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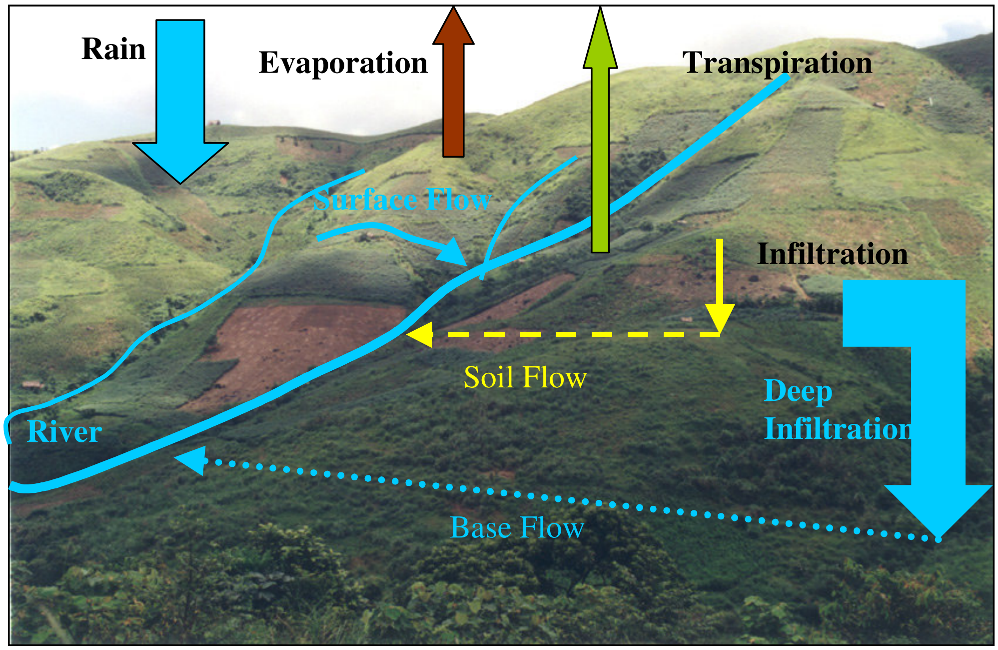

Calibration of GenRiver with GLUE for Northern Vietnamese conditions

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Emergo 2005:1
M.Sc. thesis

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Abstract

Global population growth and increasing wealth exerts pressure to convert forest into agricultural land. The forest area in the Red River Basin in Vietnam has decreased and is now less than 20 %. The consequences of land use conversions include changes in water demand, in water supply, and in water quality. Using models to predict effects of land use change is common in research since these tools are quick, cheap, powerful and are useful complements to field measurements. The objectives of this study were first to calibrate the watershed model GenRiver, developed by the World Agroforestry Centre South East Asia, for the Dong Cao catchment situated in North Vietnam, and secondly to predict the effects of agroforestry land use taking into account the parameter "uncertainty" in the predictions of GenRiver. Six parameters in GenRiver were analysed using GLUE (Generalized Likelihood Uncertainty Estimation). The predicted simulations of agroforestry and secondary forest were then compared in terms of changes in river discharge from the catchment. The GLUE method resulted in clear identification for only two of the analysed parameters. The highest likelihood value of the GLUE simulations was low (0.26) since GenRiver generated too low discharge peaks, especially during the rainy season. The model generated too little rapid drainage in the soil macropores at the expense of an overestimation of evaporation. This was due to the order of water redistribution assumed in the model (the priority is given first to evaporation, then drainage to the groundwater reserve and lastly to percolation by macropore flow). The conclusion is that GenRiver does not seem to be a suitable tool for Dong Cao conditions unless a structural change concerning water redistribution is made in the model. This should make the predictions less uncertain.

Key words: GLUE, catchment, hydrology, calibration, modelling, discharge, parameter estimation, uncertainty, river, Vietnam, Agroforestry, MFS, Minor Field Study.

Acknowledgements

I would like to thank everybody that has been involved in this study. Especially my supervisors: Dr Tran Duc Toan at NISF, Dr Didier Orange at MSEC/IWMI-Vietnam/IRD, Dr. Meine van Noordwijk at the World Agroforestry centre, Prof. Nicholas Jarvis, Prof. Ingvar Nilsson and Dr Minh Ha Fagerström at the dept. of Soil Science at SLU. I also want to thank Mr Phoung, Mr La Nguyen, Mr Thaiphien, Mr Phai, Mr Hue Dr Pascal Podowojweski, Mr Thao, Mr Phuo, Mr Bui at NISF and Mrs Betha Lusiana and Mrs Ai Farida at the World Agroforestry Centre, doctoral-student Mats Larsbo at the Dept. of Soil Science at SLU and Sida (Swedish International Development Cooperation Agency).

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1. Background

Global population growth and increasing wealth exerts pressure to convert forest to agricultural land. The increased conversion of forest into agricultural land in the uplands of the humid tropics has led to increased land degradation and reduced crop yield (Hoang Fagerström et al, 2004). This may also influence the downstream water quality in a catchment. The forests in the Red River Basin in Vietnam have decreased and cover less than 20 % in the area. There is one main problem concerning the decrease of forest cover. The high rate of population growth (both humans and livestock) has led to an over-exploitation of the natural resources resulting in erosion (Toan, et.al., 2003). From a hydrological perspective, the changes in water quality and quantity are due to the erosion that occurs when runoff water transports sediments and nutrients (Brodd & Osanius, 2002). Until recently research into the consequences of land use change has focused on 1) the effects of land-use change on climate and 2) the loss of biodiversity (van Noordwijk & Verbist, 2000). Although studies of vegetative cover, hydrological processes and water quality have a long history, it has received little attention in the study of land use change. The future demands an improved understanding of the consequences that land use change as on hydrological processes is a major need for the future. Consequences of these land use changes include changes in water demand due to changing land use practices (e.g. irrigation and urbanisation), changes in water supply from altered hydrological processes of infiltration, groundwater recharge and runoff and changes in water quality from agricultural runoff and suburban development. Understanding the interactions of the hydrological processes and changes in land use will provide the knowledge necessary to take decisions that balance trade-offs between on the one hand the positive benefits of land use change and on the other hand potentially negative and unintended consequences. This is needed to maintain ecological sustainability and human requirements for food, water and shelter in the future (DeFries & Esheleman, 2004).

The LUSLOF-project (Sustainable Land Use in the Uplands of Vietnam and Laos – Science and Local Knowledge for Food Security), started in 2002, is a project that aims to understand the interplay of techniques and land use options at the landscape scale with farmer knowledge and decision-making processes at two study sites in Vietnam and Laos (Iwald et al, 2002). The LUSLOF-project will conclude in 2004 and has until now been focused on several methods, such as Participatory Landscape Analysis (PaLA), WaNuLCAS (Water Nutrient and Light Capture in Agroforestry Systems) modeling and Farmer Field Schools (FFS) to find optional land use systems. The project from its beginning has had a participatory approach using different types of PRA-methods and tools to investigate local knowledge. Some of the results of the PaLA survey, shown by Iwald et al, (2002), are several hypotheses concerning land use options developed by the farmers within the Dong Cao Catchment. The Dong Cao catchment is also a research site of MSEC, (Managing Soil Erosion Consortium), one of the IWMI programs in six countries in South East Asia and the French IRD, Institute de Recherche Pour le Development. The program supports farmers on sloping land to reduce land degradation and alleviate poverty by adoption of sustainable land and water management systems. (Tran Duc Toan et al, 2003). The MSEC and LUSLOF project leaders agreed on the use of MSEC data for calibration of GenRiver 1.0 for Dong Cao Catchment presented in this study. The outputs of the calibration work will be considered as common results for both the MSEC and LUSLOF projects. The National Institute of Soils and Fertilizers, NISF, is the

Vietnamese partner of both the LUSLOF project and the MSEC program and is also responsible for the site.

Computer models are common tools in research and their purpose is to improve understanding of complex natural systems and to make predictions and extrapolations in time and space (e.g. the long term effects of deforestation on run-off). Models are cheap, quick and powerful complements to experiments in the field. However it is always important to be critical of model results and to make real measurements in the field as much as possible, since simulations are always uncertain. For hydrological modelling a study of the hydrological conditions for the specific catchment in question is necessary in order to gather inputs as well as to interpret the modeling results. Traditionally, an objective function is defined and described as the discrepancy between the simulated and the observed system, and this should be minimized. This procedure is usually called *calibration*. Another related aim is to try to *validate* the model by applying it to another time series that has not been used in calibration in order to test the general applicability of the model (Wagener, 2003). According to Rykiel (1996), the general applicability of a model is when it meets the requirements that are specified for a particular use. Many studies have shown that this type of approach is insufficient to adequately test the suitability of a model because the conclusions that can be drawn from such a procedure are limited. Often several, quite different parameter sets and even model structures are found to be equally acceptable (Wagener, 2003). Three commonly used calibration methods are listed below (Beven, 2001):

1. *Automatic Optimization.* A "testing by trying" method with the assumptions that the model has an optimal parameter set and that there is no predictive uncertainty.
2. *Reliability Analysis.* Assumes that there is an optimal parameter set but also makes certain assumptions about the response surface, which is a measure of how well different parameters fit the model.
3. *Equifinality Concept.* Equifinality arises when in a hydrological model many different parameter sets are equally good at reproducing the available measurements. Often spatially distributed hydrological models with a large number of parameters perform well in imitating hydrological behavior. However due to uncertainty these models are not the right tool for predicting changes in the system when some parameters in the model change because of its uncertainty (Savenije, 2001). Hornberger and Speer (1981), showed the problems in identifying a correct or optimal model given limited data, and rejected the idea of an optimum parameter set in favour of multiple possibilities for producing simulations that are acceptable. Hence, all the acceptable models should be considered in the predictions, weighted by their relative likelihood or level of acceptability. One example of this type of calibration strategy is the *Generalized Likelihood Uncertainty Estimation* (GLUE) outlined by Beven and Binley (1992).

Uncertainty evaluation of models means analysing the range of parameter sets and sometimes model structures that are considered viable for an anticipated study. This is done using theoretical approaches to estimate the prediction uncertainty as well as retaining all possible models unless and until evidence to the contrary becomes apparent (Wagener, 2003). All possible simulated model outputs are compared with available observations of the system and the distribution of the objective function is used to derive credibility intervals for the predictions. A prior sensitivity analysis of the model parameters may be important in order to gain a better understanding of the model performance and its internal structure, since the predictions depend on the assumed input distributions and their ranges. Sensitivity analyses do not estimate the errors of the model and should therefore be followed by uncertainty estimation techniques based on the comparison of model predictions with observations (Romanowicz, 2000). GLUE allows for the use of additional time series data and other sources of data in order to update or condition the model. The method has been used in a wide range of environmental applications such as soil-vegetation-atmosphere transfer modelling, biochemical modelling, flood frequency modelling, and water balance and catchment modelling (Campling et al. 2002).

The objectives of this study were to 1) calibrate GenRiver for the hydrological conditions of the small (0,5 km^2) catchment Dong Cao situated in northern Vietnam and 2) predict the effects of different land use on the catchment taking account of parameter uncertainty in GenRiver predictions. Hydrological data for 2002, gathered by MSEC, LUSLOF and Hoa Binh Weather Station was used in the calibration. Both the calibration and the uncertainty prediction estimation were made within the GLUE-procedure.

2. Material and Methods

The study was divided into 5 steps (fig. 1). The first steps were carried out in Vietnam and Indonesia as a Minor Field Study and part of the LUSLOF-project. The first step was a hydrological survey (1) followed by collection of secondary data, learning about GenRiver (2) and Sensivity Analysis (SA) (3) (table 1). The next step was the calibration of GenRiver using Generalized Likelihood Uncertainty Estimation (GLUE) (4). After the GLUE procedure the model was calibrated and two simulation scenarios (5) were investigated to predict changes in river discharge caused by changes in the actual land use in the catchment.

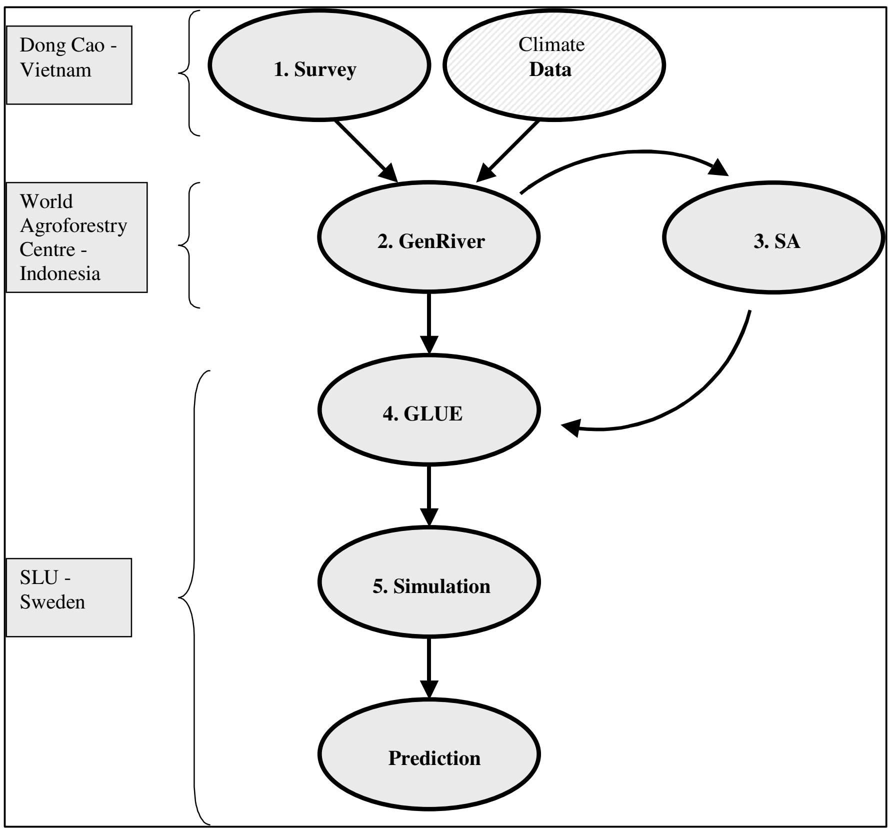

Figure 1. Research process for this study. The Climate Data step has no number and is differently coloured because it is a collection of *secondary* data originally measured by MSEC in Dong Cao Catchment. SLU stands for the Swedish University of Agricultural Sciences.

2.1 GenRiver

2.1.1 Model Overview

GenRiver is a landscape watershed model created in the Stella software package. GenRiver was developed at the CGIAR centre (Consultative Group on International Agricultural Research) ICRAF-SEA/World Agroforestry Centre, South East Asia. The model is intended to be used where data is scarce. Fig. 2 gives an overview of the model. The watershed dimension, simulating effects of different land use at catchment level, means that GenRiver is also suitable for Agroforestry land use systems in Northern Vietnam. In GenRiver, the source of a river originate in one or several sub-catchments. Each sub-catchment can be given its own daily rainfall, yearly land cover percentages and distance to the river and the catchment outlet. The model describes a daily water balance driven by local rainfall and modified by land cover and soil properties of each patch (each part of the catchment). The patch can contribute to three types of stream flow: *surface-quick flow* on the day of the rainfall event, *soil-quick flows* on the next day and *base flow*, via the gradual release of groundwater. The model has been used to predict total river flow and to simulate the nature of the different water flows in a catchment (van Noordwijk et al, 2003). Earlier the model has been used to describe the water balance and river flow with different options of land use in the Mae Chaem catchment (40 000 km^2, 140 sub-catchments in North Thailand) and Way Besai catchment (404 km^2, 15 sub-catchments in Sumberjaya, Lampung, Indonesia), (van Noordwijk, et. al., 2003).

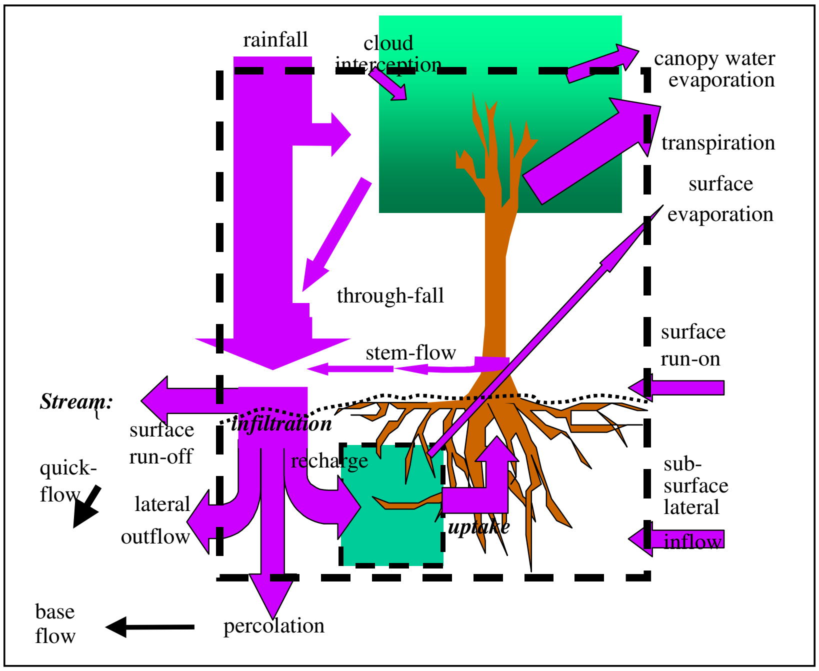

Figure 2. *An schematic overview of the GenRiver model (van Noordwijk et al., 2003).*

2.1.2 Description of important components of the model

<u>Rivers</u>

A river in the model is treated as the sum of streams, each originating in a sub-catchment with its own daily rainfall, land cover fraction, total area and distance to the outlet of the river (van Noordwijk et al, 2003).

<u>Daily Rainfall, intensity and time for infiltration</u>

The daily rainfall at the sub-catchment can be either derived from actual data or from a "random generator" that takes temporal patterns into account. The rainfall duration is estimated from the daily amount and an estimate of rainfall intensity is derived from a mean value, a coefficient of variation and a random number. The duration of the rain determines the time available for infiltration (van Noordwijk et al, 2003).

Interception, evaporation and evapotranspiration

The storage capacity of intercepted water is treated as a linear function of leaf and branch area and expressed as an index of the land cover. The interception-evaporation has priority over plant transpiration demand. The total evapotranspiration is calculated by the potential evapotranspiration, using a Penman type equation, where several parameters are taken into account. These are intercepted water, the land cover (with drought-limitation proportional to soil water content relative to field capacity below a threshold), the soil surface evaporation, the weekly multiplier on potential daily evapotranspiration and the potential relative evapotranspiration per land cover type and per month.

Surface infiltration and overland flow into streams

Infiltration, I (mm/h), is calculated as the minimum of infiltration limited runoff and saturation over land flow as:

Infiltration Limited Runoff

$$I = \frac{DIC}{24}\ , \qquad \text{Eq. 1}$$

where DIC is the daily infiltration capacity. When the infiltration capacity of the surface is less than required during a storm it leads to overland flow.

Saturation Overland Flow

$$I = W_S - W_A + W_{GW}\ , \qquad \text{Eq. 2}$$

where W_S is the amount of water that can be held at saturation, W_A is the amount water already present and W_{GW} is the amount of water that can reach the groundwater level within a day. When the surface soil layers are saturated the rate of outflow will determine the rate of inflow (van Noordwijk et al, 2003).

Soil water distribution

After a rain event, the soil starts to drain and will reach field capacity after one day. The water held between saturation and field capacity (Fig. 3) is distributed in the order, 1) Transpiration, 2) Drainage to the groundwater reserve or 3) Drain to the rivers as “soil quick flow” (van Noordwijk et al, 2003).

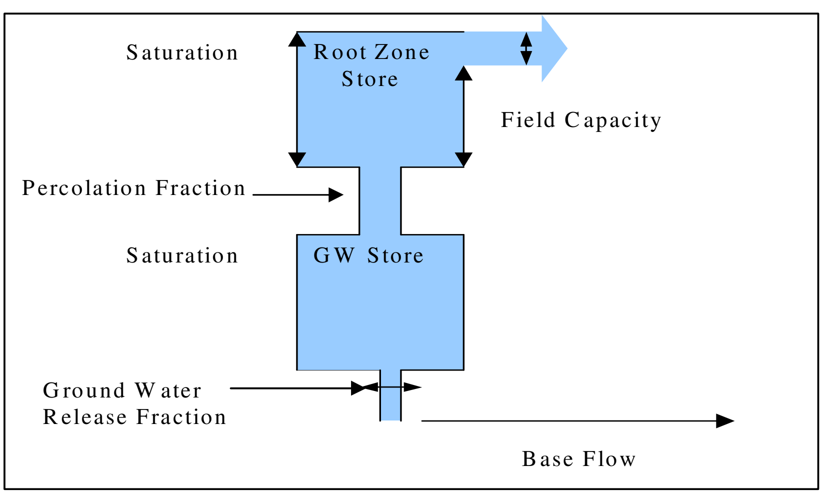

Figure 3. Soil water distribution in GenRiver. (Modification from van Noordwijk, 2004)

2.2 Catchment Characteristics

2.2.1 Land Use

The Dong Cao catchment is situated in Tien Xuan municipality, Luong Son district, Hoa Binh province in northern Vietnam (20°57 N and 105°29 E), 60 km west of Hanoi (Fig. 4 and 5). Dong Cao is a small catchment (0.50 km^2) with 40 households belonging to two ethnic groups, Muong and Kinh (Johansson, 2003).

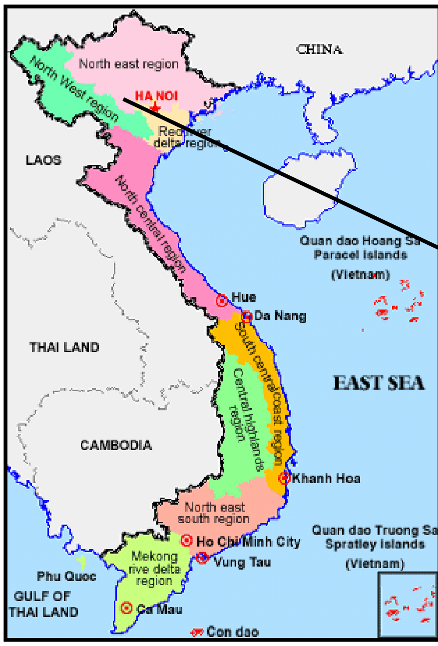

Figure 4. *Map of Vietnam***.**

(www.vietnamtourism.com)

Figure 5. *Map of the Hoa Binh province where Dong Cao is situated.*

During the last 35 years the land use in Dong Cao catchment has changed. In the 1970's the catchment was covered by forest with a limited production of crops such as cassava, arrowroot and rice. In the mid 1970's the farmers increased their crop production in the catchment and by the 80's almost the whole catchment was used for crop production like maize, taro[1] and eucalyptus. During the 1980's and the 1990's the farmers incorporated the use of fallow land widely and by the end of the 20th century indigenous trees such as keo[2], trau[3] and bamboo species[4] (Hoang, 1997 and Johansson, 2003) were often used to improve the fallow as the trees helped to conserve soil and water. The farmers also supplemented their incomes by selling the tree fruit for cash (Iwald et al., 2002). The main current land use is mixed agroforestry systems with hedgerows of *Tephrosia Candida* on contour lines and improved fallow with trees and bamboo on the field boundaries. Cassava is still the main crop, but bracharia[5] and agroforestry trees such as trám[6] , lát[7] and bôdé[8] have also been added (Siêm and Phiên, 1999).

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[1] *Colocasia esculenta,* Araceae
[2] *Acacia Mangium, Mimosaceae*
[3] *Vemicia Montana*
[4] such as *Neohouzeaua dulloa, Dentrocalamus patenllari, Arundinaria racemosa and A. Sat Balansa*
[5] (*Bracharia humidicola*)

2.2.2 Geological and Hydrological Characteristics

The parent rock is volcanic metamorphic schist dated to the upper Permian/lower Triassic. The schist layers are from some centimetres to metres thick with a sub-vertical inclination. The main axis of the stream is perpendicular to the schistosity axis. Faults are found in the same direction as the stream, resulting in stairs with discontinuous slopes from 30 % to over 100 % (Toan, et.al., 2003). Fig 6 l shows the geological characteristics of the Dong Cao Catchment.

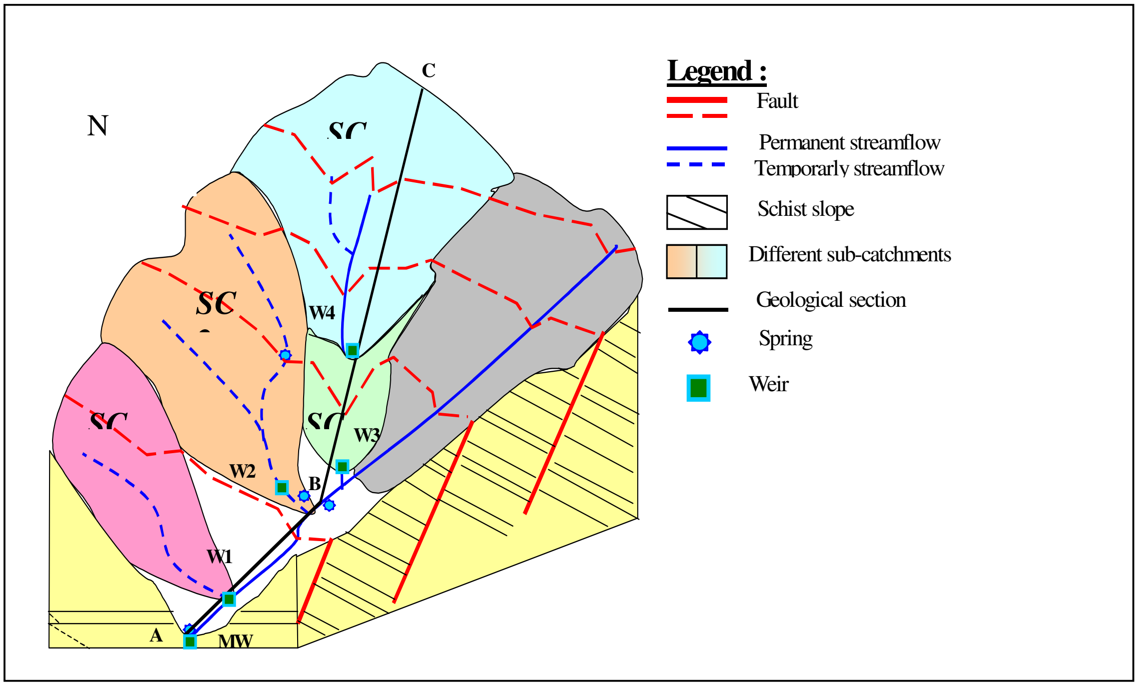

Figure 6. The geological characteristics of Dong Cao (Bayer, 2003). SC stands for Sub-catchment, MW is the Main Weir (measurement station), and W1-4 are weir-stations in each sub-catchment.

Dong Cao is a small catchment measuring 0.50 km^2 (Johansson, 2003). The catchment has been divided into 5 sub catchments by MSEC (Managing Soil Erosion Consortium), one of the IWMI (International Water Management Institute) programs in six countries in South East Asia. The program supports farmers on sloping land to reduce land degradation and poverty by adoption of sustainable land and water management systems (Tran Duc Toan et al, 2003) (Fig 6). Sub catchments, 3 and 4 are actually part of one sub catchment but are treated here as two different sub-catchments since in Vietnam the NISF, (The National Institute of Soils and Fertilizers, has installed a weir station along the stream. The catchment has a stream running through each sub catchment which discharges in to a larger stream and to the outlet. As figure 6 shows, there are permanent streams and also temporary streams that are dry during the dry season. The elevation is between 100-700 m and the slopes vary from 15° to 40° (Fagerström, 2004). The main soil types are Acrisols and Ferrasols of shallow to medium depth (Renault, 2003; Podwojewski, 2003). The soils are well

[6] (*Canarium sp., Burseracae*), or *Chukrasia tabularis A.Juss, Meliaceae*
[7] *Choespondias axillaries (roxb) Burtt.Et hill, Anacardiaceae*
[8] *Styrax tonkensis Pierre, Styracaceae*

drained, clay loams to clays with high porosity, have low nutrient status and a clay accumulation further down the soil profile.

The LUSLOF research team has measured the surface infiltration capacity using the single ring method. The data is limited however, since measurements on the upper slopes of the catchment are difficult to make. The measurements lie in the range 24-10022 cm/day, with average value of 2337 cm/day and a median of 1412 cm/day (Olsson & Schwan, 2002). The large values imply a very well developed soil structure, with continuous macropores.

The discharge from the catchment has only recently been measured by MSEC. Only discharge measurements from the Main Weir at the outlet are available and these are shown in figure 7.

2.2.3 Climate

The climate in the Dong Cao catchment is tropical with the wet season from April to October. The average temperature is 25°C and the annual rainfall in 2002 was 1052 mm (Hoang Fagerström, 2004 & MSEC / NISF, 2003). The average annual rain intensity is 28 mm/hr (MSEC / NISF, 2003).

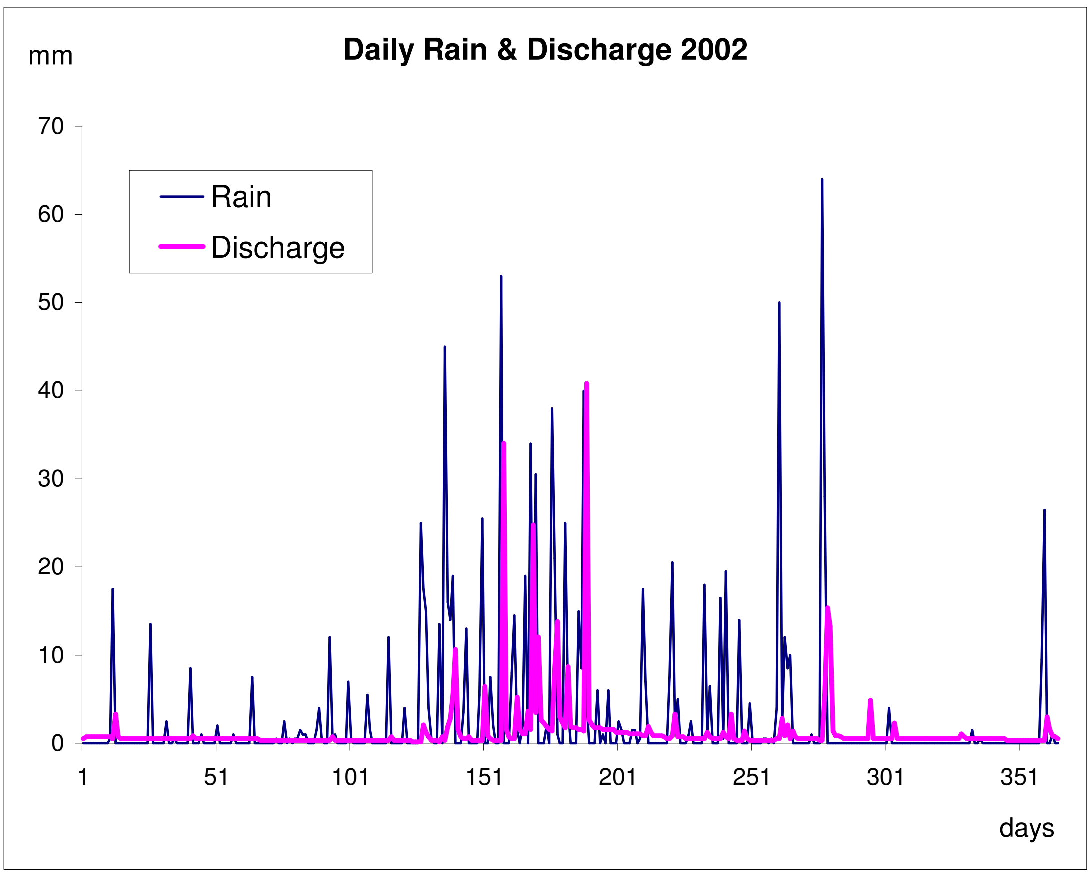

Figure 7. The daily rain and discharge in Dong Cao 2002.

2.3 Generalised Likelihood Uncertainty Estimation (GLUE)

The GLUE method is based on a large number of Monte Carlo simulations, each with randomly generated parameter set-ups sampled from prior parameter distributions. The results of each simulation are compared with available observed data. A quantitative measure of performance ("likelihood") is needed to assess the acceptability of the model parameterisation based on the model residuals. This quantitative measure of performance should be chosen with the requirement that it has to increase monotonically with increasing goodness-of-fit and that unacceptable models should have a likelihood of zero. When using GLUE for predictions, all the simulations with a likelihood measure greater than zero contribute to the distribution of the predictions. The predictions of each simulation are weighted by the likelihood measure associated with that simulation. The cumulative weighted likelihood distribution of predictions can be used to estimate percentiles for the prediction (Beven, 2001). The cumulative likelihood distribution may also be used to evaluate the uncertainty limits for future events for which observed data might be scarce or to validate a model by comparison with observed data that have not been used in the likelihood updating (Beven & Binley, 1992).

Implementation of the GLUE method requires the following decisions to be taken (Beven, 2001 & Campling, 2002):

1. A decision about the model.
2. A sampling range for each parameter.
3. A methodology for sampling the parameter space.
4. A likelihood measure of model performance.
5. A criterion for acceptance or rejection of parameter sets.

(6. A methodology for updating likelihood measure.)

2.3.1 Decision about the model

In this study, the watershed model GenRiver was calibrated for North Vietnamese conditions. The predictive simulations were also carried out using the same model. Each simulation was run for 6 years. The model needs to run for at least 3 years to become independent of the unknown initial conditions. The observed data used in this study was discharge data from 2002 measured at the catchment by MSEC. Certain input data for the catchment (land use changes during time, evapotranspiration, drought-stress threshold, discharge, area) were changed to match the Dong Cao catchment before using the GLUE method.

2.3.2 Definition of the range of the parameter values

Beven (2001) has suggested one should start with quite wide ranges and see if they can be narrowed down so as, to avoid the situation that the 'true' value might be beyond the edge of the sampled range. In this study 6 parameters of the GenRiver model were analysed. The parameters were Ground Water Release Fraction, Surface Infiltration, Soil Infiltration, Field Capacity, Rain Intensity and Percolation Fraction Multiplier. The descriptions of the analysed parameters and their ranges are given in Table 1. The ranges of the parameters were set subjectively and relied on the default values used with GenRiver for Indonesian conditions and on measured data provided by the MSEC and LUSLOF teams.

Parameter in GenRiver	Description	Random Seed	Range & Dimension
I_GWRelFracConst	The fraction of the groundwater reserve released to the river each day (fig. 2).	536	0-1
I_FieldCap	Soil water content after drying one day.	449	0-1000 mm/m depth
I_MaxInf	How much water can infiltrate into the soil surface. The daily infiltration capacity multiplied by 1/24.	126	0-10000 mm/h
I_MaxInfSoil	Infiltration below the surface, the sub soil multiplied by 1/24.	337	0-1000 mm/h
I_PercFracMultiplier	Empirical parameter controlling drainage from soil.	4	0-10
I_Rain_IntensMean	The average rain intensity representative for one year.	268	0-100 mm/h

Table 1. The analysed parameters names in GenRiver, their descriptions, ranges and the random seed for the random parameter generation.

2.3.3 Sampling strategy for the parameter sets

The number of Monte Carlo simulations was set to 30 000 and parameter values were selected using the Random Number Generation, Analysis ToolPak of Excel. The random seeds for the random number generation are shown in table 1.

2.3.4 Definition of the likelihood measure

The measure of goodness-of-fit used for this calibration is based on the sum of the squared errors, error variance and also the variance of the observed discharge.
The likelihood function used is called the error variance model efficiency, E (Nash and Sutcliffe 1970; Beven, 2001):

$$E = 1 - \frac{\sigma_e^2}{\sigma_o^2}, \qquad \text{Eq. 3.}$$

where E is the efficiency of the model, σ_e^2 is the variance of the model errors and σ_o^2 is the variance of the observed discharge. The value of E varies between 1 and -∞. The closer E gets to 1, the better the model predicts. Model efficiency values below a critical threshold value were rejected and seen as bad models. The variance of the errors is defined as,

$$\sigma_e^2 = \frac{1}{T-1}\sum_t^T \left(\hat{y}_t - y_t\right)^2, \qquad \text{Eq. 4.}$$

where $\hat{y}_t$ is the predicted and y_t is the observed value for the time step t = 1,2,3…,T (Beven, 2001). The variance of the observed values is defined as,

$$\sigma_o^2 = \frac{1}{T-1}\sum_t^T \left(y_t - \bar{y}\right)^2, \qquad \text{Eq. 5.}$$

where $\bar{y}$ is the mean value of the observations for the time step t =1,2,3,….,T.

2.3.5 Prediction using GLUE simulations

The best 1% of the simulations (300 simulations), were defended as acceptable and their likelihoods were then used as weights to the model predictions. The likelihood, was calculated as L, by follows,

$$L = \frac{W_i}{\sum_i W}, \qquad \text{Eq. 6.}$$

where W is the weighted likelihood value of the model efficiency given by:

$$W_i = E_i - E_{\min}, \qquad \text{Eq. 7.}$$

where $E_{\min}$ is the minimum value of the model efficiency for an acceptable simulation.

2.4 Simulation Scenarios

After the GLUE calibration of GenRiver, two different land use scenarios were simulated to predict the impact of different land use options on the catchment water balance:

1. *Mixed Agroforestry (AF) Systems*, 100 % in the catchment. The land use that was simulated was 1/3 Pioneer AF, 1/3 Early Prod AF, 1/3 Late Production AF. The three Agroforestry Systems agroforestry systems are cultivated in a mixed form e.g. hedgerows and improved fallows. Pioneer is a young system with seasonal crops, bushes or grass. Early production has trees less than 10 years old but giving fruit production. Late Production has trees that are older that 10 years.

2. *Secondary Forest (SF)*, 100 % in the catchment. This is a forest with trees less than 10 years old. In the whole catchment half will be Young Secondary Forest and half Old Secondary Forest.

Scenario 2 is simulated as a best-case scenario and scenario 1 is simulated as reasonable land use for the area. The object is to investigate the differences between the two different land uses in terms of the discharge in the river.

The agroforestry system is compared to secondary forest with respect to the change in discharge, ΔQ:

$$\Delta Q = \frac{(Q_{AF} - Q_{SF})}{Q_{SF}},$$

where ΔQ is the change in discharge between the predicted discharges of AF, mixed agroforestry systems and SF, secondary forest.

3 Results and Discussion

3.1 The suitability of GenRiver for Dong Cao

The water balance for 2002 of Dong Cao Catchment in 2002 is shown in fig. 8.

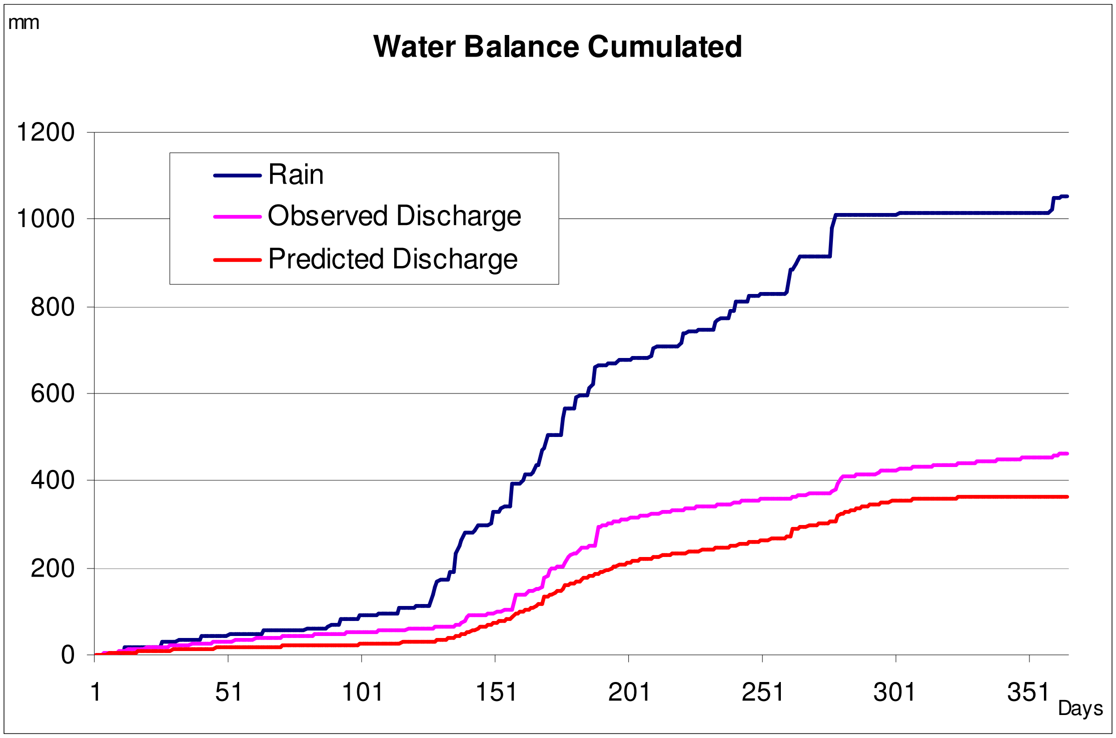

Figure 8. The water balance of the Dong Cao Catchment compared with the top ranked simulation given from the GLUE simulations. The x-axis shows the day in 2002 and the y-axis mm water.

The accumulated rain is 1052 mm, the measured discharge is 462 mm and the actual evapotranspiration calculated from the difference is 590 mm. The best GenRiver simulation predicts greater evapotranspiration, 687 mm, and underestimates accumulated discharge by 97 mm. The model seems to overestimate evapotranspiration especially during the rainy season or after a heavy rain event when discharges are under-predicted (e.g. at day 185).

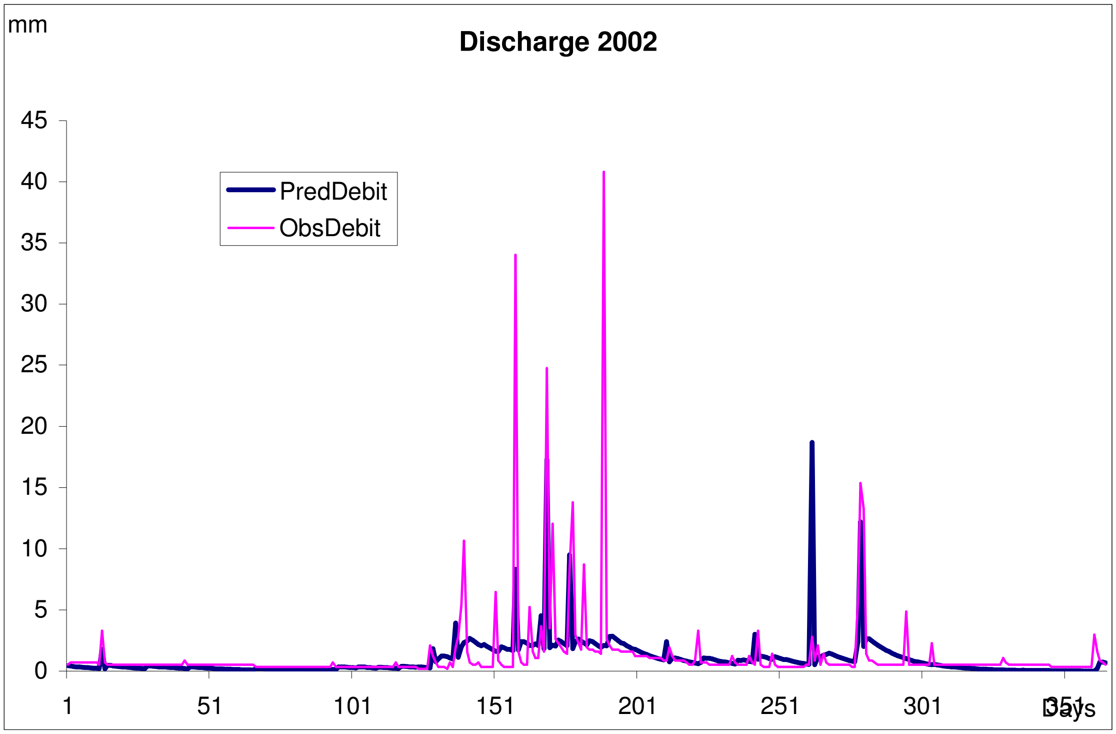

Figure 9. The annual rain and discharge in Dong Cao Catchment. The predicted discharge is from the top ranked model from the GLUE simulations.

The model generally predicts discharge peaks that are too low compared to those observed and also over-predicts recession flows, especially during the rainy season (fig. 9). The reason for this is probably an over-estimation of transpiration at the expense of SoilQuickFlow (i.e. rapid macropore flow), due to the order in which the water redistribution is calculated in the model. When rain reaches the soil surface, the water can either 1) evaporate from the soil 2) drain through the soil to the groundwater reserve or 3) percolate through the soil as macropore flow, SoilQuickFlow. This means that the water will be distributed first as evaporation and then as deep percolation to the groundwater reserve and lastly, SoilQuickFlow transports the remaining water. Considering the characteristic time-scales of the processes involved, this order seems illogical for a model run on a daily time step. If macropore flow were generated more often GenRiver would probably produce more realistic discharge hydrographs in shape and amount. The reason for the over-estimation of transpiration at the expense of the Soil Quick Flow could be in the redistribution of water in the soil. The amount of water for redistribution is defined as the difference between saturation and field capacity in GenRiver. This is not adequate since the difference between saturation and field capacity in reality is non-available water for plants (due to its fast drainage). Therefore, the difference between saturation and field capacity should not generate transpiration. Table 2 shows the water flows simulated by GenRiver for Dong Cao catchment. One can see that GenRiver hardly simulates any SoilQuickFlow and instead the water reaches the river either as surface Flow but mostly as Base Flow.

Cumulated Flow	Discharge (mm)
Surface Flow	61.6
Soil Quick Flow	11.8
Base Flow	291.7
Total Discharge	**365.08**

Table 2. Cumulative flows predicted by GenRiver for Dong Cao Catchment 2002. These originate from the top ranked parameter set from the GLUE simulations.

Figure 10 shows that GenRiver best captures flows in the dry season. (MAX) and (MIN) are the maximum and the minimum value of the predicted discharge for the 300 best simulations at each time step, in this case each day. During the rainy season, on the other hand, GenRiver does not seem to produce high peaks and the regression is both slower and higher than the observed one. The difference between the highest and the lowest discharge values differ during the rainy season where the minimum discharge each day gives values near zero, indicating that all the rain has evaporated.

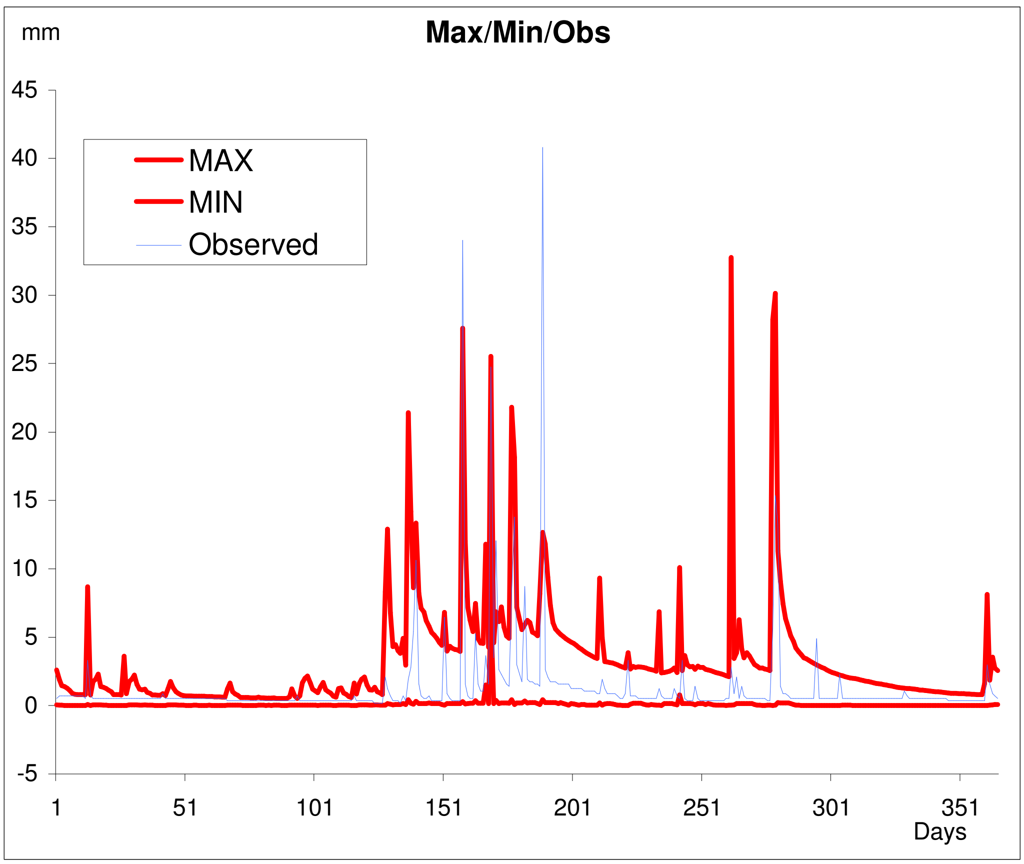

Figure 10. The maximum and the minimum discharge of each time step (day) from the best 300 GLUE simulations.

The model efficiency, E, is low in comparison with the study using TOPMODEL (Campling, 2002), where the top five likelihood values were 0,939-0,943 (1994) and 0,849-0,846 (1995). One reason for this could be that parameters in GenRiver not included in this analysis were given inappropriate values. One example of this could be the parameter I_SoilSatminusFC, which is the difference between the water storage capacity at saturation and at field capacity. This is the fraction of the water in the soil that can be transported to the river during one day. The default value in GenRiver is 100 mm/m depth. This parameter could affect water flow negatively by transporting less water through the soil leading to quicker saturation and resulting in overland flow. On the other hand this would lead to higher discharge peaks.

The responses of the different parameter sets of the six analyzed parameters are shown in scatter plots (Fig.11). The plots are diagrams of the parameter value contra the model efficiency, E. Each dot represents one Monte Carlo simulation with a randomly selected parameter set. The plots only show the Monte Carlo simulations that gave a model efficiency over zero. The highest model efficiency was 0,26.

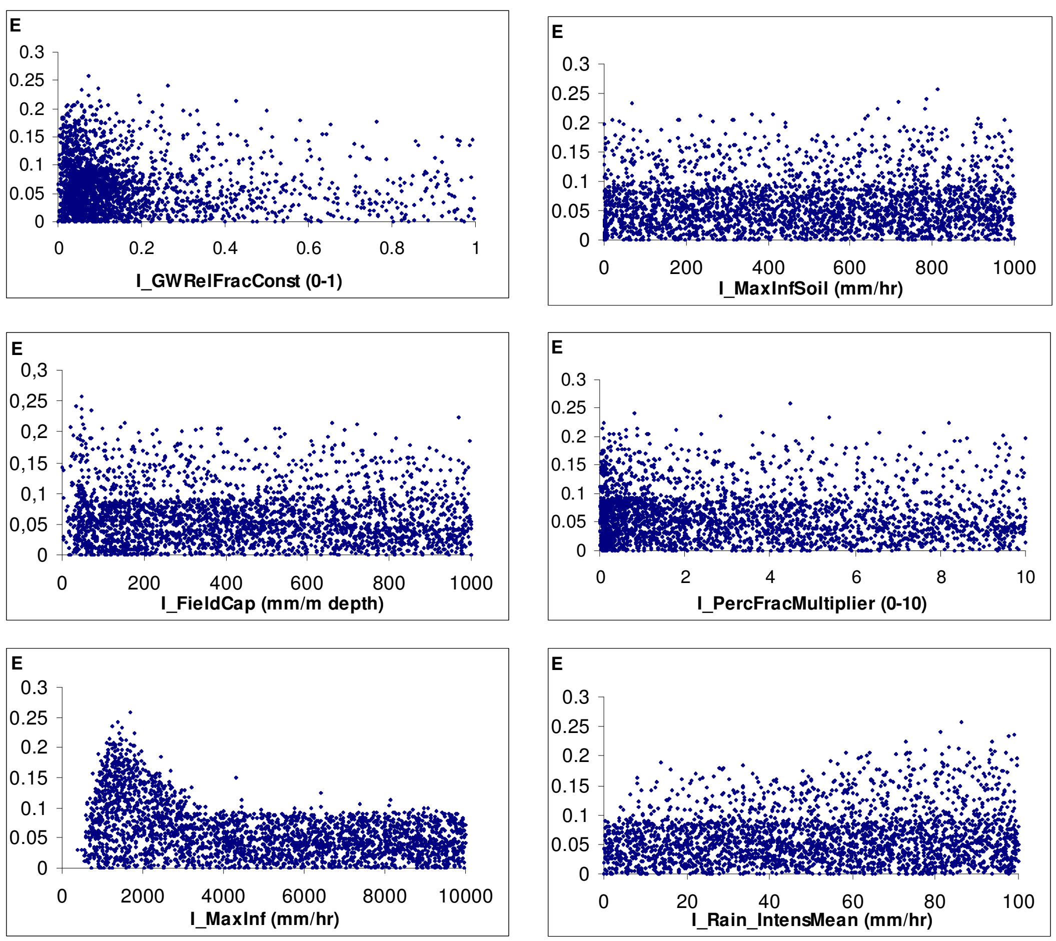

Figure 11. Scatter plots of the model efficiency measurement.

Of the six parameters tested, two are reasonable sensitive and can be estimated by the GLUE simulations (I_GWRelFracConst and I_MaxInf). Three other parameters *may* have been sensitive and identifiable if the number of simulations had been larger (I_FieldCap, I_MaxInfSoil and I_Rain_IntensMean) while, I_PercFracMultiplier is non-sensitive and can hardly be defined by the GLUE simulations. The scatter plots in fig. 11, show that the good models, with the highest E-values, have values between 0 and 0,2 for *I_GWRelFracConst*, with a peak value of 0,10. The best simulations for *I_MaxInf* are between 800 and 1 500 mm/hwith a peak at 1 500 mm/hr. This estimate reasonable correlates with the measured infiltration capacities in the catchment.

Values below 800 mm/hr produce very bad simulations (E-values below zero). These simulations produce too much overland flow to the river instead of infiltration into the soil (or interception by the vegetation). The model is neither sensitive to, nor definable for *I_FieldCap* and *I_MaxInfSoil*, giving equally good models through the whole parameter range. Concerning *I_FieldCap* there is a certain tendency towards better models at the lower end of the parameter range between 0 and 100 mm/m, with a peak at 80 mm/m. This tendency might have been clearer with more Monte Carlo simulations within this range. The estimated valued of the field capacity of 600 mm/m depth in GenRiver seems low in comparison with the default value used for Way Besai Catchment in Indonesia. However Dreissen et al (2001) writes that Ferrasols have a limited capacity to hold available water and a typical value is 100 mm/m. According to earlier studies in the Dong Cao Catchment, the soils in the catchment are very well drained. The parameter *I_MaxInfSoil,* also has a small peak at the value of 800 mm/hr and here might lie an estimation of a good parameterization. More GLUE simulations within a narrower range, e.g. 600 to 2000 mm/hr, might show a clearer identification of this parameter. For *I_Rain_IntensMean* the scatter plot shows a steady increase of the model efficiency towards higher values. More Monte Carlo simulations within a larger parameter range here might also have helped to better identify the parameter. Finally, *I_PercFracMultiplier* is not sensitive, as shown by good model efficiency values throughout the whole parameter range and cannot therefore be estimated. The Equifinality concept is clearly shown by this example, with a wide range of parameter values giving reasonable simulation results.

The conclusion of the calibration is that GenRiver does not seem suitable at presently for catchments with a well-drained soil type in combination with macropore flow. On the other hand, this problem may be easy to solve by changing the priority of the water redistribution in the model in order to favour rapid drainage in macropores.

Concerning the Stella software the GLUE method is easy to implement within Stella which has a special import data tool for different runs of the model with different parameterizations. On the other hand, the procedure requires large data storage facilities and conversions between Stella and Excel is time-consuming and also prone to error. GenRiver is a user-friendly model and not too technical to be understood.

3.2 Prediction of the impact of different land use

The scenario simulation results are presented in figure 12 and show the difference of the discharge that the two scenarios give against the cumulated weighted likelihood of the 1 % best models.

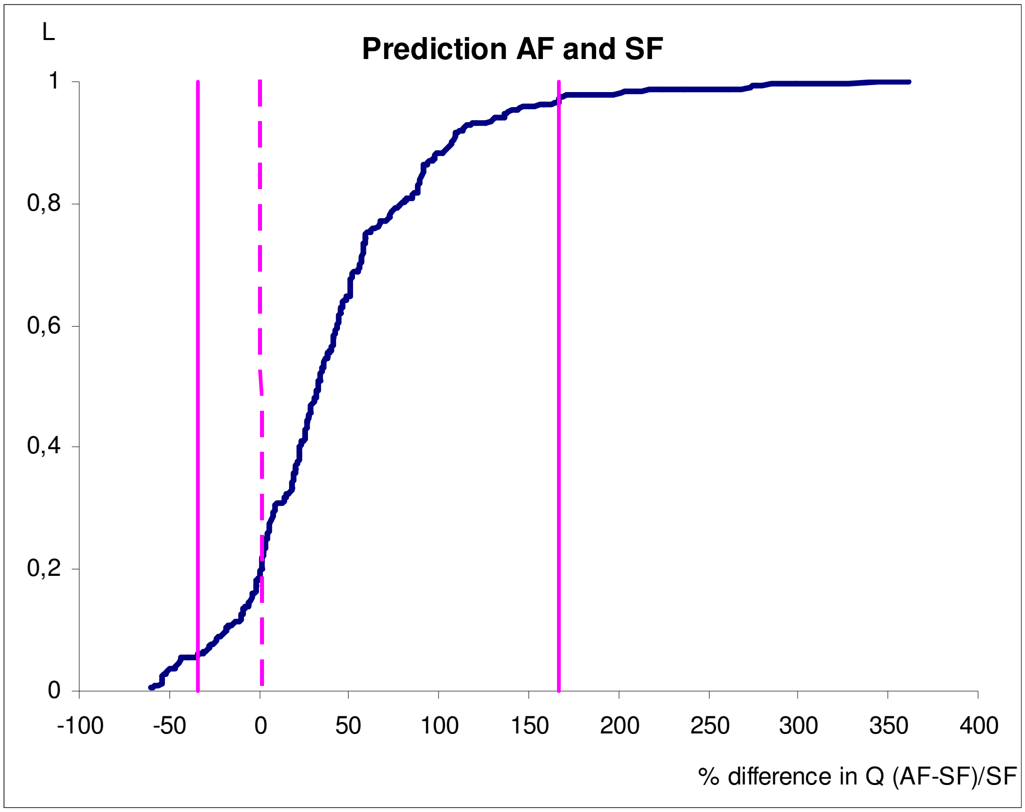

Figure 12. Prediction of difference in discharge between agroforestry systems and secondary forest. The vertical lines are the 95th and the 5th percentiles.

The predictions of change in discharge are very variable within a range of -60 % to 350 %. The majority of the simulations give a higher discharge with the mixed agroforestry system than the one with secondary forest. The predictions of the mixed agroforestry systems that give less discharge than the secondary forest are found on the right side of the broken line and those predictions that give opposite results are found on the left. The expected change is given by the 50 % percentile likelihood, and this gives a predicted 30 % increase in discharge for the agroforestry system. However the predictions show large discrepancies when using the current calibration of GenRiver so more reliable predictions should await an improved calibration of a new version of the model.

4 Recommendations

My recommendations for further investigation of the GenRiver model in the Dong Cao catchment are:

- Change the order of criteria of the water redistribution in the soil in the model.
- Look over and redefine the water that is available for transpiration.
- Make additional GLUE simulations on other parameters (*I_SoilSat_min_FC*) in GenRiver to obtain better parameter estimation and on the parameters that had a slight trend in this study (*I_Rain_IntensMean and I_FieldCap).*
- Try the hypothesis "*when applying more trees in the uplands (sub catchment 4) less water runs in the main outlet of the catchment"* pointed out by the farmers in Dong Cao, using a revised and improved calibration of GenRiver, could evaluate the geographic consequences of land use changes in water distribution.

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