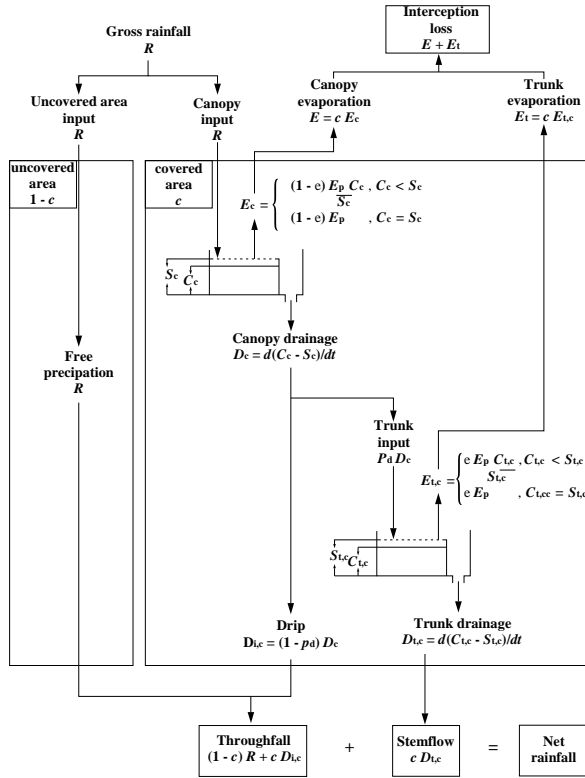
Parameter	Range		Dimension
	min.	max.	
$C_1U$	0,001	0,5	1/(10min)
$C_1D$	0,001	0,5	1/(10min)
$C_1I$	0,001	0,5	1/(10min)
$C_2D$	0,0001	0,1	1/(10min)
$C_2I$	0,0001	0,1	1/(10min)
$C_3D$	0,00005	0,002	1/(10min)
$C_3I$	0,00005	0,002	1/(10min)
$C_4D$	0,00001	0,0005	1/(10min)
$H_1U$	10	30	mm
$H_1D$	0	10	mm
$H_2D$	0	40	mm
$H_3D$	0	40	mm

**Fig.3** Structure of the Tank Model used in this study and its parameters and sampling interval.

##### (2) Tank Model coupled with Sparse Rutter Model

The interception model firstly developed by Rutter *et al.*<sup>(1,16)</sup> is based on a water budget of the canopy and trunks storage during rainfall events. Rainfall is the input to these storages and evaporation, throughfall and stemflow is output. This model was generalized to the case of sparse vegetation<sup>(12)</sup>. The rainfall is firstly subdivided by a cover factor  $c$  into free precipitation and canopy input. Water reaching the canopy firstly fills up canopy storage ( $S_c$ ), when the water in the canopy is bigger than canopy capacity ( $C_c$ ), the surplus is subdivided into drip or trunk input by a proportion  $p_d$ . Stemflow is generated when water in the trunk storage ( $S_{t,c}$ ) is above trunk storage capacity ( $C_{t,c}$ ). Evaporation is taken out from both the canopy and trunk storages, and the proportion for each tank is

relative to a fraction  $e$ . **Fig. 4** shows the flowchart for the Sparse Rutter Model. This model has five parameters (**Table 1**).



**Fig.4** Schematic representation of the Sparse Rutter Model (Adapted from Valente *et al.*<sup>12</sup>)

**Table 1** Sparse Rutter Model Parameters.

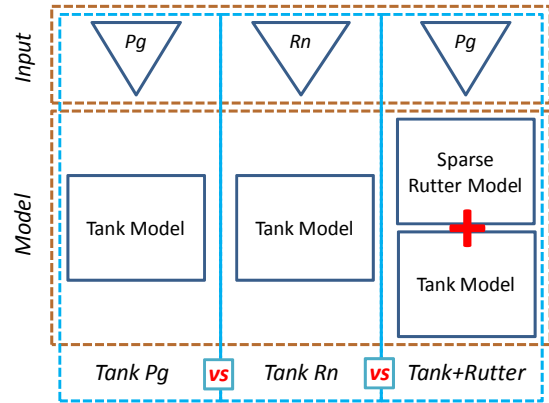
Parameter	Range		Dimension
	min.	max.	
$c$	0,50	0,95	-
$S_c$	1,50	4,00	mm
$S_{t,c}$	0,90	2,50	mm
$p_d$	0,05	0,60	-
$e$	0,05	0,50	-

The Sparse Rutter model was coupled to the Tank Model in one routine, making the model called *Tank+Rutter*. Therefore, this new model possesses 17 parameters, 12 from the original Tank Model and 5 from the Sparse Rutter Model. The main differences in the *Tank+Rutter* are that gross rainfall first goes through the interception process and only the net rainfall reaches the first tank of the Tank Model. Also the potential evapotranspiration is first taken out from the water in the canopy and trunk. Evapotranspiration is only taken from the tank system when the water in the canopy and trunks is less than potential evapotranspiration. Therefore, in this new model, it was considered that transpiration occurs only when evaporation is less than potential

evapotranspiration.

### (3) Model Comparison

Three Models were used for the analysis of the effects of interception information in rainfall-runoff modeling (**Fig. 5**): (i) Tank Model using gross rainfall as input (*Tank Pg*); (ii) Tank Model using net rainfall as input (*Tank Rn*); (iii) Tank Model coupled with the Sparse Rutter Model using gross rainfall as input (*Tank+Rutter*). The three periods found in the discharge data were separately analyzed and the comparison was carried out using the three models applied to each period. *Tank Pg* might be similar to most of models that completely disregard the interception. *Tank Rn* would be the ideal case, where all the interception information is known. *Tank+Rutter* is the case where interception information is not enough and it is necessary to compensate this process by explicitly simulating it.



**Fig.5** Comparison framework.  $P_g$  is the gross rainfall;  $R_n$  is the net rainfall; *Tank Pg* is the Tank Model with gross rainfall input; *Tank Rn* is the Tank Model with net rainfall input; and *Tank+Rutter* is the Tank Model coupled with the Sparse Rutter Model and with gross rainfall input.

In order to realize a fair comparison, no model parameters were extracted previously from the data, and it was used a framework similar to the GLUE method<sup>17</sup> which is usually used for sensitivity and uncertainty analysis of hydrological models. The procedure used in the present study was: (i) based on the literature, a feasible sampling range for the model parameters was chosen (**Table 1** and **Fig. 3**); (ii) 10,000 simulations were made by using parameter sets sampled by a Monte Carlo simulation with uniform distribution; (iii) the models performances were evaluated with the *Nash* coefficient<sup>18</sup>; (iv) a simulation was accepted if its *Nash* value was greater than zero, it means that the model was a better representation of the data than the sample average. The uncertainty intervals were estimated using the accepted simulations. The *Nash* coefficient was calculated by the following

equation:

$$Nash(\Theta) = 1 - \frac{\sum_{t=1}^J (o(t) - \hat{o}(t|\Theta))^2}{\sum_{t=1}^J (o(t) - \bar{o})^2} \quad (2)$$

where  $Nash(\Theta)$  is the Nash coefficient for the parameter set  $\Theta$ ;  $o(t)$  is the observed discharge at time  $t$ ;  $\hat{o}(t|\Theta)$  is the calculated discharge at time  $t$  using the parameter set  $\Theta$ ;  $\bar{o}$  is the discharge sample average; and  $J$  is total time steps.

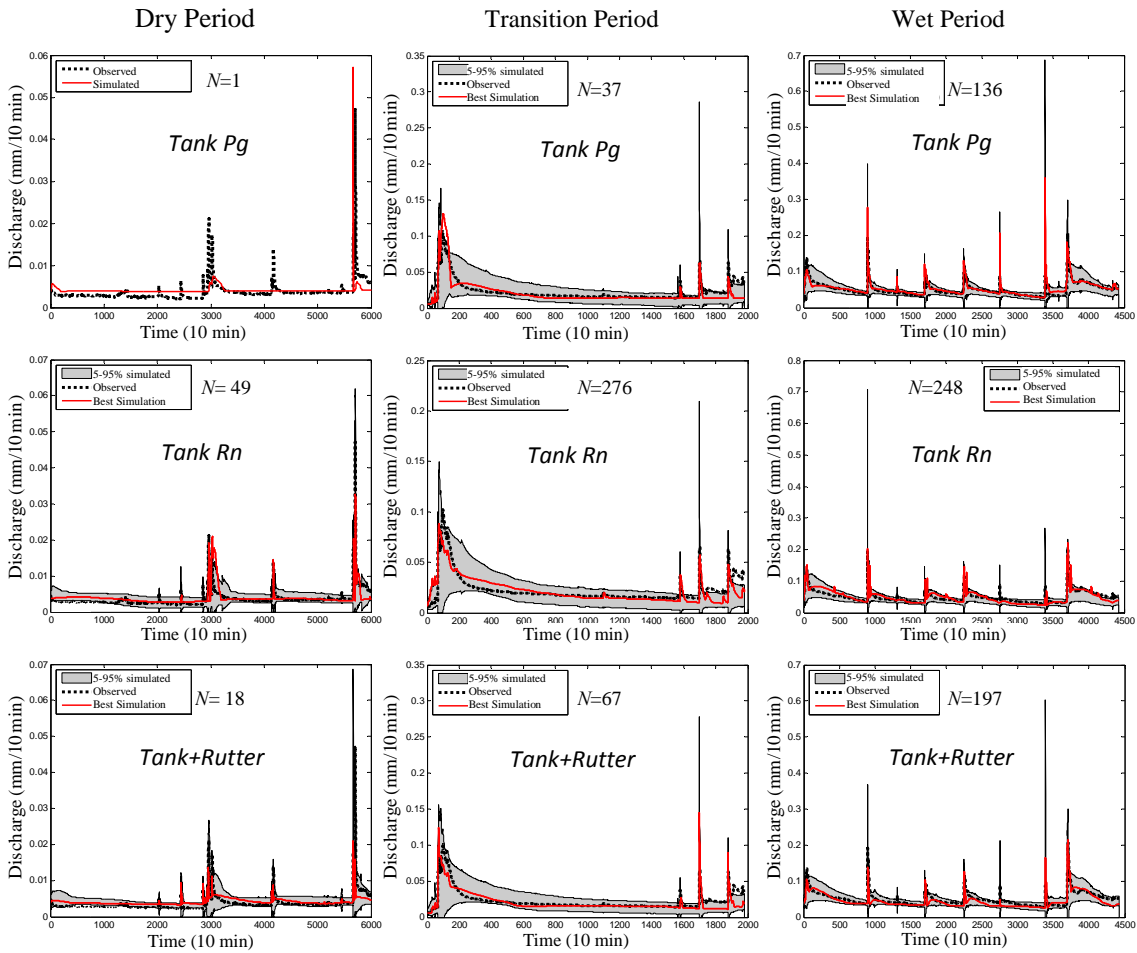
## 5. RESULTS AND DISCUSSION

The best simulations with the three models applied to the three distinct periods are presented in **Fig. 6**. All the models produced better results when simulating the Transition Period and the Wet Period. It indicates that the drier the catchment becomes, the

more difficult it is to simulate the rainfall-runoff processes. The dry condition makes the interception processes more significant in the rainfall-runoff processes.

In all the cases the *Tank Rn* model performed better with successful simulations  $N = 49, 276$  and  $248$  out of 10,000 simulations for the dry, transition and wet period respectively. The *Tank Pg* model that did not consider any interception process produced fewer simulations with  $Nash$  values above zero (successful simulations,  $N$ ). This results confirm that it is the net rainfall that enters into the catchment, and that not the gross rainfall. Even though it must be very obvious, most of all the rainfall-runoff models disregard this obvious fact.

It seems that the Sparse Rutter Model performed well to simulate the interception. However, the fact that *Tank Rn* had results better than *Tank+Rutter* implies that there is still necessity to improve the interception process model.



**Fig.6** Simulations of the three periods using the three models: (i) *Tank Pg* is the Tank Model with gross rainfall input; (ii) *Tank Rn* is the Tank Model with net rainfall input; and (iii) *Tank+Rutter* is the Tank Model coupled with the Sparse Rutter Model and with gross rainfall input. The gray area is the uncertainty interval estimated with the simulations with  $Nash$  value greater than zero ( $N$ ).

The *Tank Pg* had the worst performance for the dry period, only one simulation was successful ( $N = 1$ ). This shows that in cases where interception is greater, we cannot expect that models that do not consider this process explicitly will perform well.

The *Nash* values for the best simulation are an indication that models do not perform so differently during the Wet Period. However, the uncertainty interval in Fig. 6 shows that the *Tank Pg* tends to overestimate discharge peaks.

## 6. CONCLUSIONS

We used the data obtained at the Saci River Catchment, southern Brazil and applied the Tank Model and the Sparse Rutter Model, in order to discuss the importance of the interception information in rainfall-runoff modeling. As shown in Fig. 6, *Tank Rn* (Tank Model with net rainfall input) performed best for all the dry, transition and wet periods. That is because *Tank Rn* uses the information about interception that we actually monitored.

The results suggest that: (i) the interception information is more important to study the rainfall-runoff processes in dry condition than in wet condition; and (ii) the consideration on the interception information in the hydrological models makes their performance better in any situation.

Hence the present study teaches the necessity to investigate more the interception processes and to put it into the rainfall-runoff modeling.

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