A. $\Sigma P - \Sigma Q$ gives an estimate of total evapotranspiration. Values below 500 or above 1500 mm/year are suspect. These may indicate errors in P or Q registration, error in the area or deviation from the 'closed catchment' assumption (e.g. subsurface flows out of or into the catchment are non-negligible).

B. Cumulative ΣQ versus ΣP during the year: large jumps will require explanation.

C. Flow persistence Q_{i+1} versus Q_i plots may indicate gaps in the data or 'outliers' that indicate errors.

Parametrization of FlowPer

Once flow data have passed minimum quality checks, we can use them to parameterize the null model, esp. the F_p parameter.

If an f_p value of zero is used, the mean of Q_{add} will equal the mean flow, but the variance of daily Q_{add} estimates will be high. If an f_p value of 1.0 is used, many of the Q_{add} estimates obtained will be negative, and the variance will be relatively high. In between these extremes we expect a local minimum for the variance of Q_{add}, at an intermediate f_p value. The model uses this property to provide the final estimate.

FlowPer values of above 0.8 may reflect good watershed conditions; values below 0.4 indicate every poorly buffered watershed. These values are tentative and need further testing.

This flyer is produced by
the TUL-SEA Project
funded by the Federal Ministry for Economic
Cooperation and Development, Germany

Contacts:
TUL-SEA Project
WORLD AGROFORESTRY CENTRE
ICRAF Southeast Asia Regional Office
Jl CIFOR, Situ Gede, Sindang Barang, Bogor 16115
PO Box 161 Bogor 16001, Indonesia
Tel: +62 251 8625415
Fax: +62 251 8625416
E-mail: icraf-indonesia@cgiar.org
http://www.worldagroforestrycentre.org/sea

Credits:
Authors: Meine van Noordwijk and Lisa Tanika
Design and Layout: Diah Wulandari

FlowPer: indicator of watershed quality

Trees in Multi-Use Landscape in Southeast Asia (TUL-SEA)
A negotiation support toolbox for Integrated Natural Resource Management

Watersheds degrade and this makes river flow less predictable: bigger floods and lower dry season flow. A parsimonious null model of flow persistence links local knowledge to hard data.

In the analysis of watershed functions, we deal with a complex of factors that influence processes and patterns in the landscape that ultimately translate a temporal pattern of rainfall into a temporal pattern of stream flow, which aggregates up to a river. Downstream stakeholders start from what they want to see ('perfectly regular flow of clean water') and observe a pattern of stream and river flow that doesn't match their expectations. They search for interventions on the 'anthropogenic' groups of causes ('deforestation', 'degradation'), but need to understand the potential reach of such interventions in view of the geological and climatic background. In the absence of knowledge of what happens upstream, an observer of river flow can deduce a fair amount of information from a time series of river flow data.

The FlowPer model is focussed on that. It can serve two functions:
1) summarize the key parameters that downstream stakeholders can observe on the flow pattern, e.g. as basis for conditional ES rewards
2) serve as a parsimonious (parameter-sparse) 'null model' that allows quantification of the increments in model prediction that is achieved with spatially explicit models (with a priori parametrization rather than parameter tuning to the data).

Models of river flow, even relatively simple ones such as GenRiver, are over-parameterized relative to the information that we can use to check the statistical validity of the model. There are multiple ways of achieving a similar level of 'model fit' between measured and predicted river flow patterns, and the fit obtained may thus be 'right for the wrong reasons'. Using the 'validated model' outside of the calibration range may then be as risky as using a simple regression line. In testing the 'lack of fit' of a model we can benefit from having a 'null-model', a model that takes basic properties of the data into account, without specific hypotheses about the way rainfall translates into river flow.

The FlowPer.xls model provides a parsimonious null-model, that is based on temporal autocorrelation or an empirical 'flow persistence' in the river flow data. The basic form is a recursive relationship between river flow Q at subsequent days:

$$Q_{t+1} = f_p\, Q_t + Q_{add}$$

where Q_t and Q_{t+1} represent the river flow on subsequent days, f_p is the flow persistence factor ($[0< f_p <1]$) and Q_{add} is a random variate that reflects inputs from recent rainfall.

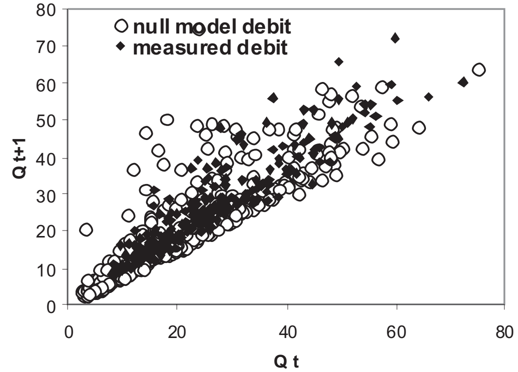
Qadd and fp are related, as $\Sigma\ Q_{add\ i} = (1 - f_p)\ Q$. Thus, if $f_p = 1$, $Q_{add} = 0$ and river flow is constant, regardless of rainfall (the ideally buffered system…). If $f_p = 0$ there is no relation between river flow on subsequent days and the river is extremely 'flashy', alternating between high and low flows without temporal predictability within the frequency distribution of Q_{add}.

The term $Q_{add,i}$ can be described as a statistical distribution with a probability of a non-zero value, a mean and a measure of variance, plus two parameters that describe a seasonal pattern (peak and shape of the distribution, e.g. Weibull). This makes for 5 parameters for $Q_{add,i}$ (and six for the whole model) that are derived from the data. It leaves many degrees of freedom for more specific models that, for example, make use of measured rainfall.

Figure 1. Multiple influences on process and pattern of river flow and the downstream perceptions of 'ecosystem services' (modified from van Noordwijk et al. 2006)

Influence	Process and pattern	Resultant river and stream flow	Downstream 'ecosystem service'
Geology Climate Land use Engineering	Substrate, slopes, channels, lakes Soil formation vs erosion, soil depth Rainfall (P) : seasonal pattern in quantity, intensity Snowmelt Evapotranspiration (E) Vegetation Modified soil porosity and surface infiltration Nutrient flows, contaminants Soil movement (landslides, erosion, deposition) Surface and/or subsoil drainage Filter functions for nutrients and soil particles Release from/ retention of water in the landscape Spatially distributed water balance models + routing function	Space-time pattern of stream flow and its water quality water balance: $Q = P – E + ?\ S$ $Q = Q_{GW}+Q_{LF}+Q_{OF}$ (streamflow is based on: groundwater, subsurface lateral flow and overland flow) $Q_t = f_p\ Q_{t-1} + Q_{add}$ $Q_{add} = F(P , E, f_p)$ $f_p =(f_{pGW} Q_{GW}+ f_{pLF}\ Q_{LF}+ f_{pOF}\ Q_{OF})/Q$ $MeanQ_{add}=(1-f_p)MeanQ$ for $f_p = 1$, $Q_{add} = 0$ for $f_p=0$, $E(Q_{add})=E(Q)$	Total quantity of water available for downstream use Seasonal pattern of water availability (esp. low flow season) Buffering of peak flows ('flooding risk') and daily 'flow persistence' Water quality in relation to different types of water use Support for aquatic & wetland ecosystems and their productivity Risks of soil mass movement; undesirable sedimentation Nutrient loading and soil (fertility) transfer
Potential feedback on 'anthropogenic' causes	Space-time process-based model of separating the multiple causes and effects	Heuristic, parsimonious 'null-model' based on flow pattern only	LEK/PEK synthesis on expectations & explanations

Institutions for feedback (carrots, sticks & sermons)



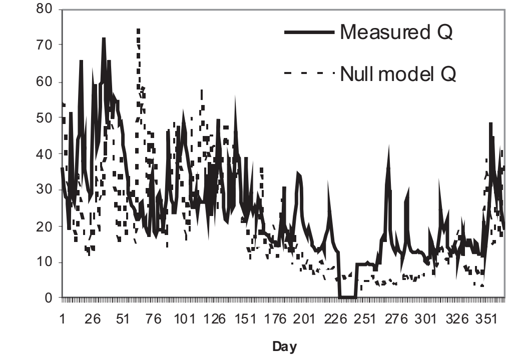


Figure 2. Example of the type of 'fit' that can be achieved for the 6-parameter null-model

If we partition the total flow Qtot into water flow by three pathways (surface runoff, interflow and groundwaterflow), we can obtain $Q_{tot} = Q_{runoff} + Q_{interflow} + Q_{gwflow}$. Each type of flow pathway will typically have a different flow persistence, $f_{p,runoff}$, $f_{p,interflow}$ and $f_{p,gwflow}$, respectively.

$$Q_{tot,t+1} = (f_{p,runoff}(Q_{runoff,t}/Q_{tot,t})+ f_{p,interflow}(Q_{interflow,t}/Q_{tot,t})+ f_{p,gwflow}\ (Q_{gwflow,t}/Q_{tot,t}))Q_{tot,t}+ Q_{add,t}$$

As we can expect values for $f_{p,runoff}$, $f_{p,interflow}$ and $f_{p,gwflow}$ of about 0, 0.5 and close to 1, respectively, we can interpret the relative contributions of the 3 flow pathways from the overall f_p value.

In a more detailed model, the daily value of f_p will shift according to the predicted contributions of the three types of flow, rather than being a constant. Together with the way $Q_{add,i}$ relates to rainfall, this gives space for improved model fits.

Part of the 'flow persistence' may in fact derive from 'rainfall persistence', or the increased probability of daily rainfall after a rainy day, and/or from the increased probability of dry days to follow dry days, even after a monthly pattern ion rainfall is accounted for.

Data quality

When applying the GenRiver model to landscapes where at least some riverflow data are available, there is an opportunity to assess the 'lack of fit' between model and measurements. Lack of fit can be due to 1) inaccuracy or error in the data (e.g. with incomplete representation of spatial variability on rainfall, and/or errors in the data records), 2) suboptimal model parametrization, 3) error and/or oversimplification in the model process description. Component 3 can only be assessed if components 1 and 2 can be quantified. Tests of data consistency can be used to assess component 1, e.g. at seasonal aggregate level. Steps can include:

TUL-SEA: A negotiation support toolbox for Integrated Natural Resource Management