

New Approach to Modelling Water Paths in Managed Rainforests

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Field observations of catchment-scale hydrological behaviour are irreplaceable, yet there is dearth of such information in tropical rainforests (Bonell, 1999; Chappell *et al.*, 2004b). This means that predicting the magnitude of changes in catchment behaviour that result from particular forestry practices becomes problematic. These constraints are considerably worsened where modelling approaches with ill-defined parameter values are utilised for such forecasts.

Limits to catchment models using micro-scale physics:

When using catchment models based on soil-water and canopy-water physics (e.g., Darcy's and Penman-Monteith Equations) one should ask if the micro-scale measurements required by these models (e.g., permeability) can adequately capture the dominant modes of whole catchment behaviour. Increasingly, studies are showing that distributions of micro-scale catchment characteristics do not adequately capture fluxes observed at catchment scales (see e.g., Chappell *et al.*, 1998; 2004b; Franks and Beven, 1997). Intermediate-scale phenomena such as natural soil pipes, gully roughness lengths, canopy roughness lengths are not properly characterised by micro-scale measurements, yet impact at the catchment scale. A further issue with physics-based models is the fact that once developed, the structure of the model is difficult to change, particularly by those with limited experience of numerical analysis. Thus, the role of hydrological pathways that might be locally important may become difficult to incorporate and evaluate. Equally, re-structuring a model according to new ways of thinking about catchment pathways (e.g., pressure and kinematic waves) would require much re-programming and re-calibration of maintained parameters. Additionally, attempting to incorporate more and more processes within a model (rather than simplifying the model to capture only the dominant modes of the large-scale behaviour) results in huge uncertainty and little meaning for the parameter values (e.g., permeability) utilised within the model. Furthermore, detailed information contained within time-series of field observations of whole-catchment behaviour is often only examined at a very superficial and non-statistical way in traditional calibration and validation of physics-based models.

Value of robust data-based modelling approaches:

In some contrast, modelling approaches that use the information contained within the dynamics of large-scale behaviour to define the structure of the simulation or predictive model should better describe whole-catchment behaviour. Clearly the robustness of the model

predictions is dependent on the sophistication of the model identification routines. As the model structures are typically much simpler, uncertainties in model predictions can be much reduced, and often more readily calculated. If key system components can be identified by modelling and related to physically-measurable phenomena, then the utility of simulations to the understanding of system behaviour increases and there may be the potential for changes to be made to internal phenomena to evaluate land-use change effects. Clearly within the humid tropics, the sustainable use of rainforests or their conversion to other land-uses is a change that is currently very extensive. A modelling approach that combines model identification with hydrological understanding and that has recently been applied to tropical rainforest environments (Chappell *et al.*, 1999, 2001, 2004bc) is the Data-Based-Mechanistic (DBM) approach of Young (2001). To date, the DBM approach has been used to identify the presence of signatures in the whole-catchment observations of multiple water-pathways within tropical forests (Chappell *et al.*, 1999, 2004b) and elsewhere in the globe (Young, 2001). The particular strength of the DBM transfer function approach is the model structure identification routine combining the Simplified Reduced Instrument Variable or SRIV with the Young Information Criterion or YIC (Young, 1985, 2001). As yet, the DBM approach has not yet been incorporated into a whole catchment model including the component water-pathways of wet-canopy evaporation, transpiration, overland flow and multiple subsurface components. We intend to show for the first time such a whole catchment model utilising DBM elements - the model we call the BARUMODEL.

Development of the BARUMODEL:

The model is called the BARUMODEL because it is being developed using data and hydrological experience gained from the 0.44 km² Baru Experimental Catchment in Sabah, East Malaysia (5°01' N, 117°48.75' E: see Sinun *et al.*, 1992; Chappell *et al.*, 1999). The catchment is in a forestry research area of the Sabah State forestry organisation of Innoprise Corporation in East Malaysia. The catchment was subject to the first phase of commercial selective logging in 1988 and given the dearth of studies on this land-use impact, it became a reference catchment for such forestry operations. In the Malay language 'baru' means 'new' in English, so the name also attempts to convey that this approach to catchment-based modelling has a number of new elements. The model presented here is a preliminary version based upon components that are identified by separate simulations of Transfer Functions using SRIV and methods of non-linearity parameterisation (see Young, 2001). Work on the identification of more of the whole catchment behaviour as a Multiple Input Multiple Output (MIMO) model is ongoing and would make a more robust structure and parameterisation. The model structure presented here is not intended to be fixed, but modified as new data and ideas are considered or where specific forestry management questions are needed. Additionally, this modelling philosophy accords with the resurgence of interest in 'top-down' modelling approaches as part of new research to Predict the behaviour of Ungauged Basins (PUB).

The version of the BARUMODEL presented here (Figure 1) uses data on catchment water-paths collected during February 1996, a period some 7 year post road construction and timber harvesting. A single month is illustrated so that the dynamics of the water flows can be seen within simple time-series plots; clearly more robust model characteristics are obtained with identifications based on longer time-series of data. Dynamics of all but the wet-canopy evaporation data is gained by field sampling at 10-second intervals and modelling at 5-minute intervals. Such a high resolution is required given the flashiness of the streams in the Baru catchment. Within those regions of the humid tropics that are not subject to extreme cyclonic rainfalls, most of the rainfall that penetrates a rainforest canopy enters the

subsurface system (Q_s) before emerging as streamflow (Chappell *et al.*, 2004b). Statistics of previous simulations of this rainfall-runoff (P-Q) system have indicated that the hydrograph can be decomposed into two subsurface components – a fast pathway (SUB_f) and slow pathway (SUB_s). The fast path may relate to the flow in natural soil pipes, pressure wave or shallow flows (Chappell *et al.*, 1998), while the slow path may relate to miscible displacement through the soil matrix or fracture flows through the melange rock. The multiple pathways were identified after the non-linearities in the catchment behaviour, probably mostly related to unsaturated zone storage, are captured either by the Store-Surrogate SubModel (SSSM) or by the Bedford Ouse Model (BOSM: Young, 2001). As this presentation will illustrate forecasts of riverflow and evapotranspiration changes associated with different selective forestry scenarios only the results from the predictive BOSM are presented (θ_{SUB}). The second component of the BARUMODEL incorporates a BOSM/DTF model of the overland flow ($Q_s : \theta_{SUR}, OF_{SUR}$) from a representative contributory area of the Baru catchment (see Chappell *et al.*, 2004a). A gain filter is used to partition the overland flow (β) and subsurface flow ($1-\beta$) components based upon the observations from multi-scale contributory areas in Chappell *et al.* (1999; 2004a). The evapotranspiration components are this version are handled differently. The wet-canopy evaporation is simply a gain filter (α) based on the difference between storm-based gross (P_G) and net (P_N) precipitation data from Bidin *et al.* (2003). The transpiration dynamics (E_{TR}) are derived from a new model of the relationship between rising-phase air temperature and sapflow (Root) from several 15-year old Dipterocarp trees (Chappell, unpublished) with a gain filter (γ) scaled by one minus the annual rainfall-runoff ratio (Figure 1).

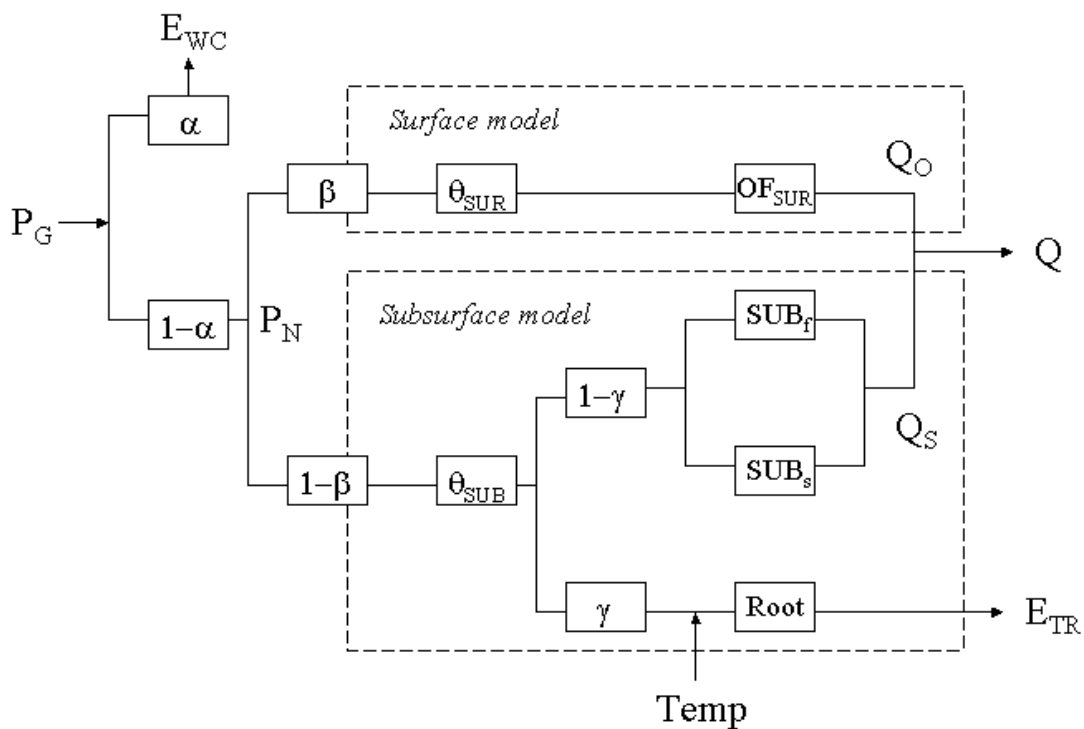


Fig. 1. Block diagram of the BARUMODEL

Application to selective forestry assessments and further model developments:

Within the version of BARUMODEL presented the regulation terms in the gain filters for wet-canopy evaporation, surface-subsurface partition and transpiration are represented as α , β , and γ , respectively. The model defaults represent the hydrological responses observed 7-years post logging with the mix of haulage roads, skidder trails and highlead foci the Baru experienced. The effect of a different level of canopy disturbance on evapotranspiration components, or the proportion of overland flow on river response resulting from different roads/trail densities (see Thang and Chappell, 2004) can be illustrated. Indeed, the compiled version of the model (to be made freely available on the internet) can, after some consideration of the guidance notes, be easily used by foresters, Environmental Impact Assessment specialists without hydrological training. Clearly, given the non-linearities inherent within any rainfall-runoff system, the results should be used for illustrative purposes, primarily to highlight issues requiring further investigation. Indeed, we have also developed the model to highlight where new data or model structures are required in our research which aims to better capture the dominant modes of catchment behaviour. Furthermore, we are already extending the model to address sediment flux from erosion/landsliding, uncertainty in the parameters and outputs, distributed mapping of some variables (e.g., soil saturation) and synchronous simulation of the time-series from the 14 contributory areas of the Baru catchment.

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