GenRiver Brief Description

1. Introduction to GenRiver and component process

1.1 Background of the model

Concerns over negative environmental effects of forest conversion are often expressed in relation to hydrological impacts. Patterns of river flow are widely perceived to change upon change in land cover from closed forest cover to an agriculturally used landscape. Different aspects of river flow such as annual water yield, the partitioning over storm flow and baseflow, and changes in water quality may, however, occur at different rates, change to different degrees, and may even move in different direction (Calder, 2002).

Various approaches exist for modelling watershed functions, ranging from directly data-driven (empirical) approaches to models based on concepts of a water balance, soil physics and hydrology. Hydrology models differ by temporal and spatial scale. A detailed level model use with detailed description of rainfall and infiltration may require a minute (or even seconds) time step, especially on slopes where water will become surface runoff if it cannot infiltrate within seconds of reaching the soil surface. At the other end of the spectrum we may find empirical equations relating annual water yield of a catchment to annual rainfall (or precipitation in climate zones where snowfall and ice rains are significant).

GenRiver is a distributed process-based model that extends a plot-level water balance to subcatchment level. It was developed for data-scarce situations and is based on empirical equations. The model can be used to explore the basic changes of river flow characteristics across spatial scales – from patch level, sub-catchment to catchment. GenRiver is simple river flow model, can be use as a tool to explore our understanding of historical changes in river flow due to land use change.

1.2 GenRiver overview

The model was initially designed as a ‘simple’ (few parameter) model that still has a link to process-based models, and that can be gradually spatially differentiated, as the need arises. The core of the model is a ‘patch level representation of a daily water balance, driven by local rainfall and modified by the land cover and soil properties of the patch. The patch can contribute to three types of stream flow: surface-quick flow on the day of the rainfall event, soil-quick flow on the next day and base flow, via the gradual release of groundwater.

Table 1. The overall water balance of the model , summed over space and time

In	Out
P = precipitation (Rainfall)	E = Evapotranspiration
- ?s = Changes in soil and groundwater storage	Q = River debit (summed over base flow, soil quick flow and surface quick flow)
- ?r =Changes in the volume of water in streams and rivers	? = Error (*unaccounted for*) term (difference between all in & out terms)

For the long -term behaviour the changes in soil and groundwater storage, as well as changes in the volume of streams and rivers will be negligible, while the error term should be negligible at all times if the model is correctly implemented.

On shorter time scales, however, the changes in storage in soil, groundwater (?s), streams and rivers (?r) are critically important for the variability in (daily) river flow as reflected in the 'hydrograph'

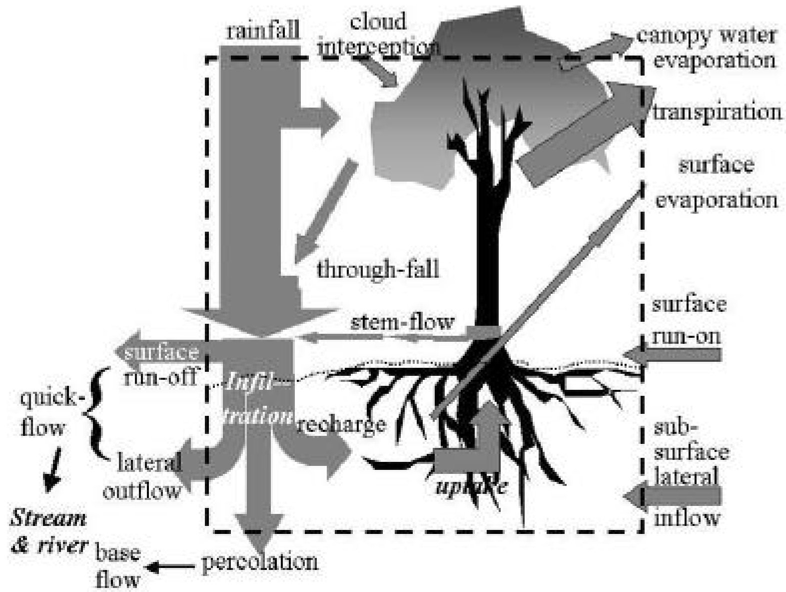

Figure 1. Water balance at patch level that forms the core of the GenRiver model

A river is treated as a summation of streams, each originating in a subcatchment with its own daily rainfall, yearly land cover fractions and constant total area and distance to the river outflow (or measurement) point. Interactions between streams in their contribution to the river are considered to be negligible (i.e. there is no 'backflow' where rivers join). Spatial patterns in daily rainfall events in each subcatchment can be derived from a linked spreadsheet model (SpatRain). The subcatchment model represents interception, infiltration into soil, rapid percolation into subsoil, surface flow of water and rapid lateral subsurface flow into streams with parameters that can vary between land cover classes. The description of the infiltration process is similar to that in WaNuLCAS and the parametrization can be derived for a wide range of land cover types (and histories) from tests with that, more detailed model.

1.3 Component process

? **Daily rainfall amount**

Rainfall at subcatchment level is implemented as daily amounts from long time records for each subcatchment, stored in an Excel spreadsheet. These data can be derived from actual records, or from a 'random generator' that takes temporal patterns (as done in Markov chain models, such as used by *Jones et al.*, for temporal autocorrelation) into account, as well as the spatial correlation of rainfall at any point in time.

? ***Rainfall intensity and time for infiltration***

Rainfall duration is estimated from the daily amount, and a rainfall intensity estimate for the given day (mm $hour^{-1}$) that is derived from a mean value, a coefficient of variation and a random number. Rainfall duration determines the 'time available for infiltration', but this can be modified by canopy interception of rainfall followed by the duration of the 'dripping' phase (default 0.5 hour).

? ***Interception***

Storage capacity for intercepted water is treated as a linear function of leaf + branch area index of the land cover, with the option of modifiers for surface properties that determine the thickness of the water film. Interception-evaporation has priority over plant transpirational demand.

? ***Surface infiltration/runoff***

Infiltration is calculated as the minimum of

- the daily infiltration capacity times the fraction of a day that is available for infiltration (the latter reflects rainfall intensity as well as the local storage capacity of the soil surface)
- the amount that can be held by the soil at saturation minus the amount already present ***plus*** the amount that can enter the groundwater within a day (which in itself is the minimum of the potential daily transport rate and the difference between maximum storage capacity of groundwater and the current amount)

If the first constraint is active, the model generates 'infiltration limited runoff', in the second case 'saturation overland flow'.

? ***Evapotranspiration***

Total evapotranspiration is driven by potential evapotranspiration (Penman type) and (partially) met by :

- Intercepted water
- Land cover, with a drought-limitation proportional to soil water content relative to field capacity below a (vegetation dependent) threshold
- Soil surface evaporation (not explicit – to be included in the land cover /vegetation properties for transpiration)
- Weekly multiplier on potential daily evapotranspiration, reflecting overall phenology
- potential relative evapotranspiration per land cover type (per month).

? ***Soil water redistribution***

During a rain event the soil may get saturated, but within one day it is supposed to drain till 'field capacity' (with an operational definition of the soil water content 24 hours after a heavy rainfall event). The difference between saturation and field capacity can be either :

- Used for transpiration (but canopy intercepted rainfall takes priority to meet the demand)
- Drain to the groundwater reserve, calculated as the minimum of the amount that can be transported downwards and the fraction of soil water that will drain on any given day
- Drain to the rivers as 'soil quick flow': any water left above field capacity by the two preceding processes

? ***Groundwater release to streams (baseflow)***
Surface quick flow, soil quick flow and base flow all feed into streams. For each subcatchment a ‘Routing’ function determines the time delay before the water passesby a defined measuring point (currently the outflow from the catchment).

? ***Distance (routing distance)***
Distance from the mid point of each subcatchment to any number of observation point This parameter will derive the routing time for each subcatchment to each of the observation point, while excluding subcatchment downstream of the observation point.

In the model a number of 'array' dimensions is used. Space-related properties are described with the 'subcatchment' array, that is (potentially) used to specify soil and groundwater properties as well as the 'routing' time for stream flow to reach the point where the river is monitored. A number of land cover classes can be distinguished (as in the 'FALLOW' model, but the GenRiver model operates on daily time steps, while FALLOW has a yearly time step), with different properties for interception of rainfall and water use by transpiration (both at the potential level and where a drought threshold is passed). Time is the main dimension of change, of course, and rainfall is the main time-dependent input, that can be made specific to each subcatchment (but not differentiating land cover classes). Surface infiltration properties are currently described as a constant, but they may well have to be made dependent on subcatchment. A relationship between this property and the land cover class is required that describes the change in this property as a function of time since land cover change.

2. Model implementation in Stella and Excel

2.1 Program implementation in Excel

The GenRive r model is accompanied by GenRiver.xls. The file contains input parameters are link to the model (in the GenRiver.STM file). Below are the explanation of each sheet of the excel file .

Raindata & Debit sheet
These sheet contains daily rainfall (mmday-1) and river debit (m3sec-1) database for the catchment area.

Land cover sheet
It contains land cover type and some qualitative and hypothetical fraction of soil parameter and evapotranspiration.

Subcatchment info
It contains subcathment area (km2) and routing distance (km) from each subcatchment to the outlet. It is also possibility to defined land cover fraction for each subcatchment.

2.2 Program implementation in Stella

The model has the following components: an initialisation part, the dynamic sectors (dealing with patch-level water balance, stream and river flow, and the operational rules of reservoirs in the river network) and two sectors for keeping track of all output parameters required.

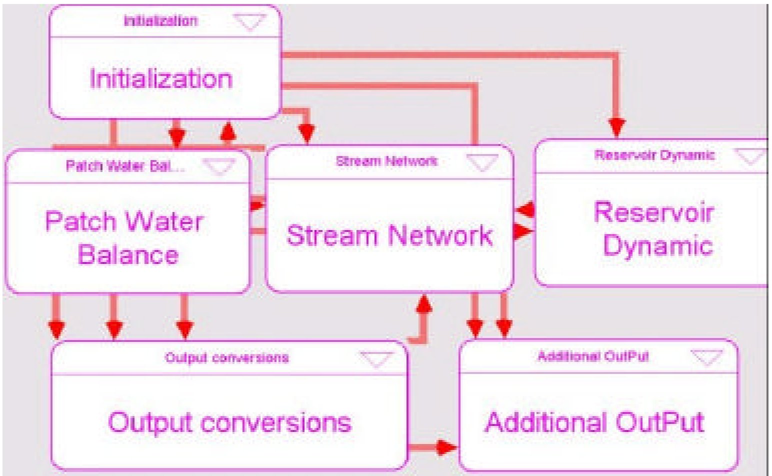

Figure 2.Sector of the model implemented in Stella.

2.2.1 Input parameters

User can define the length of simulation and the measurement period start and end. Internally, many of the input parameters are processed in the initial section to convert units and apply the area fractions of the various subcatchments and land cover fractions (in fact – these land cover fractions can be dynamic).

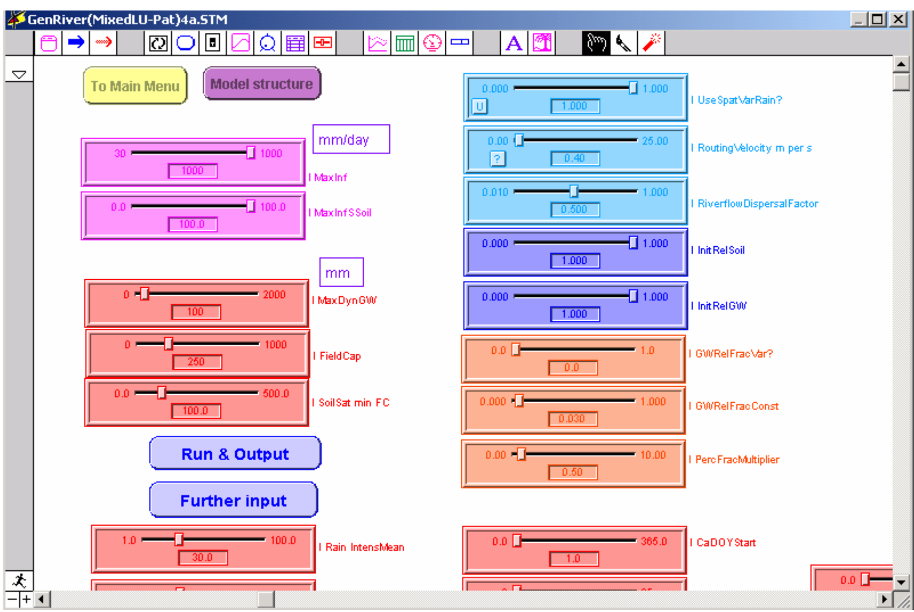

Figure 3.Input screen in Stella, the user can modify input values by using the ‘sliders’.

2.2.2 Patch-level water balance

The 'patch water balance' section in the model (Figure 4) closely follows the diagram in figure 5. The amount of rainfall for each land use category within each subcatchment is calculated from the rate per unit area and the respective area fractions. In order to implement the flows of this rainfall at the same day to either of the pools 'soil water', 'groundwater', 'cumulative evapotranspiration' or the surface runoff flow, the equations for the respective flows are linked and prioritized (with interception having priority and surface runoff being the residue of potential infiltration and rainfall *minus* interception.

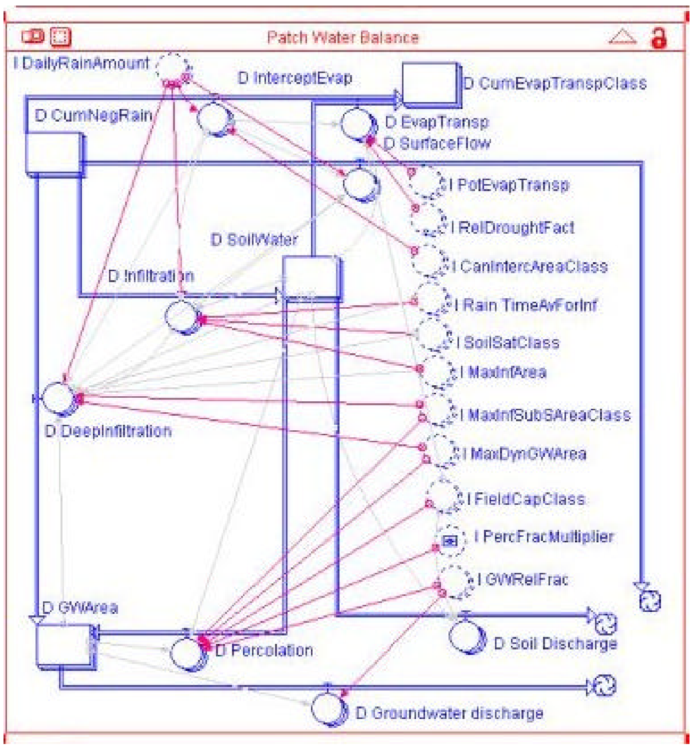

Figure 4. Diagram of the patch-level water balance with the stocks represented by rectangles, parameters by circles, water flows by double-lined arrows and information follows by single lines.

2.2.3 River flow

The implementation of the stream and river flow sector distinguishes between the part of the surface flow that can reach the observation points on the day of rainfall and the part that has one or more days of delay before reaching that point. As each calculation step (from stock to stack) takes one time step in STELLA, special care is needed to obtain same-day flows. A similar issue holds for the soil quick flow that can reach the observation point at the earliest one day after the rainfall.

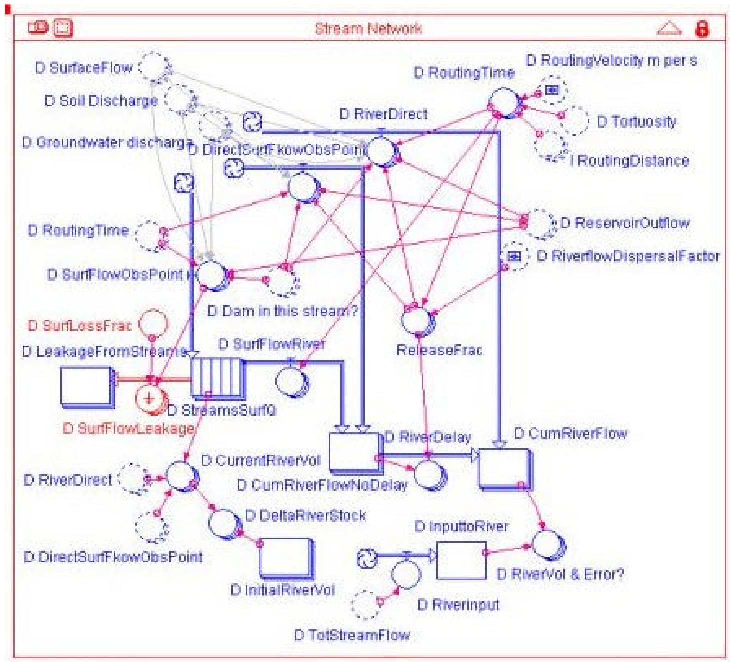

Figure 5 . Diagram of the river network with the stocks represented by rectangles, parameters by circles, water flows by double -lined arrows and information follows by single lines.

3. The example of model output

The type of output produced by GenRiver is river debit and water balance. The model has a number of parameters that require initialization, including the soil and groundwater stocks at the start of the model. As parameter values for such can not be empirically derived, we let the model run for a number of years before we derive the output -- this way the output values become independent of the choice of initialization values.

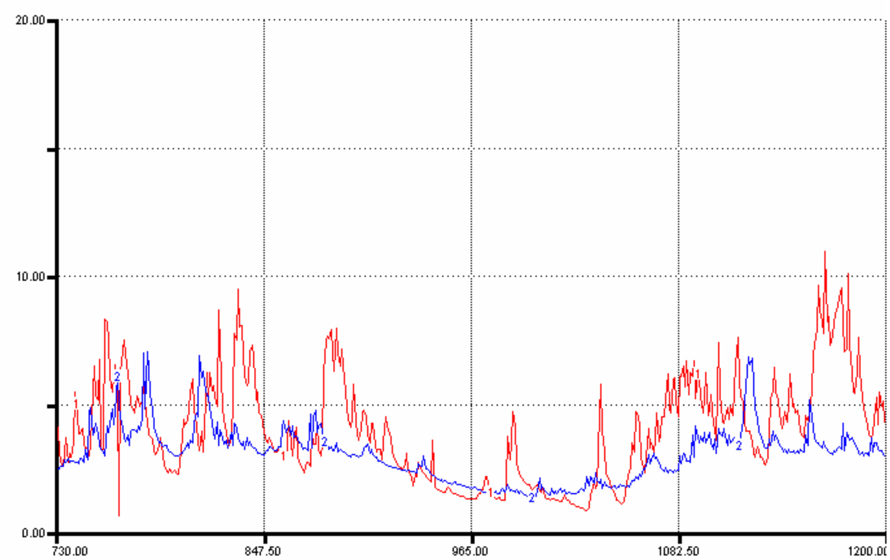

Figure 6. Example of debit prediction (blue) and debit data (red) as one of output parameter We can compare measured and simulated river flow over time – in this example no specific effort to 'fit' the model was made.

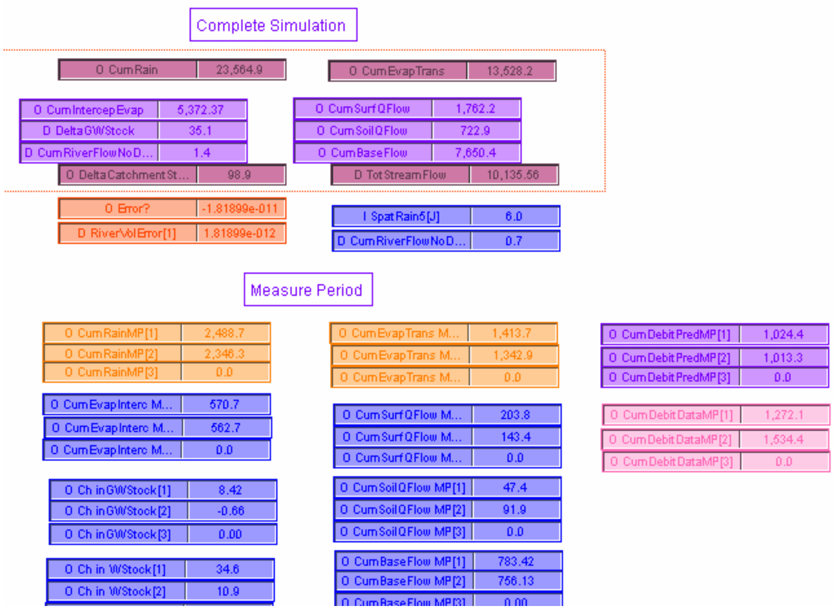

Figure 7 . An example of cumulative table as output. The balance per user defined measuring period allow us to check sensitivity of the water balance paramaters.

4. Example of model application (default)

We used Sumberjaya as default condition for the model. We define the area into 15 subcatchments with total area 404 km^2. Fraction of land cover type for the catchment in year 3 and 20 in time series is 58 and 14% for forest, respectively, 22 and 11% for cropland and pioneer stages of fallow vegetation and 12 and 70% for coffee gardens, respectively.

The overall water balance for Way Besai (Sumberjaya) as simulated with GenRiver (Fig.8). Cumulative evapotranspiration in the Way Besai is about 85% of the cumulative rainfall. Cumulative discharge (which equals the sum of Cumulative base flow (CumBaseFlow), surface quick flow (CumSurfQFlow) and soil quick flow (CumSoilQFlow) is approximately equal to cumulative rainfall (CumRain) minus cumulative evapotranspiration (CumEvapTrans). Evapotranspiration (plus river flow) and rainfall can be partially out of phase, as reflected in the 'delta catchment storage' term that ends the year at approximately zero in both simulations.

In general the terms other than rainfall show a smoother profile of increments, reflecting the buffering conveyed by soil and river system. In the current simulations discharge in the Way Besai consists largely of base flow, with soil quick flow and surface quick flow (derived mainly from December and January rainfall events) making approximately equal contributions to the rest. The Way Besai simulation mainly to changes in soil parameters affecting the partitioning between the various flow pathways.

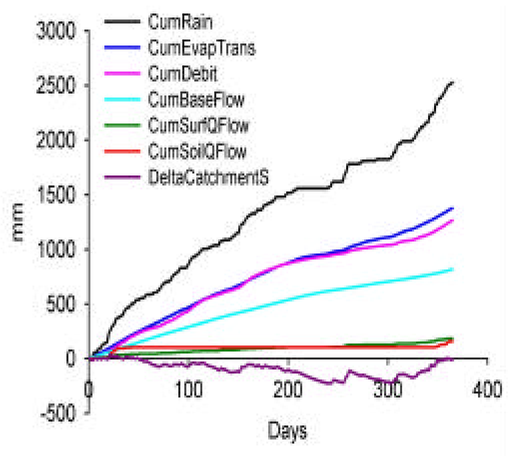

Figure 8. Cumulative water balance as output of GenRiver using Way Besai (Sumberjaya)

Using two different types of rainfall generated by SpatRain, we simulated river flow for Way Besai, Sumberjaya. Result are here shown for the beginning (year 3) and end (year 20) of the simulation (year 3 is shown since we found that result for the first year depended on initialization of a number of parameters). Year 3 and year 20 of the time series reflecting land cover fractions of 58 and 14% for forest and 22 and 11% for cropland and pioneer stages of fallow vegetation and 12 and 70% for coffee gardens, respectively.

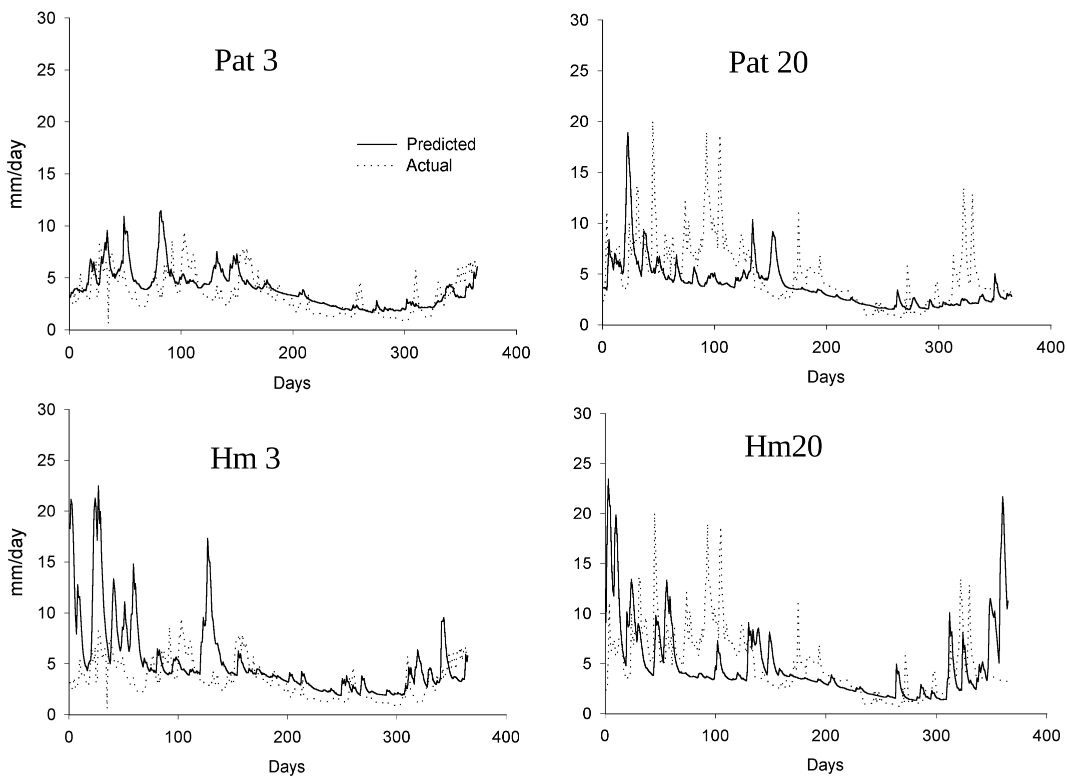

Figure 9 . Measured (dots) and predicted (lines) river flow of Way Besai, Sumberjaya (mm day –1) in year 3 and year 20 for patchy and homogenous rainfall pattern.

In the Way Besai simulation patchy rainfall produces a better match of simulated and measured patterns of river flow compared to more homogenous rainfall patterns. We don't expect the simulations to match the dates of the peaks in measured flow (as we started from a resampling of the statistical distribution rather than specific time -series), but we expect the shapes and intensities of highs and the recession during low flow periods to match.

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