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Rainfall-runoff Modeling of the Molawin Watershed of the Makiling Forest Reserve Using Five Lumped Conceptual Models

Mart Dayniel M. Clanor,[1] Romina Gloria M. Bondad,[2] Erwin C. Escobar,[2,*] Joseph M. Caburnay,[1] Jey-R S. Ventura,[2] Adeliza A. Dorado,[2] Maria Morissa D. Lu,[2] and Ariel U. Glorioso[2]

[1]Department of Civil Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños; [2]Department of Engineering Science, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños
** Corresponding author (ecescobar1@up.edu.ph)*

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Abstract

Five lumped conceptual models, namely, Australian Water Balance Method (AWBM), Sacramento, SimHyd, Soil Moisture Accounting and Routing (SMAR), and Tank were used to simulate rainfall-runoff relations in the Molawin watershed of the Makiling Forest Reserve. The software Rainfall-Runoff Library which was developed by the Cooperative Research Center for Catchment Hydrology (CRCCH) in Australia was used for all the modeling activities. The models were calibrated using four years of stream flow data. Succeeding two years of stream flow data was used for validation. Based on calibration NSE values, two models, Sacramento and Tank, have very good model performances, registering NSE values of 0.914 and 0.928, respectively. Validation results show that only SMAR and AWBM were unsatisfactory. The validation NSE values reveal that the arrangement of the models from best to poorest is as follows: Tank, SimHyd, Sacramento, SMAR and AWBM.

Keywords: Rainfall-runoff modeling, lumped conceptual models, watershed, Rainfall-Runoff Library, Makiling Forest Reserve, Nash-Sutcliffe Efficiency

Introduction

The hydrologic community has well realized the importance of relating rainfall and runoff for a specific catchment in a process called rainfall-runoff modeling. Stream flow information which is derivable from such models is identified as a major element and requisite to decision-making in water resources planning and management (Young, 2006; Vaze et al., 2011). Generally, rainfall-runoff models are critical for studies which focus on exploiting the untapped potential of surface water (Goswami et al., 2006), approximation of watershed yield and climate change impacts on stream flow characteristics (Chiew & Siriwardena, 2005), accurate forecasting of low flows which is necessary to balance needs in agriculture, industry, and domestic population while protecting aquatic and riparian ecology (Dye & Croke, 2002), flood estimation and forecasting, trend identification, and design and management of reservoirs (Perrin et al., 2005).

A large collection of rainfall-runoff models of different levels of intricacy is available in literature (Goswami et al., 2002b). It ranges from the simplest empirical models to the complicated physically-based distributed models done in GIS. According to Goswami et al. (2002a) this growth is further encouraged by the development of progressively efficient computer technology which equips hydrologists with advanced tools for the modeling task. However, despite this broad range of models, it cannot be asserted that a single specific model among these performs best for every catchment type and under different conditions (Shamseldin et al., 1997). For this reason, a viable alternative approach is to simultaneously generate runoff from different models and choose the best among them.

The purpose of this study is to perform a multi-model approach to rainfall-runoff modeling for the Molawin watershed in Makiling Forest Reserve. Five lumped conceptual models, namely, Australian Water Balance Method (AWBM), Sacramento, SimHyd, Soil Moisture Accounting and Routing (SMAR), and Tank, were applied in the catchment. Use of these simple conceptual models rather than the complex, physically-based distributed types was justified by the relatively small area of the catchment. Also, Goswami et al. (2002a) confirms that simple lumped conceptual models can exceed the accuracy of more complex models.

The whole of the modeling task for the individual models was performed using the software Rainfall Runoff Library (RRL) which is implemented within the modeling framework called The Invisible Modeling Environment (TIME). RRL offers a user-friendly interface wherein all the equations, calculations within the model, and optimization processes are embedded inside the program and are "invisible" to the user. All the models considered are classified as continuous, deterministic, lumped and conceptual rainfall-runoff models. Since lumped conceptual models are generally continuous and deterministic, they are sufficiently termed as lumped conceptual models.

Past researches involving rainfall-runoff modeling in the Molawin watershed was performed by Combalicer et al. (2010) using lumped BROOK90 model wherein they also evaluated the use of hydrologic model for the specific tropical conditions of the forested watershed. Also, Velarde (2012) performed the modeling using Australian Water Balance Model in his study assessing the irrigation capability of the Molawin creek.

This paper demonstrates the application of the modeling procedure including the computer program used. It presents a detailed methodology of the process in a manner that makes it a viable reference for conducting similar modeling studies in other catchments in the country.

Methodology

Modeling software

The modeling software used was the Rainfall Runoff Library (RRL). This modeling program was developed by the Cooperative Research Center for Catchment Hydrology (CRCCH) in Australia. This software contains five model structures, namely, Australian Water Balance Model (AWBM), Sacramento, SimHyd, Soil Moisture Accounting and Routing (SMAR) model, and Tank. For a brief discussion of these five models and their parameters, refer to the Supplementary Materials.

Climate data

Daily rainfall and evapotranspiration data from 2004 to 2009 were acquired from the UPLB-NAS (National Agrometeorology Station) which is located at 14.165° N, 121.250° E. Rainfall data was measured using a standard rain gauge. Evapotranspiration data, on the other hand, was acquired in two different sets as the procedure requires--- one measured using Class A evaporation pan, and another using Colorado sunken pan.

Potential evapotranspiration which is required for Sacramento, SimHyd, and Tank models was determined by using the one-variable potential evapotranspiration model of Tamisin (1977) shown below:

$$ET_O = 0.7836 + 0.588E_S$$

where ET_O is the potential evapotranspiration and E_S is the Colorado sunken pan evaporation. This linear model was specifically validated for UPLB conditions with an R^2 value of 0.93.

Actual evapotranspiration required for AWBM was determined using the equation of Doorenbos (1977) shown below:

$$ET_C = k_C \; x \; ET_O$$

where ET_c is the actual evapotranspiration, and k_c is the crop coefficient. The crop coefficient value of 0.9 approximated based on the results of the research of Runtunuwu (2007) was adopted for this study due to lack of available data.

Stream flow data

The daily stream flow data for the Molawin watershed was obtained from the College of Forestry and Natural Resources, UPLB. The gauging station is located at 14.1564° N, 121.234° E (ASTI, n.d.) within the Makiling Botanic Garden. The record available was from 2004 to 2009; however, there were some missing data within the time span including a six-month gap in 2007. The location of the gauging station is presented in Figure 1.

Watershed location and area

The Makiling Forest Reserve where the Molawin watershed is located stretches within 14°6' to 14°11' north latitude and 121°09' to 121°15' east longitude. The area of the Molawin watershed was determined from a GIS shapefile. Using the Measure Area function of Quantum GIS, the boundaries of the watershed, as delineated by Saplaco et al. (2001), was traced and the area was determined to be about 377 hectares. Watershed area is needed to calculate the total volume from the data expressed in depth.

Modeling preliminaries

Preliminary inspection of data was conducted by checking inconsistencies in fluctuations in rainfall and stream flow values. Upon checking, there was a number of abnormal rainfall-runoff relations observed. The most significant of these which was also identified by Velarde (2012), is the 17 consecutive days erratic data during the latter part of 2009. These portions of the data were omitted accordingly.

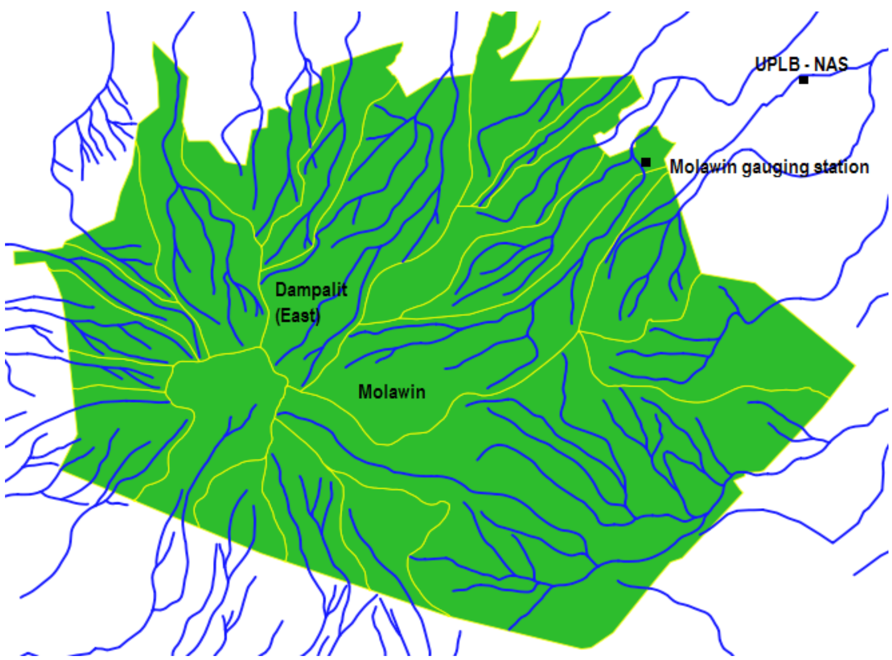

Figure 1. Relative location of the Molawin watershed and the data measurement sites.

Modeling process concept

Figure 2 summarizes the modeling process employed. Climatic data were first entered in the rainfall-runoff model with arbitrarily set initial parameters such as A, B, C and D. This resulted to an initial set of stream flow simulation which is compared to the actual stream flow using the Nash-Sutcliffe efficiency (NSE). Thereafter, the model parameters were systematically optimized using genetic algorithm and pattern search to obtain the maximum NSE.

Modeling in Rainfall Runoff Library

The Rainfall Runoff Library User Guide by Podger (2004) found on the help menu of the program provides ample discussion of the different functions and features of the program. This section presents the actual procedure used within RRL to run the five lumped conceptual models.

Several data formats and file types are enumerated in the RRL documentation and examples of these are found in the sample models included in the program. For this study, the data were saved in DAT files separately, that is, one DAT file for rainfall, one for evaporation, and another for the stream flow data. These DAT files include rows of information about specific data values with respective dates. Upon successful input of the data, RRL creates time series graphs for each as shown in Figure 3. The units of the data are manually specified.

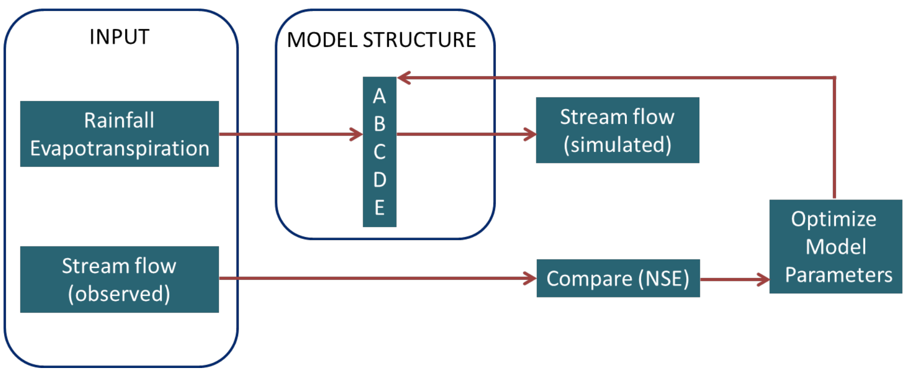

Figure 2. Modeling process flow diagram.

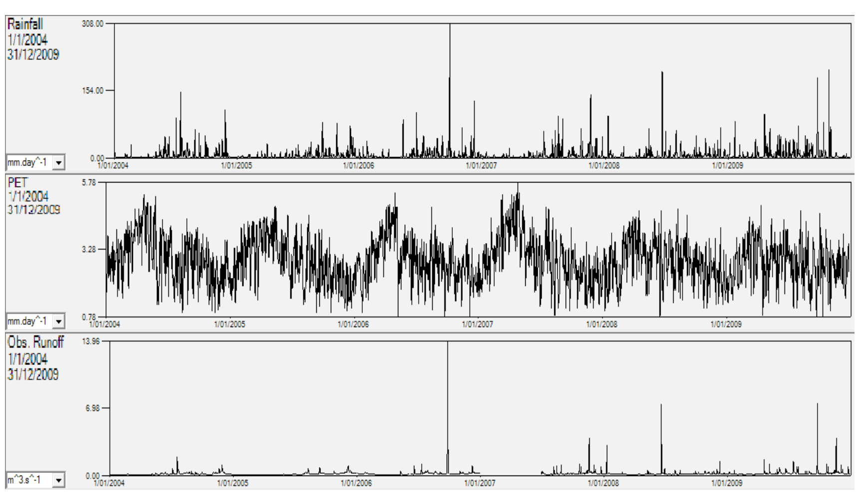

Figure 3. RRL data input interface.

Model Calibration and Validation

The process of calibration and validation was initiated by setting the calibration, validation and warm-up periods. Approximately two-thirds of the data, that is, from 2004 to 2007, was used for model calibration and the rest for model validation. Warm-up periods were set as the first six months of both the calibration and validation periods.

Calibration and validation were simultaneously performed in RRL in the form shown in Figure 4 by clicking the *Calibrate* button after the objective function was set. The process of calibration and validation were done iteratively. The first iteration was performed using genetic algorithm as the optimization method; the second iteration was performed using pattern search. This procedure was adopted since genetic algorithm focuses on global optimum search while pattern search focuses on local. In effect, pattern search was used to fine tune the calibrated parameters from genetic algorithm. Further parameter fine tuning was implemented by decreasing the step size and increasing the maximum number of iterations in the pattern search algorithm until no improvement was observed in the Nash-Sutcliffe efficiency (NSE). This was accomplished through a pop-up box that appears by clicking the *parameters* button shown in Figure 4. Finally, the optimized parameters, stream flow simulation and the maximum value of NSE for calibration and validation were obtained. The whole process, from data input to model optimization, was performed for all the five models in RRL.

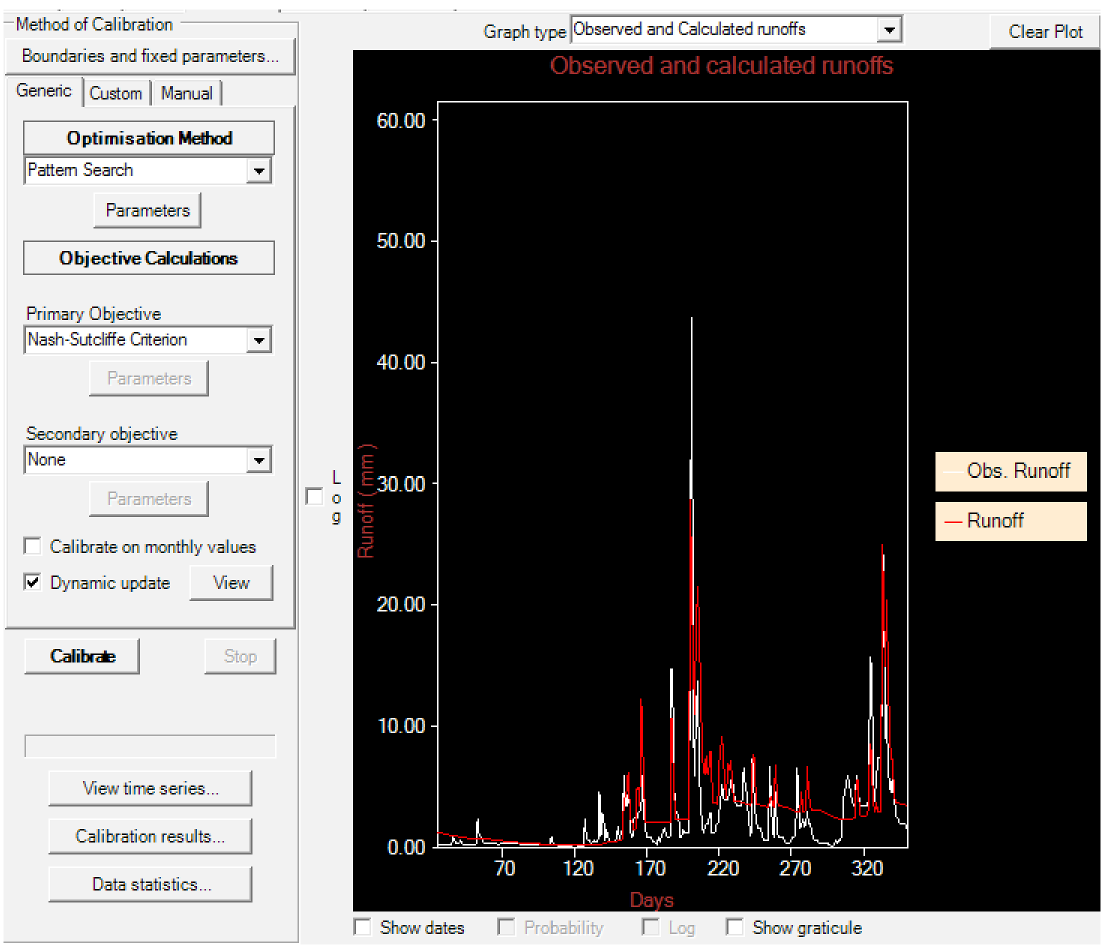

Figure 4. RRL calibration and validation interface.

Model efficiency criteria

The model criterion employed in this study was the Nash-Sutcliffe efficiency (NSE). NSE (Nash & Sutcliffe, 1970) is one of the most widely used objective functions in rainfall-runoff modeling. It measures how better the model simulation is compared to simply using the mean stream flow as the simulation (Goswami et al., 2002b). The value of NSE has 1.0 as the upper bound for perfect simulation but has no lower bound. Moreover, a value of zero suggests that the simulation is only as good as using the average runoff as the daily stream flow (Goswami et al., 2010). It is generally agreed that an NSE value of 0.6 indicates reasonable modeling while a value of 0.9 indicates good modeling (Chiew & Siriwardena, 2005; Whyte et al., 2011) although few authors like Goswami et al. (2006) consider more conservative designations with below 0.8 as unsatisfactory, 0.8 – 0.9 as a fairly good fit, and 0.9 and above as a very good model fit. The latter distinction was considered in this study. The NSE is expressed mathematically as

$$NSE = 1 - \frac{\Sigma[(Q_o)_i - (Q_s)_i]^2}{\Sigma[(Q_o)_i - Q_{ave}]^2}$$

where $(Q_o)_i$ is the observed stream flow at the ith day, $(Q_s)_i$ is the simulated stream flow at the ith day, and Q_{ave} is the average of the observed stream flow data at the time period.

Results and Discussion

For each of the five individual models, the data for area, rainfall, observed stream flow, calibration, validation and warm-up time periods were identical. Only the evaporation data differed in form for some of the models. Most utilized potential evapotranspiration while others such as AWBM and SMAR require actual evapotranspiration and pan-evaporation, respectively. Also, the same process of calibration was done for each of the models. The iterative calibration process was started by using genetic algorithm with default optimization parameters. Subsequently, pattern search optimization method was used with default optimization parameters, after which pattern search was repeated with a more elaborate set of optimization parameters. A summary of the pattern search parameters is provided in Table 1.

Table 1. Pattern Search parameters for the calibration.

PARAMETER	INITIAL VALUE	IMPROVED VALUE
Initial step size	0.1	0.01
Maximum number of iterations	100	300
Maximum number of halving step size	7	7

Upon calibration and validation in RRL, the following results were available: set of calibrated parameters, runoff simulation, and NSE values. Tables 2 to 6 show the calibrated parameters of the five individual models for the Molawin catchment, and Table 7 provides a summary of the NSE values obtained from each.

Table 2. Calibrated parameters of AWBM.

PARAMETER	CALIBRATED VALUE
A1	0.887500132
A2	0.290276276
BFI	0.744523746
C1	20.829695250
C2	48.853986700
C3	874.832150000
KBase	0.283227877
KSurf	0.992555533

Table 3. Calibrated parameters of Sacramento.

PARAMETER	CALIBRATED VALUE
Adimp	0.084705882
Lzfpm	18
Lzsfm	33.862745100
Lzpk	0.059411765
Lzsk	0.304117647
Lztwm	99.45098039
Pctim	0.055294118
Pfree	0.009411765
Rexp	0.012941176
Rserv	0.007058824
Sarva	0.004509804
Side	0.990588235
Ssout	0.008235294
Uzfwm	39.05882353
Uzk	0.822156863
Uztwm	0.647058824
Zperc	77.38039216

Table 4. Calibrated parameters of SimHyd.

PARAMETER	CALIBRATED VALUE
baseflow coefficient	0.417132353
impervious threshold	4.996446078
infiltration coefficient	341.3235294
infiltration shape	1.40245098
interflow coefficient	0.001029412
pervious fraction	0.999019608
RISC	0.006004902
Recharge coefficient	0.744044118
SMSC	499.5597059

Table 5. Calibrated parameters of SMAR.

PARAMETER	CALIBRATED VALUE
C	0.8875001
G	0.6714305
H	0.3347792
Kg	0.7163646
N	1
NK	1
T	0.9570175
Y	4999.997
Z	536.06799

Table 6. Calibrated parameters of Tank.

PARAMETER	CALIBRATED VALUE
a11	0.7441675
a12	0.1729405
a21	1
a31	0.0970121
a41	0.0009528
alpha	0.0040011
b1	0.3070935
b2	0.3551682
b3	0.3298438
c1	11.125
c2	5.6420699
c3	11.690883
c4	11.52685
h11	202.68835
h12	18.606502
h21	48.347855
h31	0
h41	56.625

Table 7. NSE values of the individual models*.

MODELS	NSE	
	Calibration	Validation
AWBM	0.706	0.599
Sacramento	0.914	0.800
SimHyd	0.878	0.802
SMAR	0.822	0.709
Tank	0.928	0.809

*NSE < 0.8, unsatisfactory; 0.8 < NSE < 0.9, fairly good fit; NSE > 0.9, very good model fit

For the calibration NSE value (NSE_c), it was observed that two models, Sacramento and Tank, have very good model performances with NSE_c values greater than 0.9; on the other hand, AWBM has poor performance in calibration with an NSE_c value of 0.706. The validation results show that only SMAR and AWBM were unsatisfactory for the modeling with validation NSE values (NSE_v) less than 0.8. The validation NSE values reveal that the arrangement of the models from best to worst model performance is as follows: Tank, SimHyd, Sacramento, SMAR and AWBM. Figure 5 shows the calibration and validation NSE of each model.

After calibration, RRL offers visualization of results through different plots available within the program. Examples of the graphs available are shown in the next figures. For brevity, only results for the best individual model, Tank, are shown.

Figure 6 illustrates the scatter plot of observed and simulated stream flow using Tank for the calibration and validation sets of data. As shown, simulated and observed stream flow values are in better agreement at lower stream flow values than at higher values, that is, for relatively small values of stream flow the points are very close to the 45-degree line that represents equality of the observed and simulated values. This is true for both the calibration and validation data sets. The figure also shows that at high stream flows, the model tends to provide underestimates of the actual stream flow as more of the validation data sets appear below the 45-degree line.

Figure 7 illustrates the graph of observed stream flow plotted against the simulated stream flow using Tank. The figure shows that the hydrographs of the observed and simulated

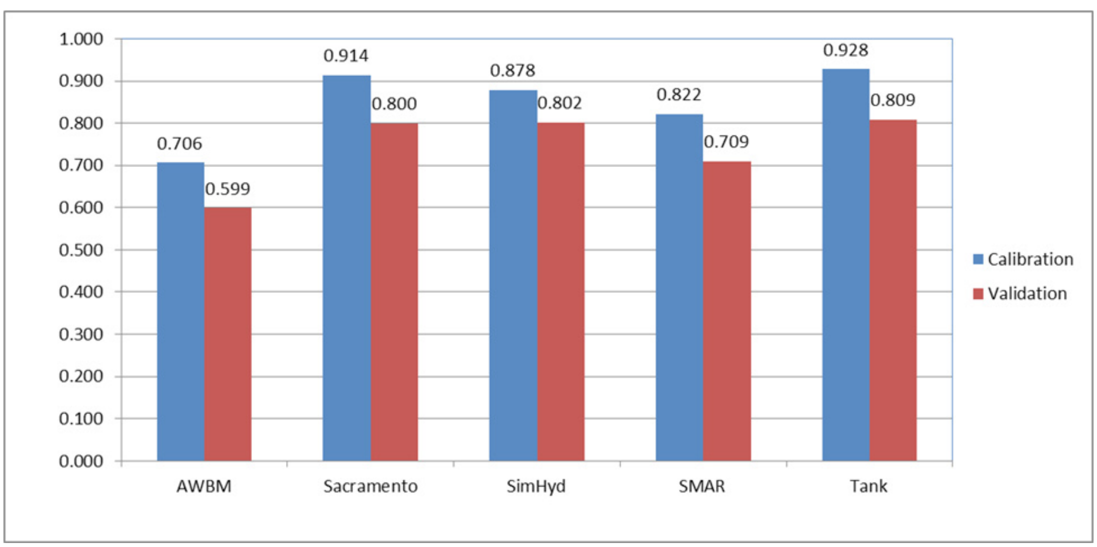

Figure 5. Calibration and validation NSE of the models.

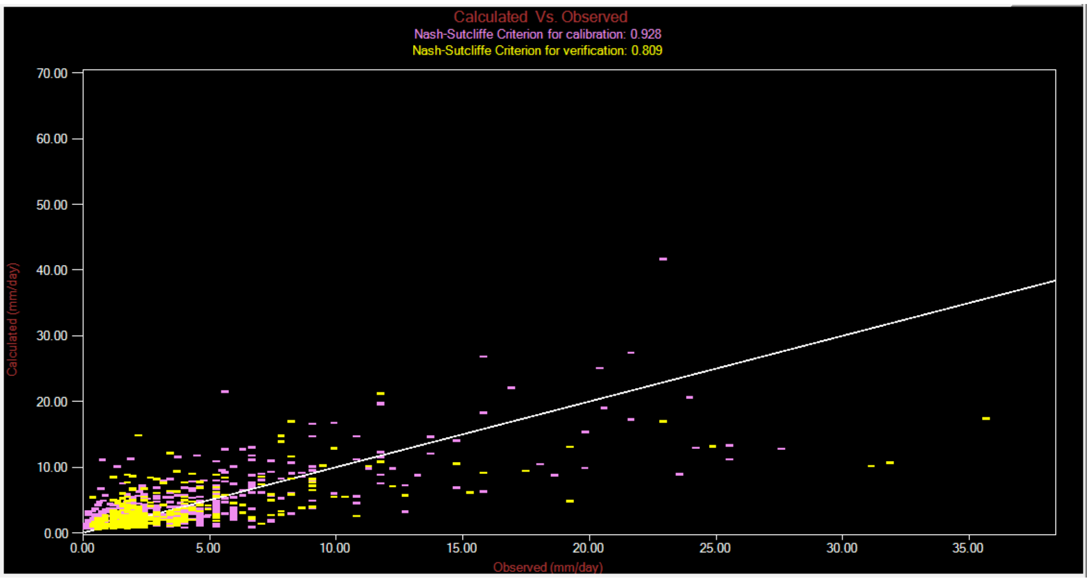

Figure 6. RRL scatter plot of observed and simulated stream flow in mm/d using Tank.

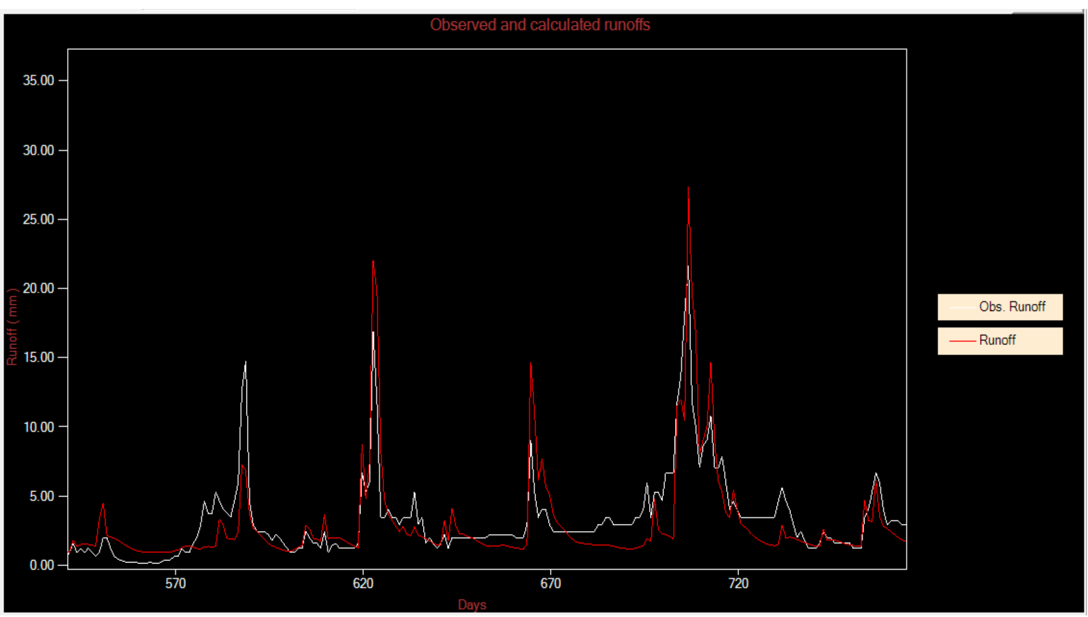

Figure 7. RRL plot of observed versus simulated stream flow in mm/d using Tank.

runoffs are almost identical and superimposable even during periods of low flow. This means that the actual runoff in the Molawin watershed can be conveniently and confidently approximated using the Tank model and its optimized parameters as long as adequate rainfall and evapotranspiration data for the catchment is available.

The Tank model and its parameters in relation to physical attributes of the watershed studied

The Tank model was developed by the Japanese hydrologist Sugawara to explain the water flow phenomena of a watershed (Basri, 2013). It consists of four tanks laid vertically in series as shown in Figure 8. Precipitation is received and evaporation released simultaneously from the top tank. In case there is no water in the top tank, evaporation is subtracted from the second tank; if there is no water in both the top and the second tanks, evaporation is subtracted from the third tank; and so on.

Streams from the side of the tank represent calculated runoffs, with the outlet stream from the top tank representing surface runoff, the second tank as intermediate runoff, the third tank as sub-base runoff and the fourth tank as base flow. This paradigm of stream flows may be considered to correspond to the zonal structure of underground water. Downward streams from the tanks represent infiltration, percolation and deep percolation.

Among the models used in this study, the Tank is conceptually the simplest. This simple conceptualization of water flow, however, does not mean that the behavior of the model is also simple since the behavior of the model is strongly influenced by the content of each tank which means that under the same rainfall and different storage volumes the runoff generated could be significantly different (Podger, 2004).

For the Molawin watershed, optimized parameters that yield the highest NSE using Tank are presented in Figure 8. Since a model is an abstraction of reality, it is often tempting to make physical interpretations of the actual system based on the best model parameters that emerge. For this case, it may be reasonable to suggest that runoff from the Molawin watershed derives primarily from surface and intermediate runoff; minimal contribution come from sub-base and base flow runoff. Judging from the infiltration, percolation, and deep percolation coefficients obtained, it may further be suggested that water movement across soil regions is essentially uniform.

Such interpretations, however, must be taken with caution since lumped conceptual models like Tank employ averaging of total rainfall and its distribution over space, soil characteristics, and overland conditions for the entire watershed, and ignore all flow-routing mechanisms that exist within the watershed. As such, although certain lumped parameters appear to represent some physical attributes of a certain watershed, these lumped parameters cannot be expected to have any direct physical interpretation. In short, the assumptions and procedures embodied by a model cannot be taken to represent the actual water balance in a watershed. This does not, however, undermine the usefulness of lumped conceptual models in watershed studies. As long as actual runoff is sufficiently replicated by a model, it becomes an important tool in water balance and water management applications.

Conclusion and Recommendations

Lumped conceptual models can provide excellent rainfall-runoff simulations for the Molawin watershed. Of the five models employed, Tank, SimHyd, and Sacramento register high validation Nash-Sutcliffe efficiencies corresponding to fairly good model fit. However, considering model simplicity and overall performance, Tank is considered the best model for the watershed. This means that stream flow in the catchment can be predicted with a great degree of accuracy using the Tank model and its optimized parameters obtained through this study.

To improve the performance of all lumped conceptual models in rainfall-runoff modeling of the Makiling Forest Reserve (MFR), it is recommended that alternatives to or improvements on the crop coefficient provided by Runtunuwu (2007) be explored in order to account for forest foliage for the estimation of actual evapotranspiration. Further improvements to the NSE values are recommended to be sought by considering longer calibration periods. Finally, it is recommended that the methodology detailed in this paper be adopted to simulate stream flow in other watersheds in the Philippines.

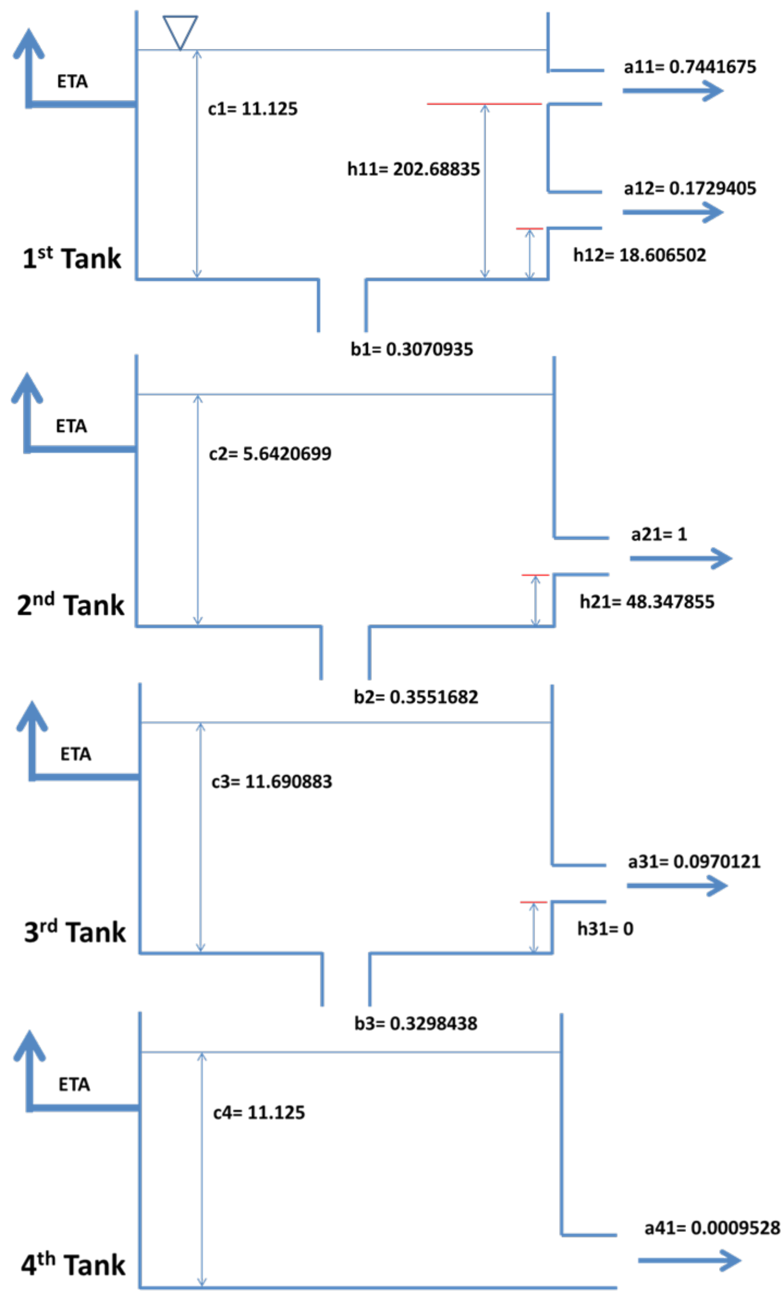

Figure 8. Best-fitted Tank model parameters for the Molawin watershed.

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SUPPLEMENTARY MATERIALS

The models used in this research are Australian Water Balance Model (AWBM), Sacramento, SimHyd, Soil Moisture Accounting and Routing (SMAR) model, and Tank. These five models are available in the software Rainfall Runoff Library (RRL). The model information in this section are cited from RRL's user's guide prepared by Podger (2004) and the software documentation paper.

Australian Water Balance Model (AWBM)

Introduced by Dr. Walter Boughton in 1993, AWBM remained to be one of the most popular rainfall runoff models. For every time increment, rainfall is added to each of the three independent surface stores while evapotranspiration is subtracted. Excesses from any store are considered runoff and is distributed to surface runoff and baseflow using the baseflow index which is a model parameter that represents the ratio of baseflow to the total flow. The AWBM schematic diagram is illustrated in Figure 9.

Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 8 lists the default values for the AWBM model.

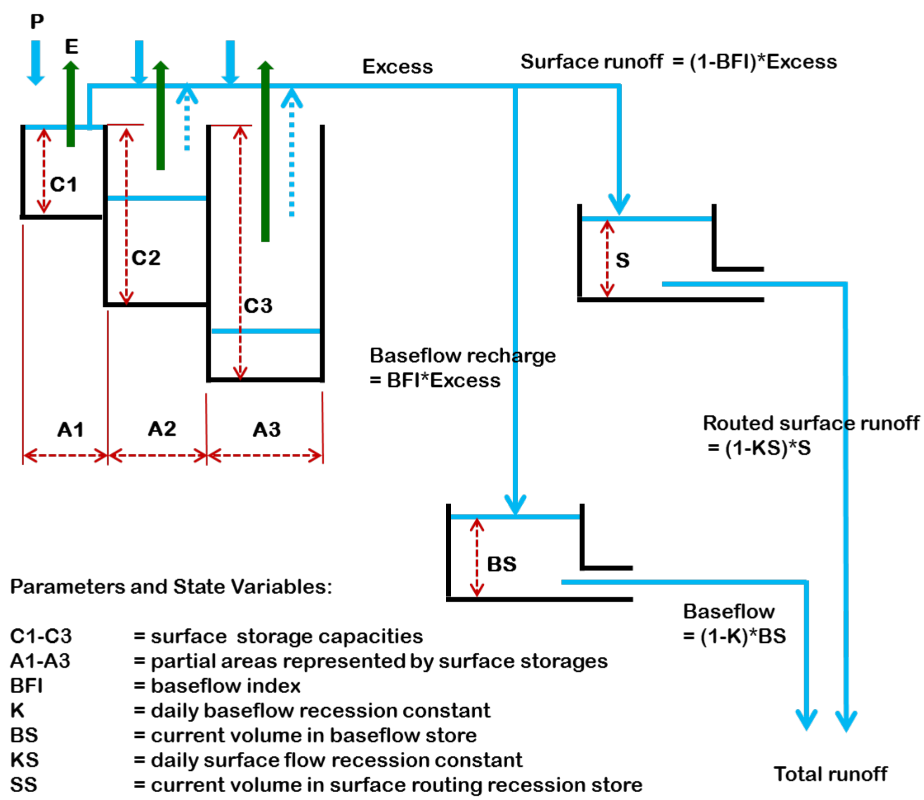

Figure 9. Structure of the AWBM in RRL.

Table 8. Default AWBM model parameters.

Parameter	Default value	Default minimum	Default maximum
A1	0.134	0.000	1.000
A2	0.433	0.000	1.000
BF1	0.350	0.000	1.000
C1	7	0	50
C2	70	0	200
C3	150	0	500
KBase	0.950	0.000	1.000
KSurf	0.350	0.000	1.000

Sacramento

This rainfall runoff model was developed by the US National Weather Service (NWS) in the early 1970s and is originally called the Sacramento Soil Moisture Accounting Model. The five moisture storages in this model is increased by precipitation and reduced by evapotranspiration and outflows from the storage. Model parameters determine the size and moisture capacity of the storages which in turn determine the portion of the rainfall absorbed as the actual evapotranspiration and the portion released as outflow. Excess fraction of rainfall not absorbed becomes runoff and is superimposed on lateral flows to give the stream flow. Figure 10 illustrates the schematic diagram of Sacramento, while Table 9 defines its model parameters.

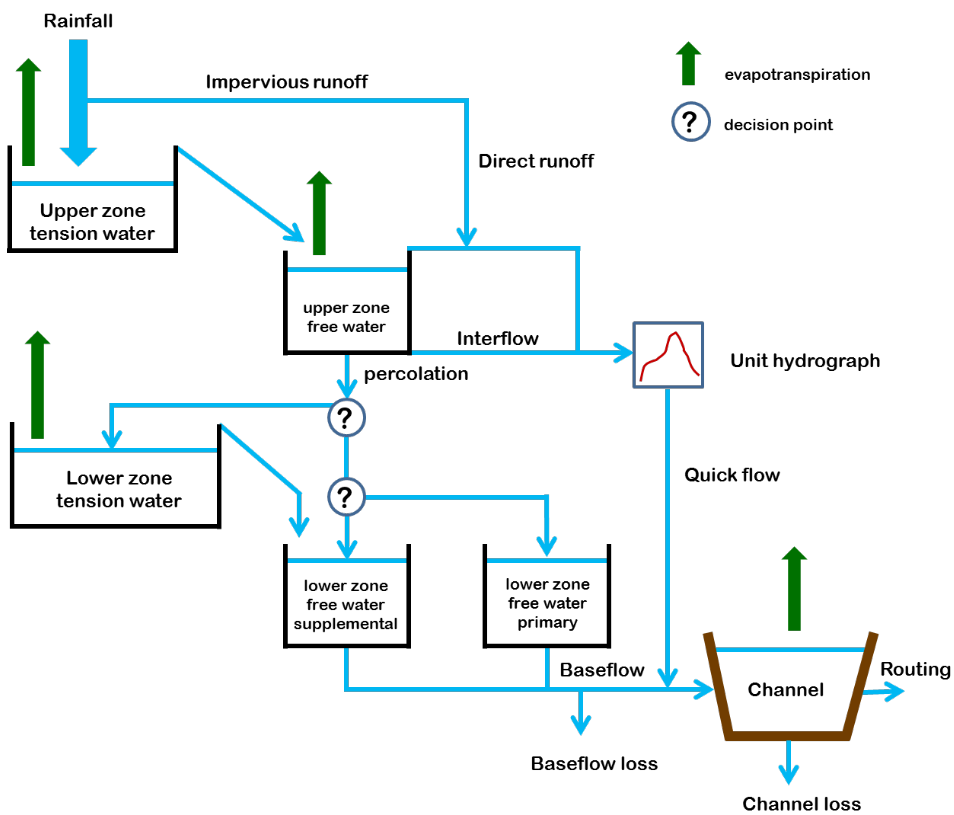

Figure 10. Structure of Sacramento rainfall runoff model in RRL.

The Sacramento model uses a total of 16 parameters to simulate the water balance. Of these, five define the size of soil moisture stores, three calculate the rate of lateral outflows, three calculate the percolation water from the upper to the lower soil moisture stores, two calculate direct runoff, and three calculate losses in the system.

Table 9. Sacramento parameters.

Parameter	Unit	Description
UZTWM	mm	*Upper Zone Tension Water Maximum*. The maximum volume of water held by the upper zone between field capacity and the wilting point which can be lost by direct evaporation and evapotranspiration from soil surface. This storage is filled before any water in the upper zone is transferred to other storages.
UZFWM	mm	*Upper Zone Free Water Maximum*. This storage is the source of water for interflow and the driving force for transferring water to deeper depths.
LZTWM	mm	*Lower Zone Tension Water Maximum*. This is the maximum capacity of lower zone tension water. Water from this store can only be removed through evapotranspiration.
LZFSM	m	*Lower Zone Free Water Supplemental Maximum*. This is the maximum volume from which supplemental base flow can be drawn.
LZFPM	mm	*Lower Zone Free Water Primary Maximum*. This is the maximum capacity from which primary base flow can be drawn.
UZK	1/day	The ratio of water in UZFWM which drains as interflow each day.
LZSK	1/day	The ratio of water in LZFSM which drains as base flow each day.
LZPK	1/day	The ratio of water in LZFPM which drains as base flow each day.
PFREE	-	The minimum proportion of percolation from the upper zone to the lower zone directly available for recharging the lower zone free water stores.
REXP	-	An exponent determining the rate of change of the percolation rate with changing lower zone water storage.
ZPERC	-	The factor applied to base percolation (PBASE) to define maximum percolation rate.
SIDE	-	The decimal fraction of observed base flow which leaves the basin as groundwater flow.
SSOUT	$m^3/s \cdot km^2$	The volume of the flow which can be conveyed by porous material in the bed of stream.
PCTIM	-	The impervious fraction of the basin which contributes to direct runoff.
ADIMP	-	The additional fraction of pervious area which develops impervious characteristics under soil saturation conditions.
SARVA	-	A decimal fraction representing that portion of the basin normally covered by streams, lakes and vegetation that can deplete stream flow by evapotranspiration.

SimHyd

SimHyd simulates runoff from three sources: infiltration excess, interflow, and base flow. Infiltration excess runoff is the excess in the infiltration capacity which is determined by the excess rainfall in the interception store of the model. Interflow is approximated as a first degree function of the ratio of soil moisture level to the soil moisture capacity. Base flow is then determined as a function of the groundwater store. The schematic diagram of SimHyd is presented below in Figure 11 and its default parameter values are listed in Table 10.

In SimHyd, daily rainfall first fills the interception store which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff.

Moisture that infiltrates is subjected to a soil moisture function that diverts the water to the stream (interflow), groundwater store (recharge) and soil moisture store.

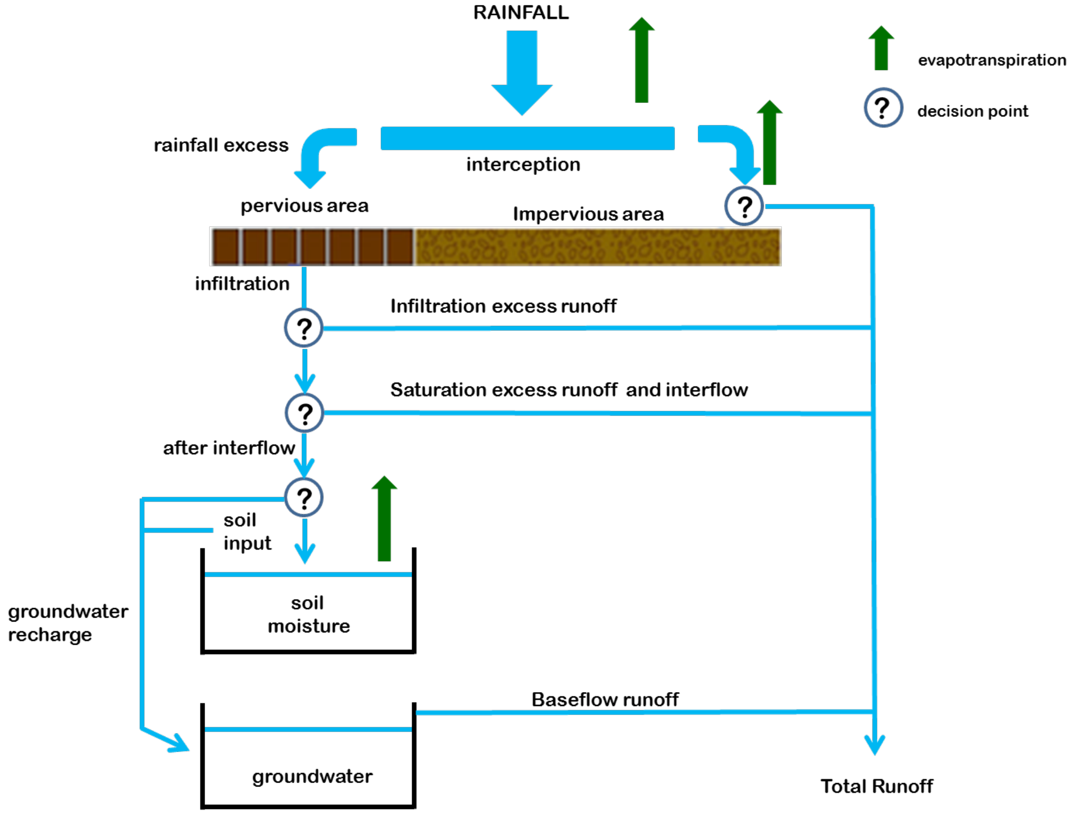

Figure 11. Structure of SIMHYD rainfall runoff model in RRL.

Table 10. Default parameter values for the SimHyd model.

Parameter	Default value	Default minimum	Default maximum
Base flow coefficient	0.3	0.0	1.0
Impervious threshold	1	0	5
Infiltration coefficient	200	0	400
Infiltration shape	3	0	10
Interflow coefficient	0.1	0.0	1.0
Pervious fraction	0.9	0.0	1.0
Rainfall interception store capacity	1.5	0.0	5.0
Recharge coefficient	0.2	0.0	1.0
Soil moisture store capacity	320	1	500

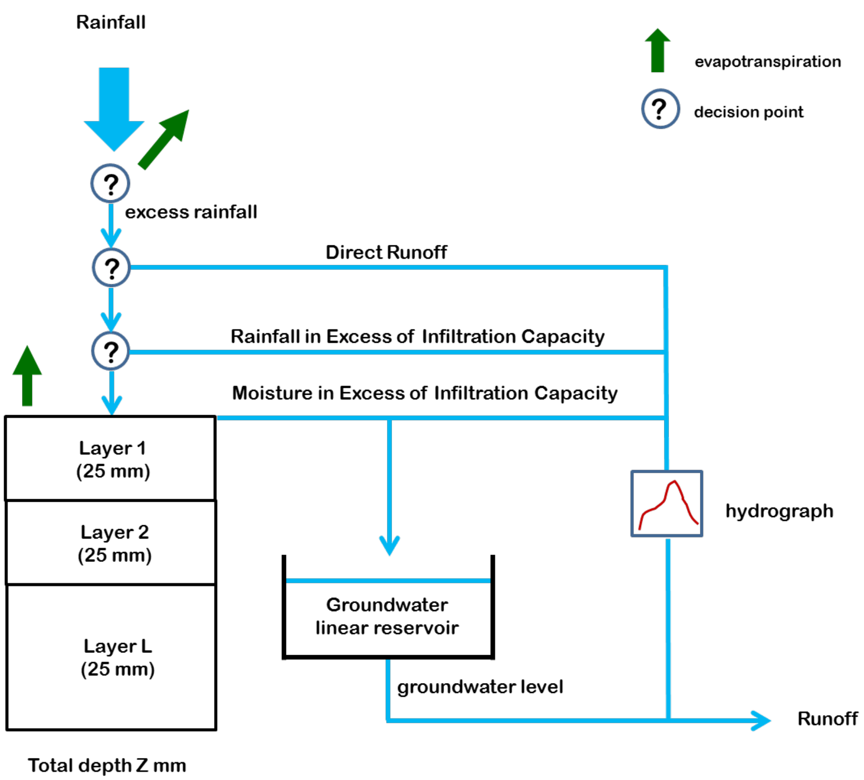

Figure 12. Structure of SMAR rainfall runoff model in RRL.

SMAR

The Soil Moisture Accounting and Routing Model is comprised of two components – water balance and routing components which is elaborated in Figure 12. This model assumes a pile of horizontal soil layers with different water holding capacities. Table 12 provides the descriptions and default values of the SMAR model parameters.

Table 12. Default parameter values for the SMAR model.

Parameter	Description	Default value	Default minimum	Default maximum
C	Evaporation	0	0	1
G	Groundwater runoff coefficient	0	0	1
H	Direct runoff area index	0	0	1
KG	Number of time step groundwater K	0	0	1
N	Parameter for linear reservoir	1	1	6
NK	Number of time step	1.00	0.01	1.00
T	Potential evaporation factor	0	0	1
Y	Soil infiltration capacity	0	0	5000
Z	Total soil moisture capacity	200	0	5000

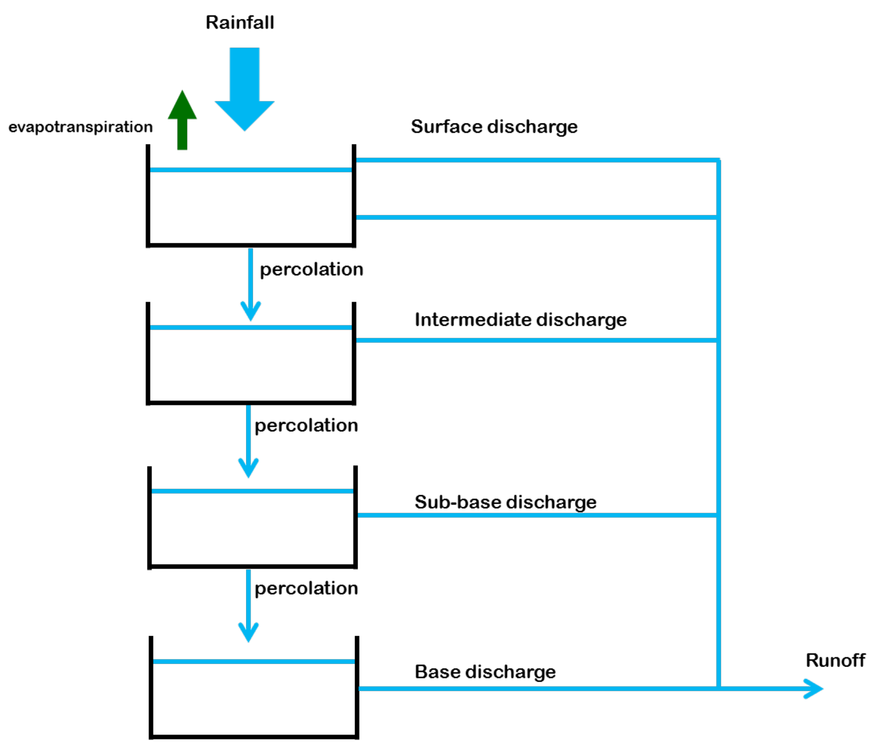

Figure 13. Structure of Tank rainfall runoff model in RRL.

Tank

Figure 13 shows the four vertically connected tanks in this model. Tank model is based from the basic tank drain principle. Precipitation is added to the top, while evaporation is subtracted starting from the upper tank down to the bottom tank until it is empty. The side outlets represent the runoffs, that is, the surface runoff for the first tank, intermediate for the second, sub-base runoff for the third and base flow for the bottom tank. Table 13 lists the default values for the tank model.

Table 13. Default parameter values for the Tank model.

Parameter	Default value	Default minimum	Default maximum
H11	0	0	500
a11	0.2	0.0	1.0
a12	0.2	0.0	1.0
a21	0.2	0.0	1.0
a31	0.2	0.0	1.0
a41	0.2	0.0	1.0
alpha	0.1	0.0	1.0
b1	0.2	0.0	1.0
b2	0.2	0.0	1.0
b3	0.2	0.0	1.0
C1	20	0	100
C2	20	0	100
C3	20	0	100
C4	20	0	100
H12	0	0	300
H21	0	0	100
H31	0	0	100
H41	0	0	100