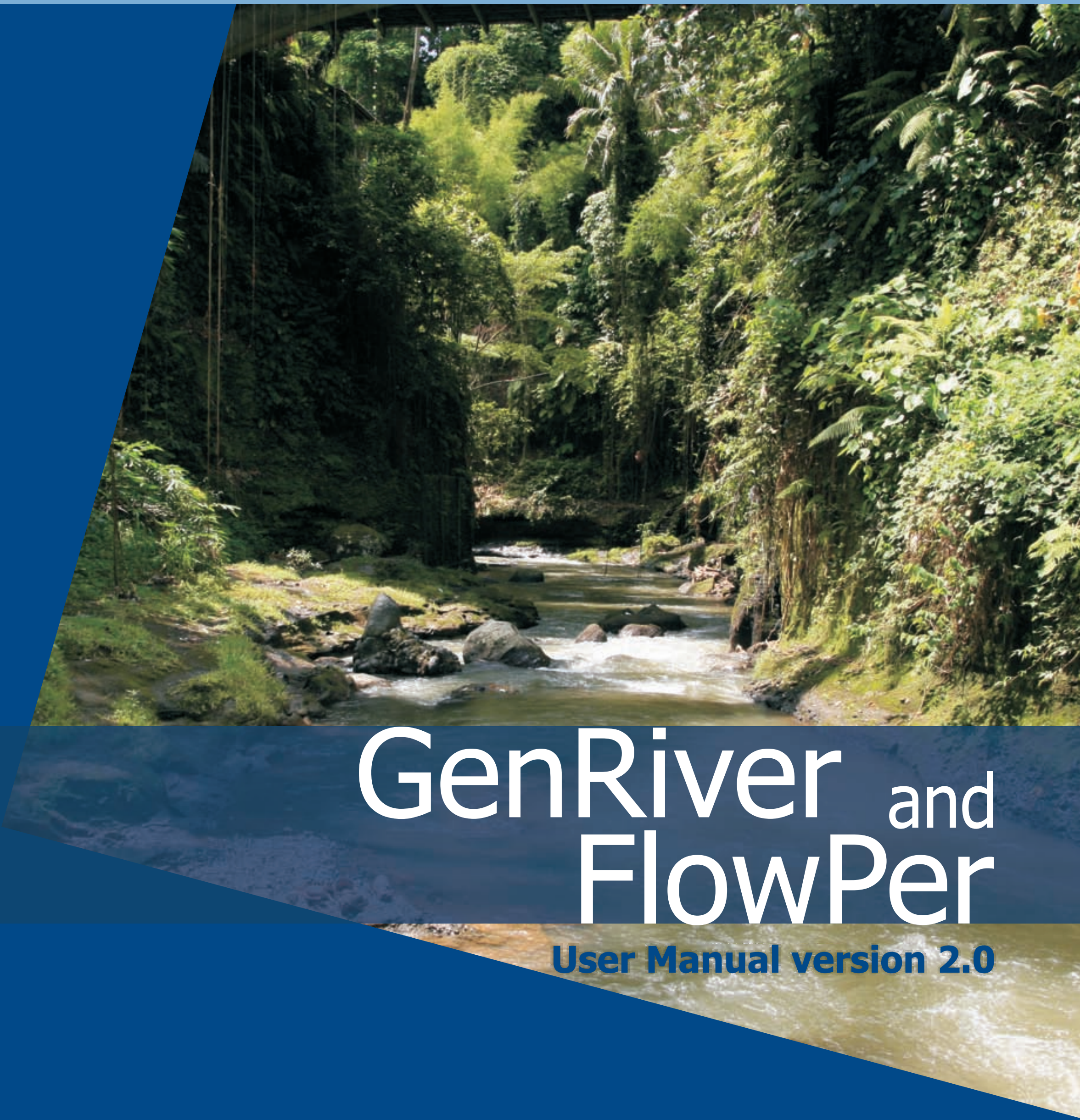
Generic River and Flow Persistence Models



GenRiver and FlowPer

User Manual version 2.0

Meine van Noordwijk, Rudy Harto Widodo, Ai Farida, Desi A Suyamto,
Betha Lusiana, Lisa Tanika, Ni'matul Khasanah

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This is version 2.0 of a model on river flow. Although efforts have been made to incorporate relevant process knowledge on a range of interactions, the model is no more (and no less) than a research tool. Model predictions may help in developing specific hypotheses for research, in exploring potential management options and extrapolation domains, but they should not be used as authoritative statements.

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Copies of the software are available from
http://www.worldagroforestry.org/sea/genriver

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Ni’matul Khasanah, Rudy Harto Widodo and Degi Harja

2011

PREFACE

Water flow in rivers is generated by rainfall and modified by landscape topography, vegetation and soil and also by human engineering to enhance drainage and/or retention of water. The degree to which river flow is influenced by land-cover change (deforestation, reforestation, agroforestation and other such practices) is hotly debated, as is the influence of climate change. A simple tool that relates plot-level to river-level consequences was deemed relevant to assist in the analysis of catchment data. Existing models were either too complex and data-hungry or left out important processes, such as the impact of land-use change on the soil and its physical condition.

GenRiver is a generic river flow model that responds to spatially explicit rainfall and keeps track of a plot-level water balance that responds to changes in vegetation and soil. The model treats a river as a summation of streams, each originating in a subcatchment with its own daily rainfall, yearly land cover fractions and routing time based on distance to the river outflow (or measurement) point. Interactions between streams in their contribution to the river are considered to be negligible (that is, there is no “backflow” problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each subcatchment in a separate module (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.

GenRiver was first developed as part of an Australian Centre for International Agricultural Research-funded project on watershed functions in landscape mosaics. This manual is reproduced through the TUL-SEA (Trees in Multi-Use Landscapes in Southeast Asia) project, funded by the German Federal Ministry of Economic Cooperation and Development (BMZ) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). However, these sponsors are not responsible for any of the information provided in this manual.

The authors wish to acknowledge many colleagues and users for their valuable contributions and advice.

Base flow is the portion of stream flow that derives from groundwater and is not related to current or recent rainfall.

BD/BDref is the bulk density of a soil layer relative to the "reference bulk density" that can be expected for a soil of similar texture under natural forest conditions.

Buffering capacity is the ability of a system to reduce the impact of external variation on internal properties, for example, reducing the variation in stream flow relative to variation in rainfall.

Buffering indicator is derived from the ratio of above-average stream flow and above-average rainfall.

Buffering for peak events is the "buffer" function demonstrated at peak rainfall events.

C/Cref is the organic soil carbon content of a soil relative to the "reference soil Corg concentration" that can be expected for a soil of similar texture, pH and mineralogy under natural forest conditions at the given elevation (temperature regime).

Discharge or Outflow of a river is the volume of water transported by it in a certain amount of time. The unit used is usually m^3/s (cubic meters per second).

Evapotranspiration is a term used to describe the sum of evaporation and plant transpiration from the earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

Field capacity is the volumetric soil water content measured one day after a saturating rainfall event, when rapid drainage and interflow have removed excess water to streams or groundwater

Flash floods is floods caused by heavy or excessive rainfall in a short period of time, generally under six hours, leading to stream flow and water levels that rise and fall quite rapidly.

Flow persistence is the fraction of flow on the previous day that can be expected as minimum volume of river flow on a given day.

Gradual water release is gradual release of (ground) water during periods without rainfall ('dry season').

Ground water discharge is the release of groundwater to streams or subsurface flows.

Interflow see **Quickflow**

Low flow is flow through a watercourse after prolonged absence of rainfall.

Overland flow see **surface runoff**

Overflow or Bank overflow is flow of water outside of the regular river bed during conditions where recent inflow minus outflow has exceeded the storage capacity.

Peak flows is maximum flows through a watercourse.

Precipitation is all forms of water particles, whether liquid or solid, that fall from the atmosphere to the ground. Distinguished from cloud, fog, dew and frost, precipitation includes rain, drizzle, snow and hail.

Quickflow or Interflow is the part of a storm rainfall which moves laterally through hill slope soils to a stream channel; it infiltrates the soil, but cannot be retained by the soil at its “field capacity”; shallow groundwater or interflow may emerge at the surface at the bottom of slopes and flow across the ground surface to the stream.

Relative buffering indicator is the “buffer” function adjusted for relative annual water yield.

River flow is the flow of water in the river channel.

Storage capacity is the total amount of water that can be stored in a reservoir before overflow occurs.

Stream flow is the flow of water in streams, rivers and other channels.

Surface runoff or Overland flow is the flow across the land surface of water when rainfall rate exceeds the infiltration capacity of the soil. The rate of infiltration, and therefore the possibility of surface runoff, is determined by such factors as soil type, vegetation and the presence of shallow, relatively impermeable, soil horizons. Saturated overland flow can occur when a temporary rise of the watertable inhibits infiltration and causes flow over the surface.

Total discharge fraction is total water yield (discharge) per unit rainfall, usually on an annual basis.

Water balance is the comparison over a certain time period (for example, month or year) of inflow of water (precipitation) and outflows by evapotranspiration, stream flow and subsurface flows.

Water quality is the chemical, physical and biological characteristics of water with respect to its suitability for a particular use.

Water storage is the volume of water that can be (temporarily) withheld from evapotranspiration, stream flow or subsurface flows, either above ground in lakes, rivers and other waterways or below ground as ground water.

Water transmission is the fraction of incoming precipitation that is converted into stream flow.

CONTENT

FIGURES

CHAPTER 1

1. General information

1.1. GenRiver model overview

Land-cover change can significantly affect watershed functions through

a) changes in the fraction of rainfall that reaches the ground;
b) the subsequent pathways of water flow over and through the soil as related to surface and subsurface structure of the soil, surface roughness and landscape drainage; and
c) the rate of water use by plants (Figure 1.1).

Simple characteristics of vegetation (monthly pattern of leaf biomass, influencing canopy interception and transpiration, and ability to extract water from deeper soil layers) and soil (especially compaction of the macro-pores in the soil that store water between "saturation" and "field capacity") can probably explain a major part of the impacts on river flow.

Empirical assessment of the dynamics of water flows as a function of land-cover change and soil properties takes time and resources and needs to take temporal and spatial variation of rainfall into account. A model based on "first principles" that integrates land-cover change and change in soil properties as driving factors of changes in river flow can be used as a tool to explore scenarios of land-use change, if it passes a validation test against observed data.

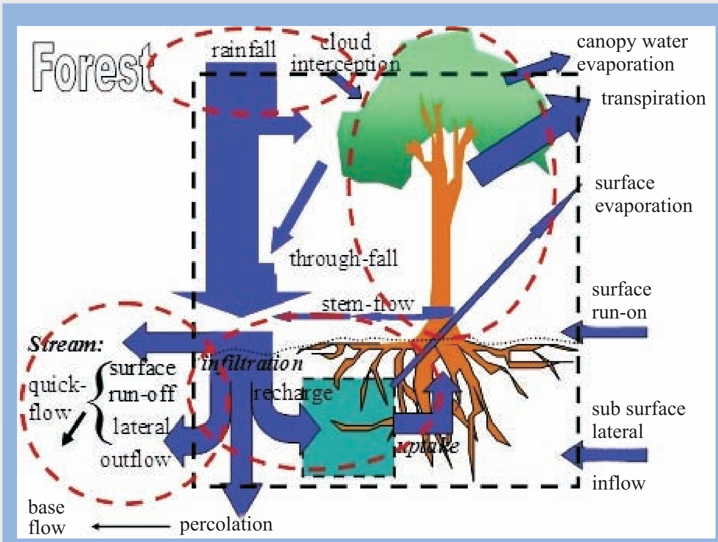


Figure 1.1 Multiple influences of tree cover and (forest) soil condition on the water balance

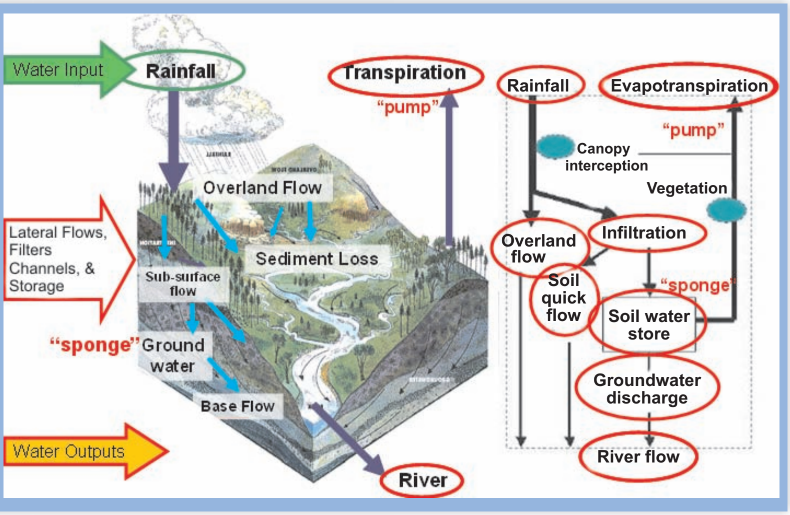


Figure 1.2 Landscape-scale processes that relate the spatial and temporal aspects of rainfall to river flow

GenRiver is a generic river model on river flow. As is common in hydrology, it start the accounting with rainfall or precipitation (P) and traces the subsequent flows and storage in the landscape that can lead to either evapotranspiration (E), river flow (Q) or change in storage (ΔS) (Figure 1.3):

$$P = Q + E + \Delta S$$

Models differ in the relations between the different terms of the balance equation and in the way they account for the "slow flows" that derive from water that infiltrates into the soil but can take a range of pathways, with various residence times, to reach the streams and rivers, depending on land form, geology and extractions along the way.
The core of the GenRiver model is a "patch" level representation of a daily water balance, driven by local rainfall and modified by the land cover and land-cover change 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.

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 (that is, there is no "backflow" problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each subcatchment. 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.

This user's manual is designed to help people who work with the GenRiver model. The text of the manual is organized as

(1) general overview on GenRiver model and minimum system requirement to run it;
(2) guide on working with GenRiver model and evaluation on model output;
(3) number of examples of model application; and
(4) detail on model description and its component and appendices on description of model input and output parameter, advice on dealing with data inputs parameter and advice on model calibration.

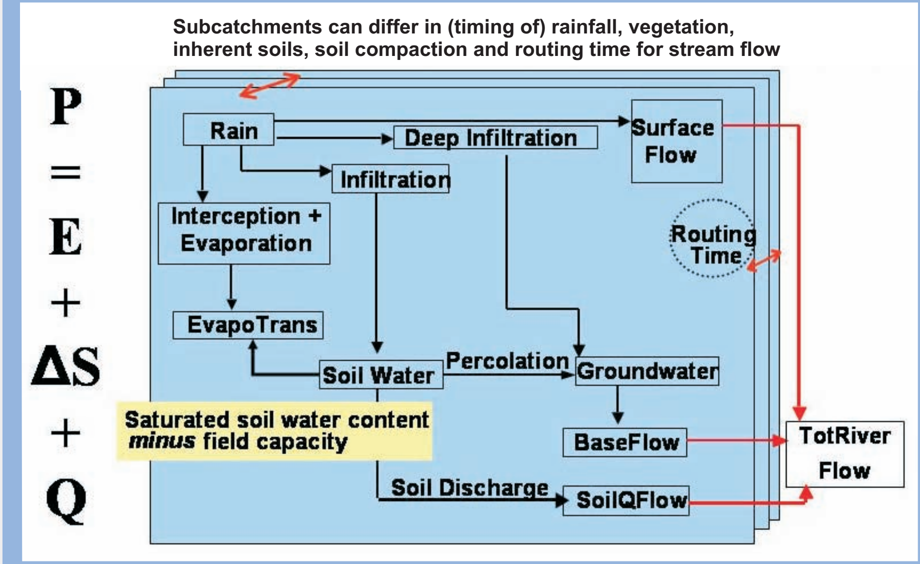


Figure 1.3 Overview of the GenRiver model: the multiple subcatchments that make up the catchment as a whole can differ in basic soil properties, land-cover fractions that affect interception, soil structure (infiltration rate) and seasonal pattern of water use by the vegetation. The subcatchment will also typically differ in “routing time” or in the time it takes the streams and river to reach the observation point

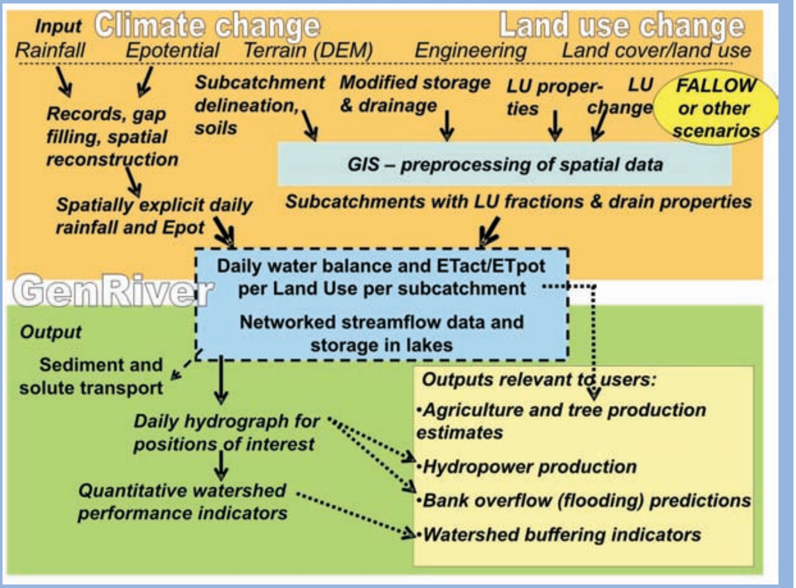


Figure 1.4
GenRiver model:
key types of input
and main output

1.2. Minimum system requirements

GenRiver was developed in the Stella modelling platform. The GenRiver model is accompanied by an MS Excel file (GenRiver.xls). GenRiver.xls is to help users initialize and estimate some input parameters. Before you run the model, you must have the Stella program in your PC. A free demonstration version (a save-disabled) of Stella can be downloaded through http://www.iseesystems.com/.

Minimum system requirements to run GenRiver model

Windows	**Macintosh**
- 233 MHz Pentium	- 120 MHz PowerPC
- Microsoft Windows™ 2000/XP	- Any Intel-based Mac
(English Version)	- Mac OS 10.2.8 or higher (English Version)
- 128 MB RAM	- 128 MB RAM
- 70 MB hard disk space	- 70 MB hard disk space
- 16-bit color	- Thousands of colors

1.3. Installing GenRiver model

You may copy and decompress the GenRiver model (GenRiver.stm) and the MS Excel file (GenRiver.xls) into any directory.

CHAPTER 2

2. Working with the GenRiver model

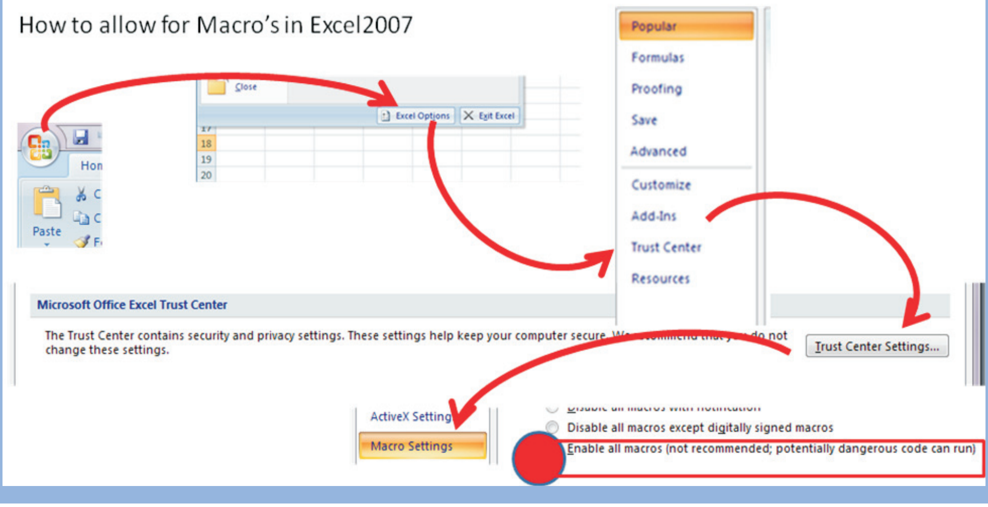
2.1. Starting the GenRiver model

The GenRiver.xls file contains a number of macros. The default setting in most MS Windows and MS Excel installations is to not allow such macros and to not even ask whether the user wants them or not. If your computer security settings don't allow any macro to run, you may need to change the security level for macros.

If you are working with MS Excel 2003, to change the security level go to “Tools” and “Macro” and choose “low”, then close and re-open GenRiver.xls. It will give a warning that the file contains a macro. Choose “enable macro” and then you will see something like Figure 2.1.

If you working with MS Excel 2007, to change the security level for macros, follow the diagram below. This is to make sure the macro built to ease inputting parameters in the model is working properly.

Then run Stella and open GenRiver.stm. If you are working with Stella 7 or 8, to update the linked input from GenRiver.xls into GenRiver.stm, click “Yes” when the question, “This model contain links. Re-establish link?”, appears on your screen when you open GenRiver.stm. If you working with Stella 9, to update the linked input from GenRiver.xls into GenRiver.stm use the “ImportData” option under the “Edit” menu.



How to allow for Macro's in Excel2007

Microsoft Office Excel Trust Center

The Trust Center contains security and privacy settings. These settings help keep your computer secure. [illegible] do not change these settings.

○ Disable all macros except digitally signed macros

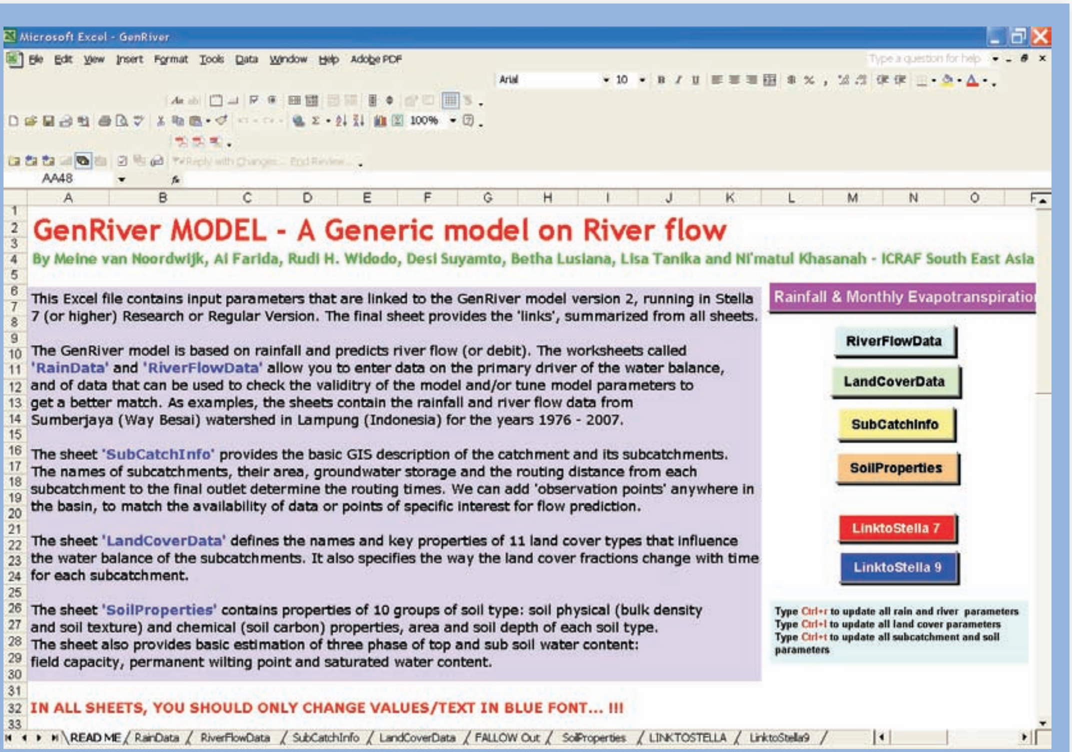
● Enable all macros (not recommended; potentially dangerous code can run)

There are two types of importing data: the first one is import data “one time”, meaning the data is imported without establishing a link; the second is “persistent” data import, meaning the data is imported and a link established.

To cross-check whether input parameters were updated both in MS Excel and Stella, open a table in Stella, tabulate input parameters and compare them with the MS Excel file.

You are now inside the main menu of GenRiver and ready to work. On your screen you will see something like Figure 2.2.

> The active link between the MS Excel file GenRiver.xls and the Stella file GenRiver.stm requires that the filename for the Excel file remains the same. If you want to differentiate multiple versions of the input parameters, please make separate copies in different subdirectories (folders), otherwise the links are lost.



GenRiver MODEL - A Generic model on River flow

By Meine van Noordwijk, Ai Farida, Rudi H. Widodo, Desi Suyamto, Betha Lusiana, Lisa Tanika and Ni'matul Khasanah - ICRAF South East Asia

This Excel file contains input parameters that are linked to the GenRiver model version 2, running in Stella 7 (or higher) Research or Regular Version. The final sheet provides the 'links', summarized from all sheets.

The GenRiver model is based on rainfall and predicts river flow (or debit). The worksheets called 'RainData' and 'RiverFlowData' allow you to enter data on the primary driver of the water balance, and of data that can be used to check the validitry of the model and/or tune model parameters to get a better match. As examples, the sheets contain the rainfall and river flow data from Sumberjaya (Way Besai) watershed in Lampung (Indonesia) for the years 1976 - 2007.

The sheet 'SubCatchInfo' provides the basic GIS description of the catchment and its subcatchments. The names of subcatchments, their area, groundwater storage and the routing distance from each subcatchment to the final outlet determine the routing times. We can add 'observation points' anywhere in the basin, to match the availability of data or points of specific interest for flow prediction.

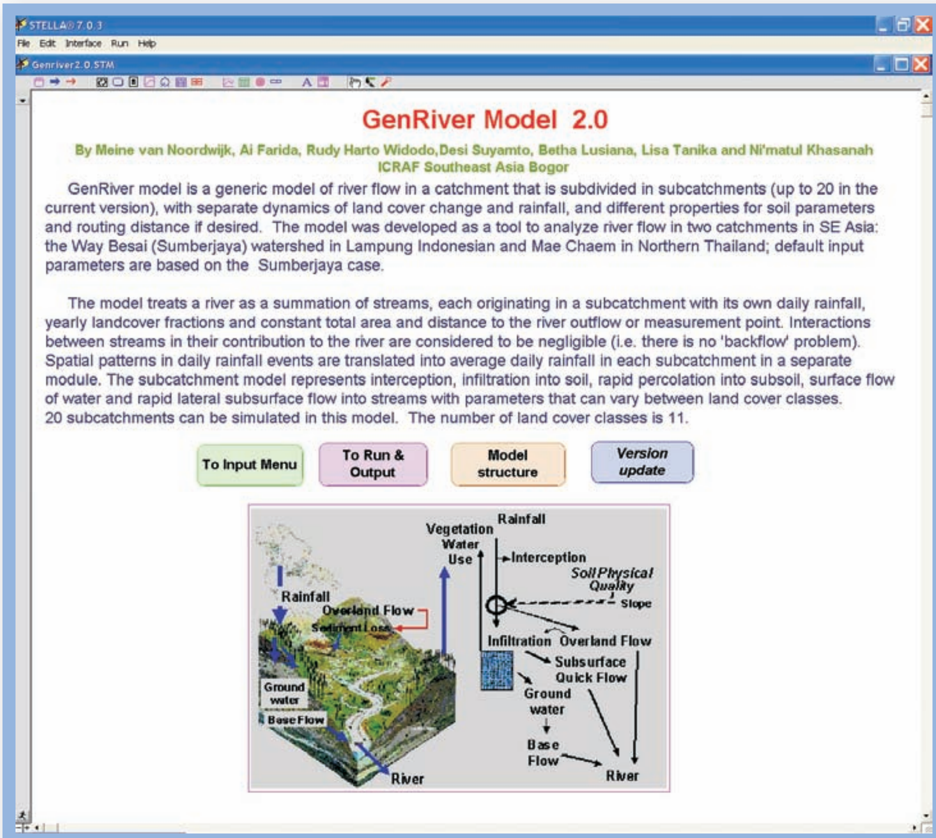
The sheet 'LandCoverData' defines the names and key properties of 11 land cover types that influence the water balance of the subcatchments. It also specifies the way the land cover fractions change with time for each subcatchment.

The sheet 'SoilProperties' contains properties of 10 groups of soil type: soil physical (bulk density and soil texture) and chemical (soil carbon) properties, area and soil depth of each soil type. The sheet also provides basic estimation of three phase of top and sub soil water content: field capacity, permanent wilting point and saturated water content.

IN ALL SHEETS, YOU SHOULD ONLY CHANGE VALUES/TEXT IN BLUE FONT... !!!

Type Ctrl+r to update all rain and river parameters
Type Ctrl+l to update all land cover parameters
Type Ctrl+t to update all subcatchment and soil parameters

Figure 2.1 Main Menu of MS Excel file accompanying GenRiver model



GenRiver Model 2.0

By Meine van Noordwijk, Ai Farida, Rudy Harto Widodo,Desi Suyamto, Betha Lusiana, Lisa Tanika and Ni'matul Khasanah
ICRAF Southeast Asia Bogor

GenRiver model is a generic model of river flow in a catchment that is subdivided in subcatchments (up to 20 in the current version), with separate dynamics of land cover change and rainfall, and different properties for soil parameters and routing distance if desired. The model was developed as a tool to analyze river flow in two catchments in SE Asia: the Way Besai (Sumberjaya) watershed in Lampung Indonesian and Mae Chaem in Northern Thailand; default input parameters are based on the Sumberjaya case.

The model treats a river as a summation of streams, each originating in a subcatchment with its own daily rainfall, yearly landcover 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' problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each subcatchment in a separate module. 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. 20 subcatchments can be simulated in this model. The number of land cover classes is 11.

Figure 2.2 Main menu of GenRiver model

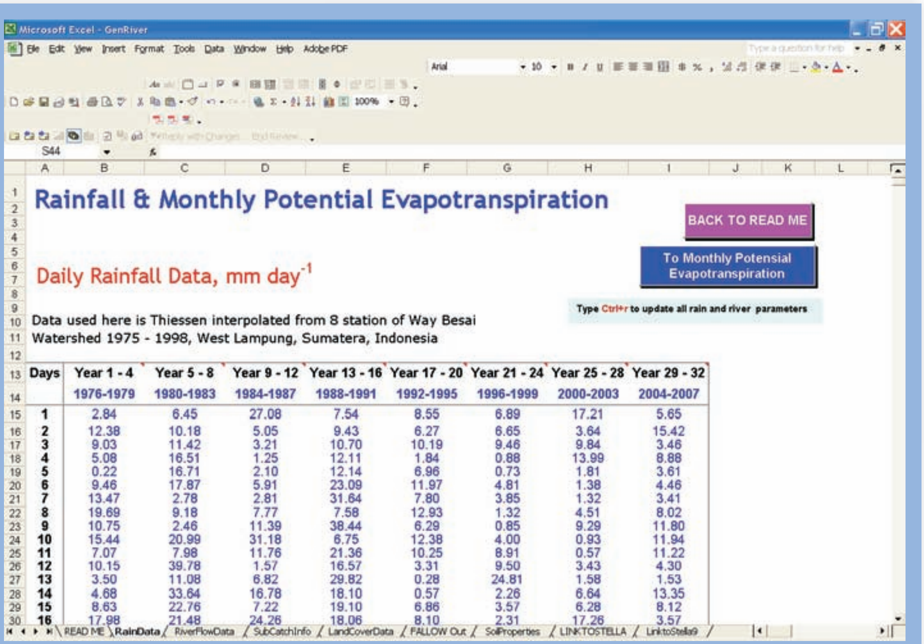
2.1.1. Familiarize yourself with GenRiver.xls

GenRiver.xls is organized into nine sheets, labeled READ ME, RainData, RiverFlowData, SubCatchInfo, LandCoverData, Fallow OUT, SoilProperties, LinktoStella and LinktoStella9. The last two sheets provide two alternative formats for linking the input parameters the GenRiver.stm model, depending on the version of Stella used.
The basic purpose of this Excel file is to help with organizing and modifying input parameters needed to run the GenRiver model. Changing input parameters that link to GenRiver model should not be done once you run the GenRiver.stm and GenRiver.xls simultaneously.

In all sheets, you can only change values in blue font. Below are explanations of each sheet. Definition of each acronym of input parameter refers to appendix 1.

RainData sheet

The sheet, RainData, stores rainfall data and is implemented as daily amounts (mm day^{-1}) from long-term records. This sheet also stores monthly evapotranspiration data (Figure 2.3). The rainfall data can be derived from actual daily rainfall data records or from a "random generator" that takes temporal patterns (as done in Markov chain models, such as was used by Jones et al. 2001 for temporal autocorrelation) into account, as well as the spatial correlation of rainfall at any point in time.



Rainfall & Monthly Potential Evapotranspiration

Daily Rainfall Data, mm day^{-1}

Data used here is Thiessen interpolated from 8 station of Way Besai Watershed 1975 - 1998, West Lampung, Sumatera, Indonesia

Days	Year 1 - 4	Year 5 - 8	Year 9 - 12	Year 13 - 16	Year 17 - 20	Year 21 - 24	Year 25 - 28	Year 29 - 32
	1976-1979	1980-1983	1984-1987	1988-1991	1992-1995	1996-1999	2000-2003	2004-2007
1	2.84	6.45	27.08	7.54	8.55	6.89	17.21	5.65
2	12.38	10.18	5.05	9.43	6.27	6.65	3.64	15.42
3	9.03	11.42	3.21	10.70	10.19	9.46	9.84	3.46
4	5.08	16.51	1.25	12.11	1.84	0.88	13.99	8.88
5	0.22	16.71	2.10	12.14	6.96	0.73	1.81	3.61
6	9.46	17.87	5.91	23.09	11.97	4.81	1.38	4.46
7	13.47	2.78	2.81	31.64	7.80	3.85	1.32	3.41
8	19.69	9.18	7.77	7.58	12.93	1.32	4.51	8.02
9	10.75	2.46	11.39	38.44	6.29	0.85	9.29	11.80
10	15.44	20.99	31.18	6.75	12.38	4.00	0.93	11.94
11	7.07	7.98	11.76	21.36	10.25	8.91	0.57	11.22
12	10.15	39.78	1.57	16.57	3.31	9.50	3.43	4.30
13	3.50	11.08	6.82	29.82	0.28	24.81	1.58	1.53
14	4.68	33.64	16.78	18.10	0.57	2.26	6.64	13.35
15	8.63	22.76	7.22	19.10	6.86	3.57	6.28	8.12
16	17.98	21.48	24.26	18.06	8.10	2.31	17.26	3.57

Figure 2.3 View of RainData sheet

Input parameters	Location in Excel file	Location in Stella
I_DailyRainYear…to…[Subcatchment]	Cells B15 – I1474	Input Section – Rainfall
I_SpatRain1…7[Subcatchment]		Input Section – Rainfall
I_Evapotrans (RainData Sheet)	Cells T15 – T26	Input Section – Subcatchment Parameter

This option is activated by switching on or off the slider I_UseSpatVarRain? in GenRiver.stm, Input Section-Rainfall. Value 1 means using spatial rainfall distribution generated from SpatRain model and 0 means using actual daily rainfall data records.

Default values are based on the actual daily rainfall data from Sumberjaya (Way Besai) watershed in Lampung (Indonesia) for 32 years (1976–2007). The data are arranged in eight columns containing data for four years for each column, as this is the maximum length that can be copied to Stella and it is linked to Stella I_DailyRainYear…to…[Subcatchment] (Figure 2.4).

You can adjust the daily rainfall data records for a station representing the area (or multiple stations if these are supposed to be similar) or using generated daily rainfall data using SpatRain model. For generated data using SpatRain model, you should manually copy the data to GenRiver.stm input parameters, I_SpatRain1…7[Subcatchment] (Figure 2.4).

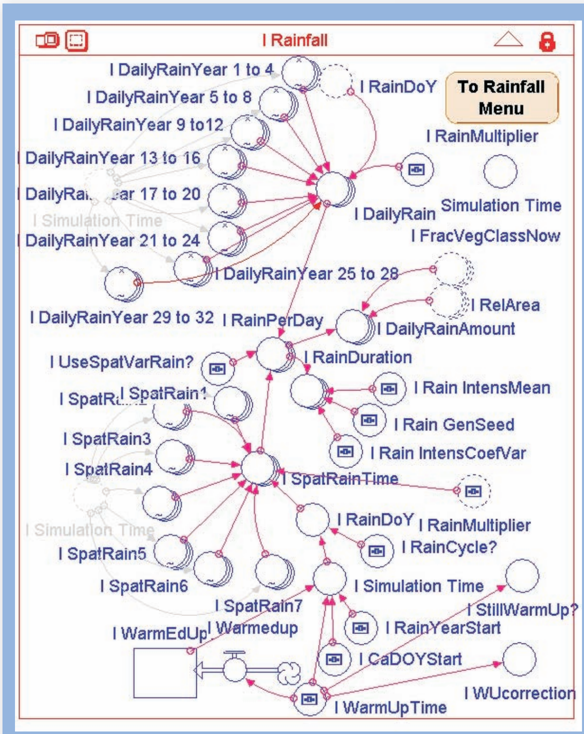
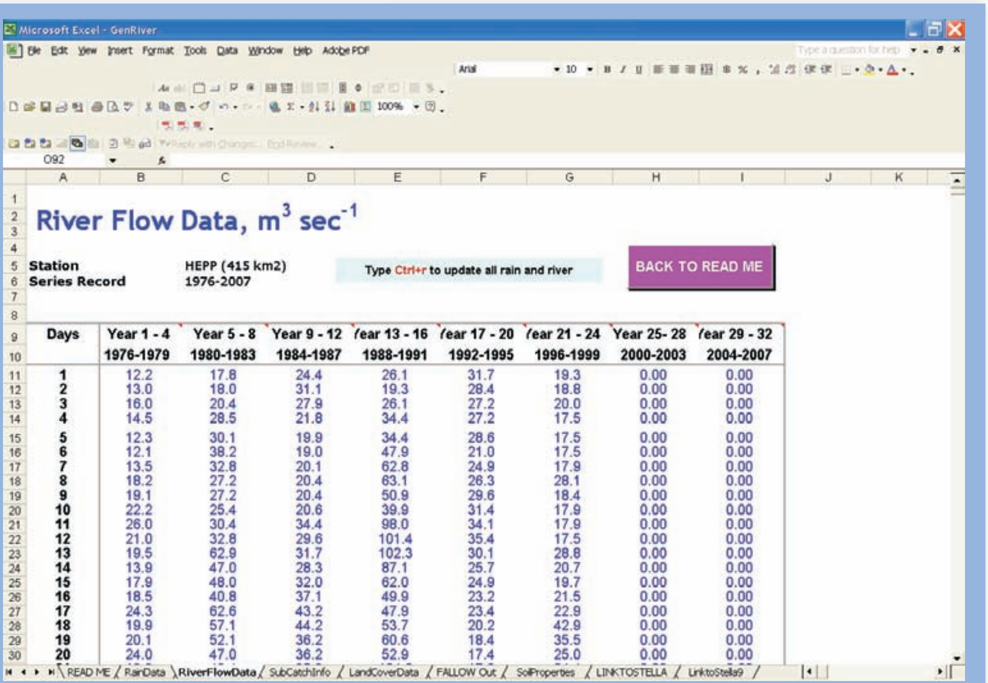


Figure 2.4 View of converter to copy Rainfall data in I_Rainfall model sector

RiverFlowData sheet

The sheet, RiverFlowData, contains the daily river flow data, $m^3 s^{-1}$ (Figure 2.5). Default values are the river flow data from Sumberjaya (Way Besai) watershed in Lampung (Indonesia) for 32 years (1976–2007). You can adjust the river flow data to the local situation and at the same period with rainfall data. This data links to Stella, I_DebitDataYear…to….. This data will be valuable in “constraining” the simulations.



River Flow Data, m^3 sec^{-1}

Station HEPP (415 km2)
Series Record 1976-2007

Type Ctrl+r to update all rain and river

Days	Year 1 - 4	Year 5 - 8	Year 9 - 12	ear 13 - 16	ear 17 - 20	ear 21 - 24	Year 25- 28	ear 29 - 32
	1976-1979	1980-1983	1984-1987	1988-1991	1992-1995	1996-1999	2000-2003	2004-2007
1	12.2	17.8	24.4	26.1	31.7	19.3	0.00	0.00
2	13.0	18.0	31.1	19.3	28.4	18.8	0.00	0.00
3	16.0	20.4	27.9	26.1	27.2	20.0	0.00	0.00
4	14.5	28.5	21.8	34.4	27.2	17.5	0.00	0.00
5	12.3	30.1	19.9	34.4	28.6	17.5	0.00	0.00
6	12.1	38.2	19.0	47.9	21.0	17.5	0.00	0.00
7	13.5	32.8	20.1	62.8	24.9	17.9	0.00	0.00
8	18.2	27.2	20.4	63.1	26.3	28.1	0.00	0.00
9	19.1	27.2	20.4	50.9	29.6	18.4	0.00	0.00
10	22.2	25.4	20.6	39.9	31.4	17.9	0.00	0.00
11	26.0	30.4	34.4	98.0	34.1	17.9	0.00	0.00
12	21.0	32.8	29.6	101.4	35.4	17.5	0.00	0.00
13	19.5	62.9	31.7	102.3	30.1	28.8	0.00	0.00
14	13.9	47.0	28.3	87.1	25.7	20.7	0.00	0.00
15	17.9	48.0	32.0	62.0	24.9	19.7	0.00	0.00
16	18.5	40.8	37.1	49.9	23.2	21.5	0.00	0.00
17	24.3	62.6	43.2	47.9	23.4	22.9	0.00	0.00
18	19.9	57.1	44.2	53.7	20.2	42.9	0.00	0.00
19	20.1	52.1	36.2	60.6	18.4	35.5	0.00	0.00
20	24.0	47.0	36.2	52.9	17.4	25.0	0.00	0.00

Figure 2.5 View of RiverFlowData sheet

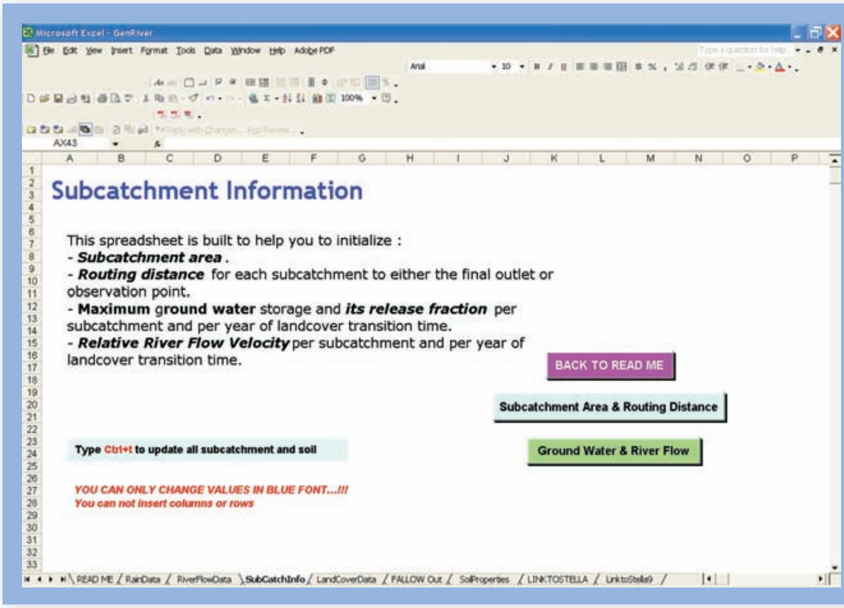
Input parameters	Location in Excel file	Location in Stella
I_DebitDataYear…to….	Cells B11 – I1470	Model Sector (I_RivFlowData)

SubCatchInfo sheet

The sheet, SubCatchInfo, is designed to help you initialize the subcatchment area (I_Area) and its routing distance (I_RoutingDistance) to the outlet (Figure 2.6). This sheet is also designed to initialize maximum ground water storage (I_MaxDynGWSub1…4) and its release fraction (I_GWRelFrac1…4) and relative time of river flow velocity ((I_RivFlowTime1…4) per subcatchment and per year of land-cover transition time.

Routing distance is the distance from the midpoint of each subcatchment to any number of observation points. This parameter will derive the routing time for each subcatchment to each of the observation points, while excluding subcatchment downstream of the observation point.

Estimated values of the “differential storage” in “active groundwater” as well as a “groundwater release” fraction were “tuned” to the recession phase of actual river flow during periods without rainfall. In the absence of such data we need to “guesstimate”. If data on the seasonal variation in depth of ground water table are available, we can use those.



Subcatchment Information

This spreadsheet is built to help you to initialize :
- ***Subcatchment area*** .
- ***Routing distance*** for each subcatchment to either the final outlet or observation point.
- **Maximum ground water** storage and ***its release fraction*** per subcatchment and per year of landcover transition time.
- ***Relative River Flow Velocity*** per subcatchment and per year of landcover transition time.

Type Ctrl+t to update all subcatchment and soil

YOU CAN ONLY CHANGE VALUES IN BLUE FONT...!!!
You can not insert columns or rows

Figure 2.6
View of SubCatchInfo sheet

Input parameters	Location in Excel file
I_Area	Cells B52 – B71
I_RoutingDistance	Cells D52 – J71
I_RivFlowTime1…4[Subcatchment]	Cells B100 – B119; E100 – E119; H100 – H119; K100 – K119
I_MaxDynGWSub1…4[Subcatchment]	Cells C100 – C119; F100 – F119; I100 – I119; L100 – L119
I_GWRelFrac1…4[Subcatchment]	Cells D100 – D119; G100 – G119; J100 – J119; M100 – M119

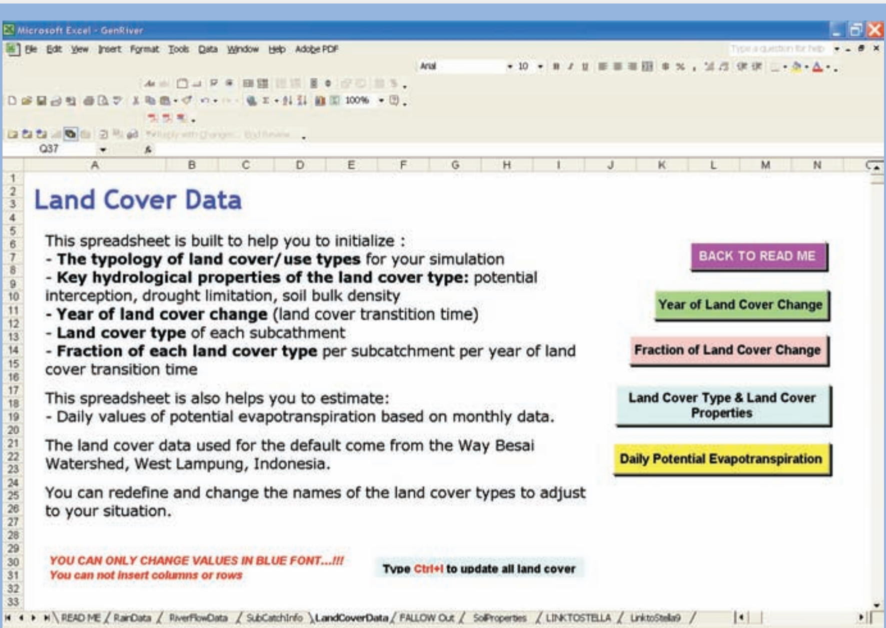
LandCoverData sheet

The sheet, LandCoverData, (Figure 2.7) is designed to help you initialize

(1) land-cover type of each subcatchment;
(2) year of land-cover change;
(3) fraction of land-cover change for each subcatchment and each transition year; and
(4) potential interception, drought limitation, BD/BDRef per land-cover type and multiplier of daily potential evapotranspiration.

Year of land-cover change

GenRiver arranges changing of land-cover type based on a given year of transition with linear interpolation for years in between. This data links to Stella, I_InputDataYears.



Land Cover Data

This spreadsheet is built to help you to initialize :
- **The typology of land cover/use types** for your simulation
- **Key hydrological properties of the land cover type:** potential interception, drought limitation, soil bulk density
- **Year of land cover change** (land cover transtition time)
- **Land cover type** of each subcathment
- **Fraction of each land cover type** per subcatchment per year of land cover transition time

This spreadsheet is also helps you to estimate:
- Daily values of potential evapotranspiration based on monthly data.

The land cover data used for the default come from the Way Besai Watershed, West Lampung, Indonesia.

You can redefine and change the names of the land cover types to adjust to your situation.

YOU CAN ONLY CHANGE VALUES IN BLUE FONT...!!!
You can not insert columns or rows

Type Ctrl+l to update all land cover

Figure 2.7 View of LandCoverData sheet

Input parameters	Location in Excel file
I_InputDataYears	Cells C51 – C54

Land-cover type and fraction of land-cover change

Default land-cover types are of Way Besai watershed, West Lampung, Indonesia. You can change the names of the land-cover types to adjust to the local situation.

There are two options to initialize fraction of land cover of each subcatchment: it can be either uniform for all the subcatchments (land-cover identification = 1) or different for each subcatchment (land-cover identification = 0). The different land cover for each subcatchment can be either generated from spatial data or using output data from the FALLOW model (land-cover identification = 2). To specify this option, fill in cell BS11 in the Excel file.

If the second option is chosen and you are using spatial data, you need to enter the fraction of land-cover change for each subcatchment that corresponds to the year of land-cover change. These data link to Stella, I_Frac1_1…11_4[Subcatchment]. If the second option is chosen and you use output from the FALLOW model, you have to copy “genriver1, genriver2, …, genriver 25” file from the FALLOW model to the FALLOW Out sheet.

Input parameters	Location in Excel file
Land Cover Type	Cells A105 – A115
I_Frac1_1…11_4[Subcatchment]	Cells BR15 – BR325 Cells BS15 – BS325 Cells BT15 – BT325 Cells BU15 – BU325

Potential interception, drought limitation and potential evapotranspiration

You should provide storage capacity for intercepted water (I_InterceptClass) of each land-cover type (mm day^{-1}). It 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: forest = 4; young secondary forest/young agroforestry = 3.

You should also provide drought limitation to transpiration per land-cover class relative to field capacity (I_RelDroughtFact). The values depend on drought resistance: highest resistance = 1 (teak); lowest resistance = 0.1 (durian).

The sheet, LandCoverData, also will contain potential evapotranspiration (mm day^{-1}) data. These can be either daily (I_DailyETYear…to…) or monthly data (I_Evapotrans). These values can be derived from open pan evaporation measurements or from equations such as Penman's that calibrate such data.

The monthly pattern of potential evapotranspiration for each land-cover type is calculated by multiplying these monthly values by a multiplier of daily potential evapotranspiration (I_MultiplierEvapoTrans[LandCoverType]). These multiplier values follow seasonal patterns of crop, tree and paddy. The highest value = 1 (rice field, pine) and the lowest = 0.1 (houses). All these data are linked to Stella.

Input parameters	Location in Excel file
I_InterceptClass[LandCoverType]	Cells B105 – B115
I_RelDroughtFact[LandCoverType]	Cells C105 – C115
I_MultiplierEvapoTrans[LandCoverType]	Cells E105 – P115
I_DailyE TYear…to…	Cells AZ11 – BG1470
BD/BDref per land cover type	Cells D105 – D115

SoilProperties sheet

The SoilProperties sheet (Figure 2.8) is designed to help you initialize

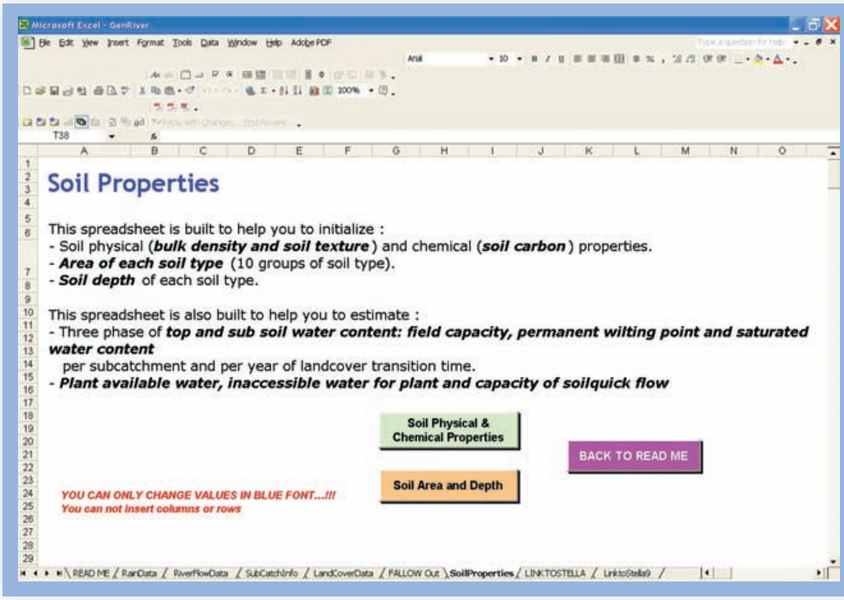
(1) soil physical (bulk density and soil texture) and chemical (soil carbon) properties of 10 groups of soil type;
(2) area of each soil type; (10 groups of soil type); and
(3) soil depth of each soil type.

This spreadsheet also provides basic estimates of

(1) three phases of top- and subsoil water content:
    i. field capacity,
    ii. permanent wilting point and
    iii. saturated water content
    per subcatchment and per year of land-cover transition time; and
(2) plant-available water, inaccessible water for plants and the capacity of soil quick flow.

Soil physical (bulk density reference and soil texture) and chemical (soil carbon) properties of 10 groups of soil type are derived from the soil database. They are used to generate generic values of field capacity, permanent wilting point and saturated water content for 10 soil groups.

You should provide bulk density relative to its reference value (BD/BDref) for each land-cover type and for each year of land-cover transition time. Values of BD/BDref) for each land-cover type are defined based on the range of BD/BDref, forest soil = 0.7, agriculture soil = 1, degraded soil = 1.3 while BD/BDref for each year of land-cover transition time is the generic value within the range of BD/BDref of forest to degraded soil.



Soil Properties

This spreadsheet is built to help you to initialize :
- Soil physical (***bulk density and soil texture***) and chemical (***soil carbon***) properties.
- ***Area of each soil type*** (10 groups of soil type).
- ***Soil depth*** of each soil type.

This spreadsheet is also built to help you to estimate :
- Three phase of ***top and sub soil water content: field capacity, permanent wilting point and saturated water content*** per subcatchment and per year of landcover transition time.
- ***Plant available water, inaccessible water for plant and capacity of soilquick flow***

YOU CAN ONLY CHANGE VALUES IN BLUE FONT...!!!
You can not insert columns or rows

Figure 2.8 View of Soil Properties sheet

These values will be used to estimate BD/BDref (I_TopSoilBD_BDRef1…4), three phases of top- and subsoil water content: saturated hydraulic conductivity, field capacity and permanent wilting point proportionally to area fraction of soil type and soil depth per subcatchment and per year of land cover transition time. Plant-available water (I_PlantAvWatSub1…4), inaccessible water for plants (I_PWPSub1…4) and capacity of soil quick flow (I_SoilSatMinFCSub1…4) for each subcatchment and per year of land-cover transition time estimated from these three phase of top- and subsoil water content.

Input Parameters	Location in Excel
BD/BDref per year of land-cover transition time	Cells F44 – F47
BDref, soil texture and soil carbon	Cells B79 – F88
Area of each soil type per subcatchment	Cell AE8 – AN27
Soil depth of each soil type	Cell AE35 – AI44

Estimated Input Parameters	Location in Excel
I_SoilSatMinFCSub1…4	Cells AN101 – AN120; AW101 – AW120; BF101 – BF120; BO101 – BO120
I_PlantAvWatSub1…4	Cells AO101 – AO120; AX101 – AX120; BG101 – BG120; BP101 – BP120
I_PWPSub1… 4	Cells AP101 – AP120; AY101 – AY120; BH101 – BH120; BQ101 – BQ120
I_TopSoilBD_BDRef1…4	Cells B145 – U145; B161 – U161; B177 – U177; B193 – U193

Link to Stella sheet

This sheet stores all input parameters linked to Stella. No changes are allowed on this worksheet.

2.1.2. Familiarize yourself with GenRiver.stm

To familiarize yourself with GenRiver.stm we suggest you try the following exercise:

- First, view the model component by clicking “model structure” then go to each component of the model. At the end return to the main menu.
- Second, run the model using the default parameters, looking at the simulation result.
- Third, modify the input parameters, try a new run and import the result.

In the following sections you will find descriptions on how to perform each of the above exercises.

View the model components

On the “Main Menu”, you will see something like in Figure 2.9 on your screen by clicking “model sector” button. The model has the following components:

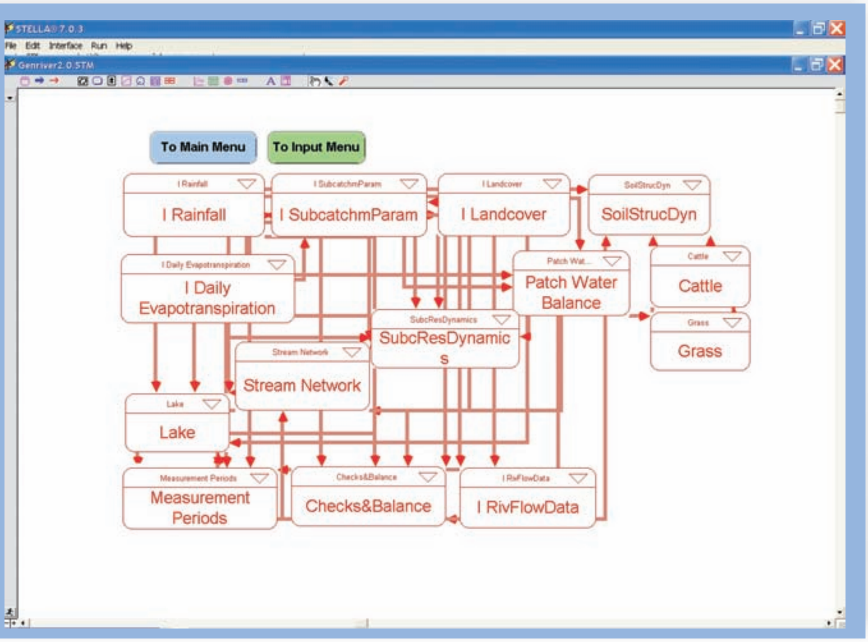


Figure 2.9 Components of GenRiver Model implemented in Stella

(1) an initialization sector, dealing with input data related to rainfall data (I_Rainfall), river flow data (I_RivFlowData), subcatchment condition (I_SubcatchmParam), daily evapotranpiration (I_DailyEvapotranspiration) and land-cover type(I_LandCover);
(2) dynamic sectors, dealing with patch-level water balance (PatchWaterBalance), stream and river flow (StreamNetwork), and the operational rules of reservoirs in the river network (SubcResDynamic);
(3) two sectors for keeping track of all output parameters required (Check&Balance and Measurement Period); and
(4) influence of existing cattle and grass on the dynamics of soil structure (Catle, Grass and SoilStrucDyn).

You will see how the model is constructed by clicking the triangle on the right top corner of each component. An example view of the constructed model component is shown in Figure 2.10A and 2.10B.

To return to the “model sector” menu, click the small “up” triangle on the left top corner then click “To Main Menu”. Below are brief descriptions of each of the model components.

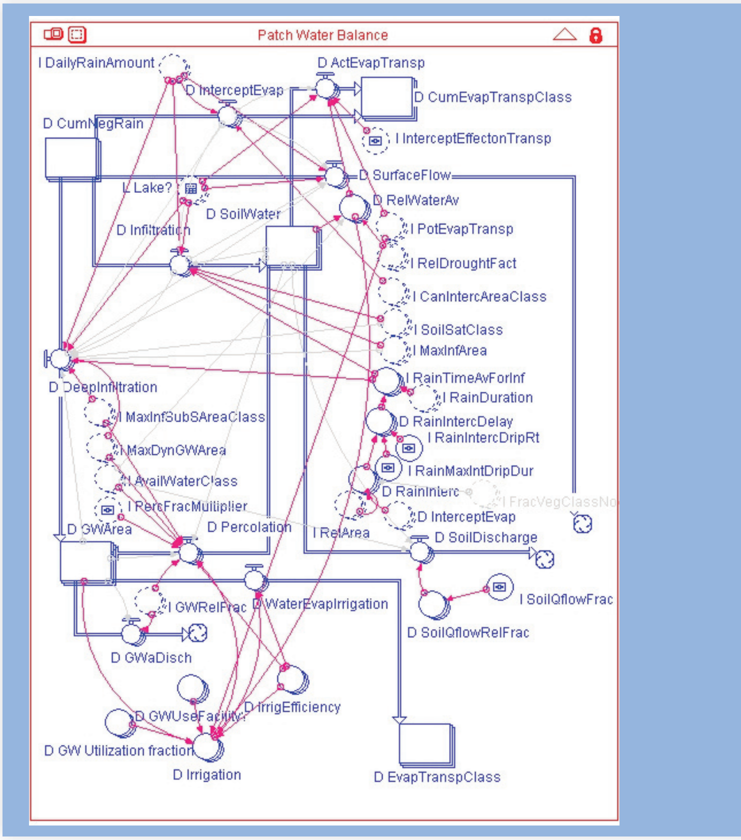


Figure 2.10A Diagram of the patch-level water balance in Stella with the stocks represented by rectangles, parameters by circles, water flows by double-lined arrows and information flows by single lines

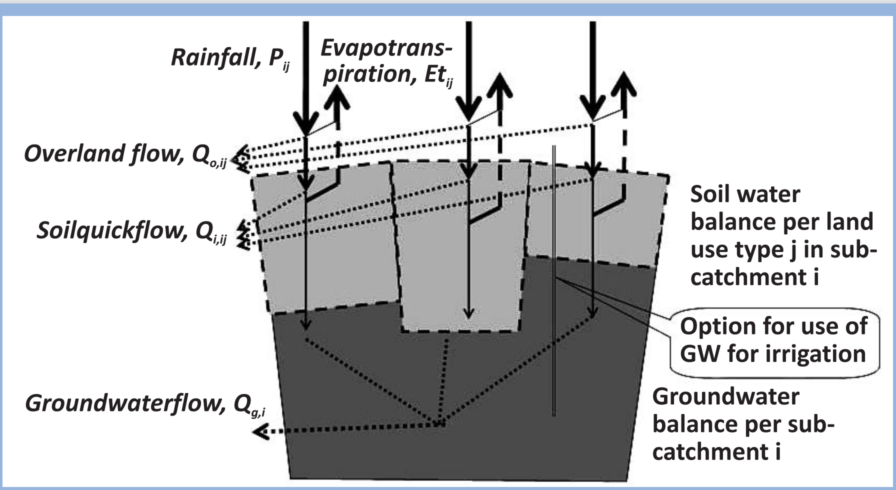


Figure 2.10B Diagram of the patch-level water balance overland flow and soil quick flow calculated at "land use subcatchment" array elements, and groundwater relations at the subcatchment level

Initialization

The model has a number of parameters that require initialization. Some of the input parameters to initialize the model are organized in the MS Excel file and some are stored in the model, GenRiver.stm, in Input Section and will be explored in the third part, "modify input parameters".

Patch-level water balance

The amount of rainfall for each land-cover type 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 of "soil water", "ground water", "cumulative evapotranspiration" or the surface runoff, 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.

Stream and river flow network

The implementation of the stream and river flow (Figure 2.11) 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 them. As each calculation step 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.

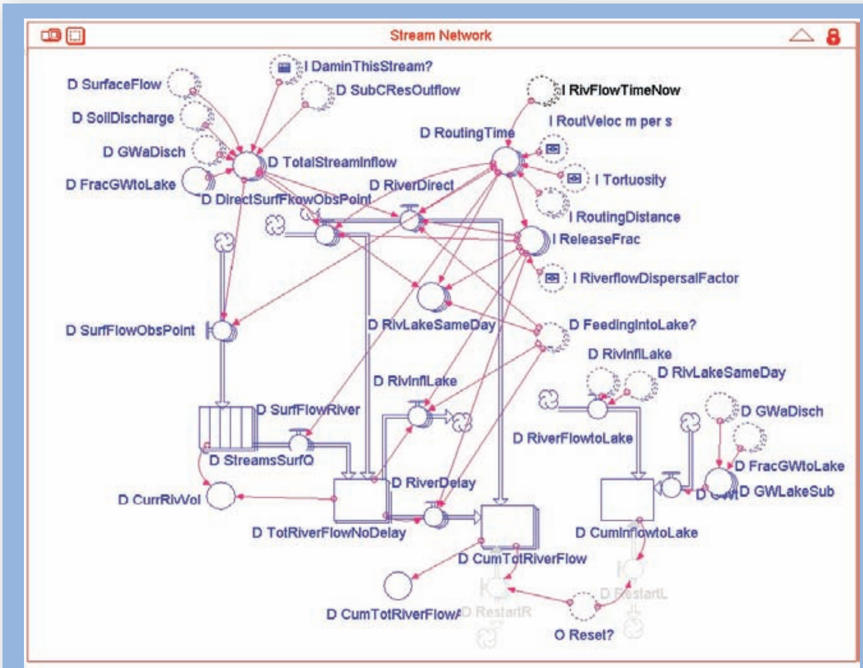


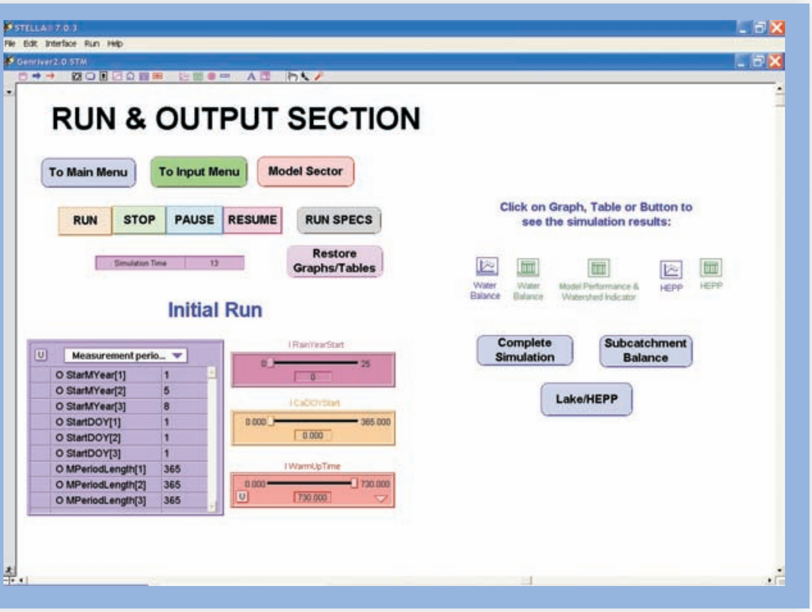
Figure 2.11 Diagram of the stream network model sector. The incoming flows (surface flow, soil discharge and groundwater discharge) are delayed according to travel distance and flow velocity on their way to reach the various measuring points

Run the model using default parameters

To run or to see simulation results from Main Menu, click “To Run & Output”. You will see something like Figure 2.12 on your screen.

Running GenRiver

On the “Run & Output Section” screen you will find five buttons (see Figure 2.12) which control the simulation run as listed in Table 2.1. The model will run using default parameters by clicking “Run” Button. The default setting will run for 12410 days with incremental time of simulation as one day. By clicking “Time Specs” Button (you will see something like Figure 2.13) allowing you to change the beginning and ending times of the simulation, also DT, which is incremental time of simulation. We strongly advise you to keep DT value at 1.



Simulation Time 13

Measurement perio...

O StarMYear[1]	1
O StarMYear[2]	5
O StarMYear[3]	8
O StartDOY[1]	1
O StartDOY[2]	1
O StartDOY[3]	1
O MPeriodLength[1]	365
O MPeriodLength[2]	365
O MPeriodLength[3]	365

I RainYearStart: 0 – 25, 0

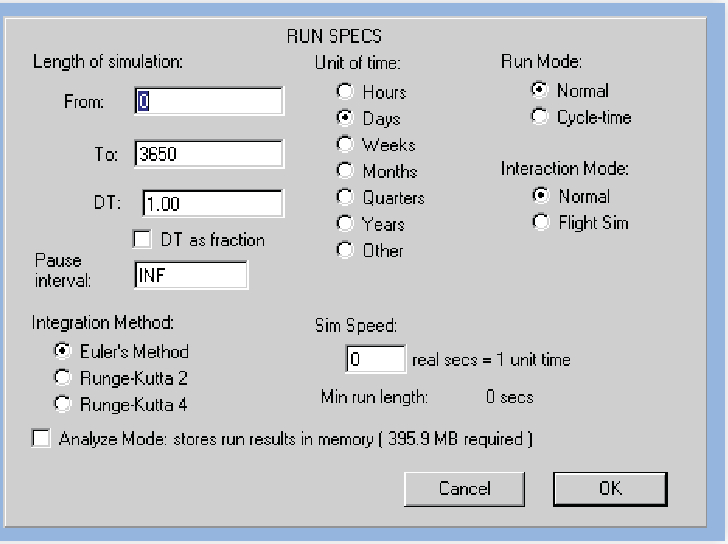
I CaDOYStart: 0.000 – 365.000, 0.000

I WarmUpTime: 0.000 – 730.000, 730.000

Figure 2.12 View of Run & Output Section

Table 2.1 Five buttons which control the simulation run

Buttons	Purpose
Run	To start simulation
Pause	To pause during simulation run
Stop	To stop simulation
Resume	To resume simulation after pausing
Run Spec	To specify length of simulation time



RUN SPECS

Length of simulation:
From: 0
To: 3650
DT: 1.00
☐ DT as fraction
Pause interval: INF

Unit of time:
○ Hours
● Days
○ Weeks
○ Months
○ Quarters
○ Years
○ Other

Run Mode:
● Normal
○ Cycle-time

Interaction Mode:
● Normal
○ Flight Sim

Integration Method:
● Euler's Method
○ Runge-Kutta 2
○ Runge-Kutta 4

Sim Speed:
0 real secs = 1 unit time
Min run length: 0 secs

☐ Analyze Mode: stores run results in memory (395.9 MB required)

Figure 2.13 View of Time Specification screen

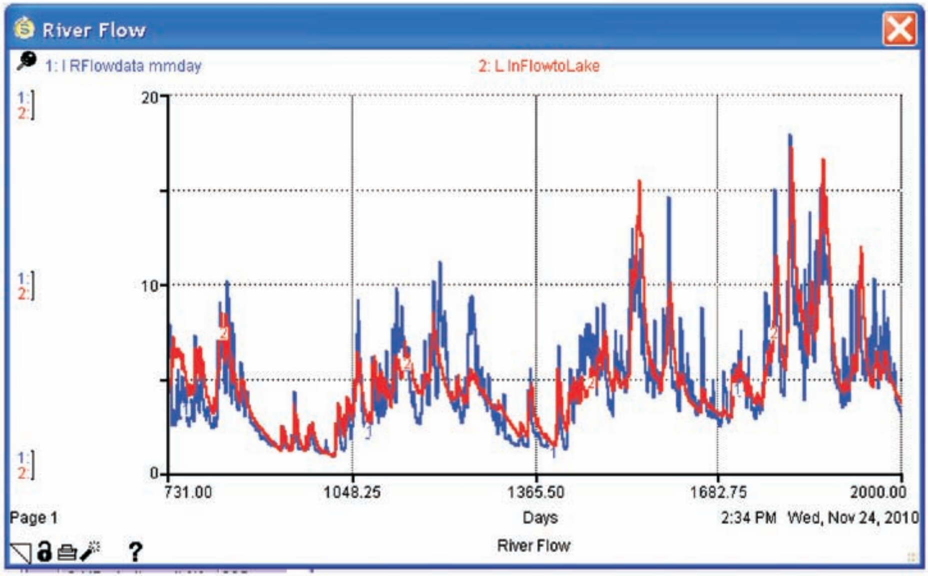
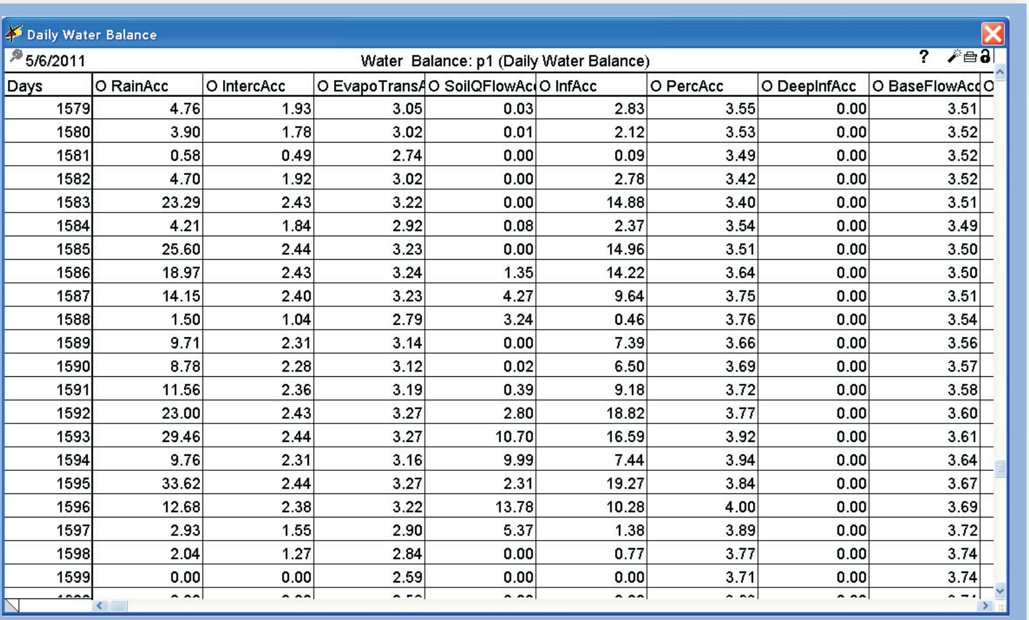


Figure 2.14 Example of river flow prediction (blue) and river flow data (red) as one of the output parameters. We can compare measured and simulated river flow over time – in this example no specific effort to “fit” the model was made

Output result

The type of output produced by GenRiver is river flow and water balance. There are three types of output presented: (1) Tables; (2) Graphs; and (3) Output summary.

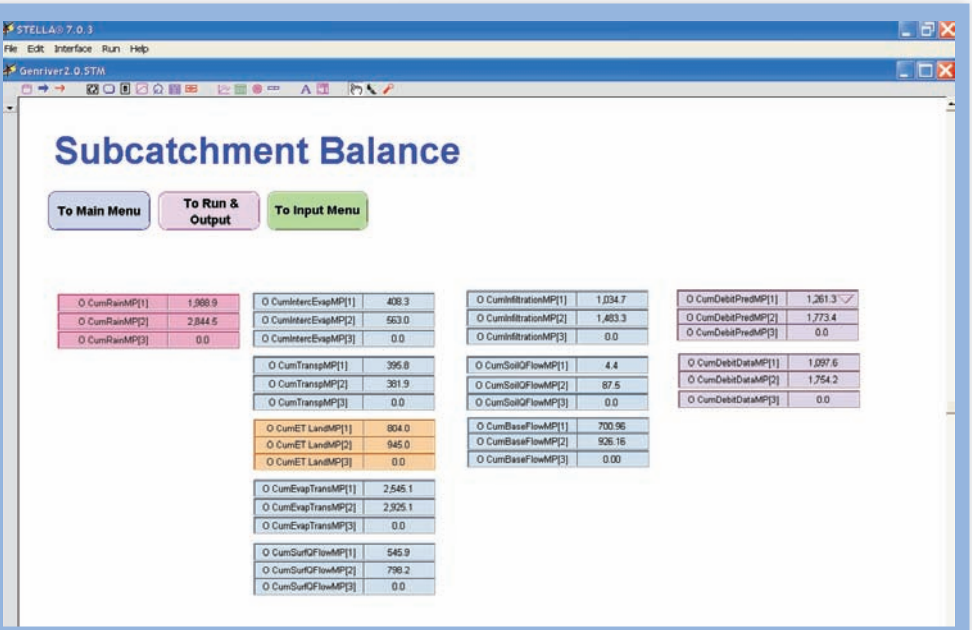
To view output simulation results in a graph or table, double click on the graph or table icon. What you will see is actually a stack of graphs or tables (Figure 2.14 and Figure 2.15). To view the rest of the graphs or tables, click on the folded page at the bottom left corner. When you look at the graphs, notice that the scale on Y axis between parameters on the same graph can be different. Match the index number of parameters with index number of scales in the Y axis. To view output simulation result in output summary (Figure 2.16), click on each button below the graphs and tables. You will see a box displaying output parameters.



Water Balance: p1 (Daily Water Balance)

Days	O RainAcc	O IntercAcc	O EvapoTransA	O SoilQFlowAc	O InfAcc	O PercAcc	O DeepInfAcc	O BaseFlowAcc	O
1579	4.76	1.93	3.05	0.03	2.83	3.55	0.00	3.51	
1580	3.90	1.78	3.02	0.01	2.12	3.53	0.00	3.52	
1581	0.58	0.49	2.74	0.00	0.09	3.49	0.00	3.52	
1582	4.70	1.92	3.02	0.00	2.78	3.42	0.00	3.52	
1583	23.29	2.43	3.22	0.00	14.88	3.40	0.00	3.51	
1584	4.21	1.84	2.92	0.08	2.37	3.54	0.00	3.49	
1585	25.60	2.44	3.23	0.00	14.96	3.51	0.00	3.50	
1586	18.97	2.43	3.24	1.35	14.22	3.64	0.00	3.50	
1587	14.15	2.40	3.23	4.27	9.64	3.75	0.00	3.51	
1588	1.50	1.04	2.79	3.24	0.46	3.76	0.00	3.54	
1589	9.71	2.31	3.14	0.00	7.39	3.66	0.00	3.56	
1590	8.78	2.28	3.12	0.02	6.50	3.69	0.00	3.57	
1591	11.56	2.36	3.19	0.39	9.18	3.72	0.00	3.58	
1592	23.00	2.43	3.27	2.80	18.82	3.77	0.00	3.60	
1593	29.46	2.44	3.27	10.70	16.59	3.92	0.00	3.61	
1594	9.76	2.31	3.16	9.99	7.44	3.94	0.00	3.64	
1595	33.62	2.44	3.27	2.31	19.27	3.84	0.00	3.67	
1596	12.68	2.38	3.22	13.78	10.28	4.00	0.00	3.69	
1597	2.93	1.55	2.90	5.37	1.38	3.89	0.00	3.72	
1598	2.04	1.27	2.84	0.00	0.77	3.77	0.00	3.74	
1599	0.00	0.00	2.59	0.00	0.00	3.71	0.00	3.74	

Figure 2.15 Example of output parameters in Table



Subcatchment Balance

O CumRainMP[1]	1,988.9
O CumRainMP[2]	2,844.5
O CumRainMP[3]	0.0
O CumIntercEvapMP[1]	408.3
O CumIntercEvapMP[2]	563.0
O CumIntercEvapMP[3]	0.0
O CumTranspMP[1]	395.8
O CumTranspMP[2]	381.9
O CumTranspMP[3]	0.0
O CumET LandMP[1]	804.0
O CumET LandMP[2]	945.0
O CumET LandMP[3]	0.0
O CumEvapTransMP[1]	2,545.1
O CumEvapTransMP[2]	2,925.1
O CumEvapTransMP[3]	0.0
O CumSurfQFlowMP[1]	545.9
O CumSurfQFlowMP[2]	798.2
O CumSurfQFlowMP[3]	0.0
O CumInfiltrationMP[1]	1,034.7
O CumInfiltrationMP[2]	1,483.3
O CumInfiltrationMP[3]	0.0
O CumSoilQFlowMP[1]	4.4
O CumSoilQFlowMP[2]	87.5
O CumSoilQFlowMP[3]	0.0
O CumBaseFlowMP[1]	700.96
O CumBaseFlowMP[2]	926.16
O CumBaseFlowMP[3]	0.00
O CumDebitPredMP[1]	1,261.3
O CumDebitPredMP[2]	1,773.4
O CumDebitPredMP[3]	0.0
O CumDebitDataMP[1]	1,097.6
O CumDebitDataMP[2]	1,754.2
O CumDebitDataMP[3]	0.0

Figure 2.16 An example of cumulative table as output. The balance per user-defined measuring period allow us to check sensitivity of the water balance parameters

Table 2.2 is summary of available output on display. See more detailed definition on each output parameter presented in Appendix 2.

Table 2.2 Summary of available output

Graph & Table Content	Graph Page	Table Page	Output Parameters	Graph/Table Type
WaterBalance	1	1	I_RFlowData mmday	Time series
			L_InflowtoLake	Time series
	2		O_RainAcc	Time series
			O_IntercAcc	Time series
			O_EvapotransAcc	Time series
			O_SurfQFlo	Time series
			O_InfAcc	Time series
	3		O_RainAcc	Time series
			O_DeepInfAcc	Time series
			O_PercAcc	Time series
			O_SoilQFlowAcc	Time series
			O_BaseFlowAcc	Time series
	4	2	O_CumRain	Time series
			O_CumInterc	Time series
			O_CumEvapot	Time series
			O_CumSurfQFlow	Time series
			O_CumInf	Time series
	5		O_CumRain	Time series
			O_CumDeepInf	Time series
			O_CumPerc	Time series
			O_CumSoilQFlow	Time series
			O_CumBaseFlow	Time series
	6	-	I_RFlowData mmday	Scatter
			L_InflowtoLake	Scatter
HEPP	1	-	L_HEPPWatUseFlow	Time series
		-	L_HEPPkwh	Time series
		-	L_LakeVol	Time series
		-	L_LakeLevel	Time series
	-	1	O_BestYHEPP	Time series
	-		O_WorstYHEPP	Time series
	-		L_CumHEPPUse	Time series
	-		O_FrBaseFlow	Time series
	-		O_FrSoilQuickflow	Time series
	-		O_FrSurfQuickFlow	Time series

Adding additional output parameters

- To add more parameters to your tables or graphs, do the following.
  - Double click on your graph or table. After a graph/table appears, double click again on it. You will see a box emerge with two small boxes in the upper section (Figure 2.17). The left box (allowable box) contains parameters that can be loaded into the graph or table. The right box (selected box) contains parameters already in the graph or table. A graph can contain up to five parameters while a table can contain more than 40.
  - To load a parameter into the graph or table, highlight the parameter in allowable box then click an adjacent arrow pointing to the selected box.
  - If you want to load a parameter to a new clean page, prior to the above you need to click an arrow pointing upward at the bottom left corner (adjacent to Page). Keep on clicking until you see NEW as page number.

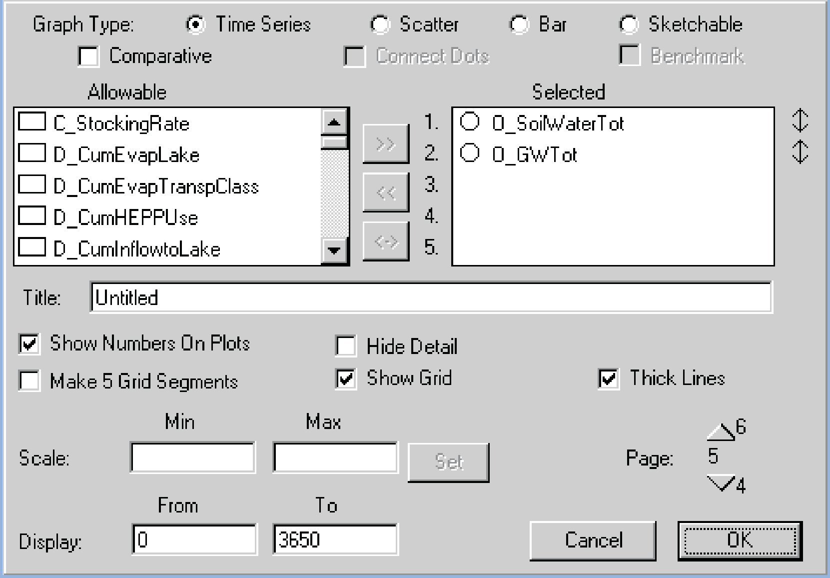
- To add more parameters in box as in output summary, do the following.
  - Click on icon "numeric display" in the menu bar then click on the working area. After a numeric display box appears, double click on it. Now, you will see a box emerge with two small boxes in the upper section.
  - To load a parameter into this numeric display, highlight the parameter in the allowable box then click an adjacent arrow pointing to the selected box.

Locking graphs or tables to speed your simulation

You can lock pages in your graphs and tables that you do not need. Locked graphs or tables will not be updated in the next simulation run. This saves a lot of time needed to run the model. To lock a graph or table, click on the lock icon. It is in the bottom left corner of your graph or on the top right corner of your table.

Importing output results

You can save your table as a text file and your graph as a pct file. You can open the table saved as a text file in MS Excel. You can also use copy (Ctrl-C) and paste (Ctrl-V) your output table. For graphs or summary output you can use screen dump (Shift-Print) then paste to your favourite software.



Graph Type: ● Time Series ○ Scatter ○ Bar ○ Sketchable

☐ Comparative ☐ Connect Dots ☐ Benchmark

Allowable:

☐ C_StockingRate
☐ D_CumEvapLake
☐ D_CumEvapTranspClass
☐ D_CumHEPPUse
☐ D_CumInflowtoLake

Selected:

1. ○ O_SoilWaterTot
2. ○ O_GWTot

Title: Untitled

☑ Show Numbers On Plots ☐ Hide Detail

☐ Make 5 Grid Segments ☑ Show Grid ☑ Thick Lines

Scale: Min Max

Page: 5

Display: From 0 To 3650

Figure 2.17 View of box in working graph or table to load output parameters

Modify input parameters and try new run

Click on “To Input” in Main Menu. You will see some categories of input parameter organized in buttons as shown in Figure 2.18. You can see the input parameters by clicking each button. See Appendix 1 for more detailed definition on these input parameters.

Many of the input parameters, both organized in the MS Excel file and this input section, are processed in the initialization component 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).

You can start make you own simulation scenario by changing the input parameters in the MS Excel file and modifying the input values in this input section (write over the current value).

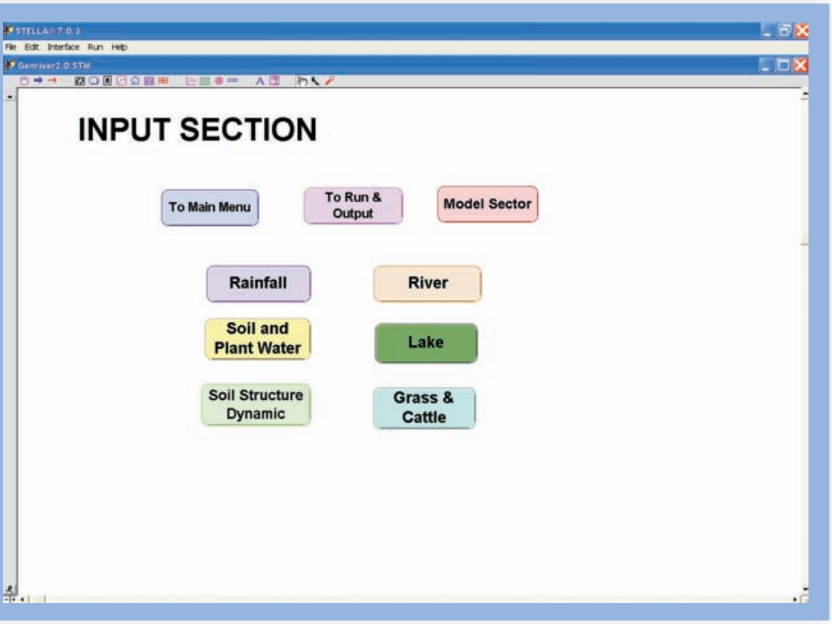


Figure 2.18 Input screen in Stella: the user can modify input values

2.2. Simulation with your own scenario

2.2.1. Minimum data requirements

In order to make a new GenRiver application for a different watershed, you need to prepare the following minimum data inputs (Table 2.3). Some advice on dealing with data input parameter is presented in Appendix 3.

1. Climate

- Rainfall

A number of formats are possible, as long as they allow a reconstruction of monthly exceedance curves of daily rainfall intensity:

  - 30 (or at least 20) years of daily rainfall records for a station that can represent the area (or multiple stations if these are supposed to be similar) or
  - any “rainfall simulator” equation with the appropriate parameters that can be used to generate a 30-year dataset for the site (for example, MarkSim).

Table 2.3 Minimum data requirements to be able to run the GenRiver model

No.	Input Parameters	Dimension
1	Climate	
	Σ Rainfall (i)	mm day^{-1}
	Σ Average rainfall intensity	mm day^{-1}
	Σ Monthly or daily potential evapotranspiration	Mm
2	Actual river discharge	m^{3}s^{-1}
3	Vegetation and land cover	
	Σ Fraction of land cover (i,t)	[]
	Σ Year of land cover change	mm
	Σ Potential interception (j)	[]
	Σ Drought limitation (j)	Mm
4	Soil	
	Σ Soil texture and soil carbon	%
	Σ BD/BDref (i,t)	[]
	Σ Fraction soil area (s)	[]
	Σ Soil depth (t,s)	cm
	Σ Average of infiltration rate of top and sub soil	mm day $^{-1}$
5	Geology	
	Σ Percolation	[]
	Σ Ground water release fraction	[]
	Subcatchment and river behaviour	
	Σ Area of subcatchment (i)	km
	Σ Routing Distance (i)	[]
	Σ Tortuosity (i)	[]
	Σ Dispersal Factor (i)	[]
	Σ River Velocity (i)	m s^{-1}

Note: index t refers to time dependent input, i to subcatchment, s to soil type and j to land-cover classes

- Rainfall intensity

Data on rain duration and amount for a sampling period that is deemed representative to estimate the mean and coefficient of variation of rainfall depth per hour

- Potential evapotranspiration

Average values per month or daily data, derived from open pan evaporation measurements or from equations such as Penman's that is calibrated on such data

- Rainfall spatial correlation (optional)

An indication of the degree of spatial correlation in rainfall (correlation coefficient of daily rainfall as function of distance between stations) or of the generic nature of rainfall (frontal rains with high spatial correlation or convective storms that are "patchy" and show low correlation)

2. Actual river discharge

If available, river debit data for any period of time (expressed in $m^3 s^{-1}$ in the river or mm day^{-1} over the whole contributing subcatchments) will be valuable in "constraining" the simulations. If not available, we will simply have to "believe" the model predictions as such.

3. Vegetation and Land Cover

- Year of transition of land-cover change
- Fractions of total land covers, an example:
    - Deciduous (reducing LAI in dry season to near 0)
    - Semi-deciduous (reducing LAI in dry season to less than 0.5 of value in wet season)
    - Evergreen (maintaining LAI at over 0.5 of the maximum value)
    - Bare soil or built-up areas
    - Open surface water
    - Other land-cover classification
- Interception storage capacity per land-cover class
- Drought limitation to transpiration per land-cover class relative to field capacity

4. Soils

- Average texture (or soil type in a way that allows texture to be estimated) as input to "pedotransfer" functions to estimate soil water retention curve (saturation, field capacity, wilting point)
- Estimated bulk density relative to the reference value for soils under agricultural use, to estimate saturated hydraulic conductivity and potential infiltration
- Fraction of soil area of each soil type per subcatchment
- Mean soil depth (till major restriction for root development)
- Maximum infiltration rate of top- and subsoil

5. Geology

We need to estimate the "differential storage" in "active groundwater" as well as a "groundwater release" fraction. So far these parameters were "tuned" to the recession phase of actual river flow during periods without rainfall. In the absence of such data we will need to "guesstimate". If data on the seasonal variation in depth of ground water table are available, we can use those.

6. Subcatchment and river behaviour
Coarse DEM that allows for derivation of overall difference in elevation within the subcatchment, and a delineation of sub-subcatchments. If there is a generic "language" for the shape of the subcatchments relative to the main channel, we may use this.

2.2.2. Evaluation of model performance

Evaluation of model performance can be done by comparing simulation results to measurement data. Statistical indicators proposed by Nash and Sutcliffe (1970) are used for checking the performance of the model. The performance of the model can also be checked using coefficient correlation or double mass cumulative rainfall-river flow curve. "PerformanceTestGenRiver" is a file that consists of an explanation on the process of this evaluation.

Nash-Sutcliffe Efficiency

The Nash-Sutcliffe Efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance (Nash and Sutcliffe 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right]$$

where Yi^{obs} is the observation for the constituent being evaluated, Yi^{sim} is the simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. Performance of the model result will be evaluated annually, and will be accepted when performed NSE criteria are more than 0.50 (Table 2.4).

Table 2.4 Reference stream flow model performance (Moriasi et al. 2007)

Performance Rating	**NSE**
Very Good	0.75<NSE≤1. 00
Good	0.65<NSE≤0. 75
Satisfactory	0.50<NSE≤0. 65
Unsatisfactory	NSE≤0. 5

Coefficient of correlation

The coefficient of correlation representing the change direction of simulation data compared with the observation data.

$$r = \frac{\sum (x_i - x_{mean})(y_i - y_{mean})}{\sqrt{\sum (x_i - x_{mean})^2 (y_i - y_{mean})^2}}$$

where x_i is observation data, y_i is simulation result, x_{mean} is mean observation data and y_{mean} is mean simulation.

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 parameterization;
(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, for example, at seasonal aggregate level. Steps can include:

A. P - Q gives an estimated top 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 (for example, subsurface flows out of or into the catchment are non-negligible).

B. “Double Mass” curves of cumulative Q versus P during the year: large jumps will require explanation (see next section).

C. Flow persistence Q_{i+1} versus Q_i plots may indicate gaps in the data or “outliers” that indicate errors (see further in Chapter 5).

Double Mass Curves of Cumulative Rainfall and River Flow

We compared the cumulative river flow against the cumulative rainfall to visually inspect the relationship between rainfall toward simulated and observed river flow for discrepancies.

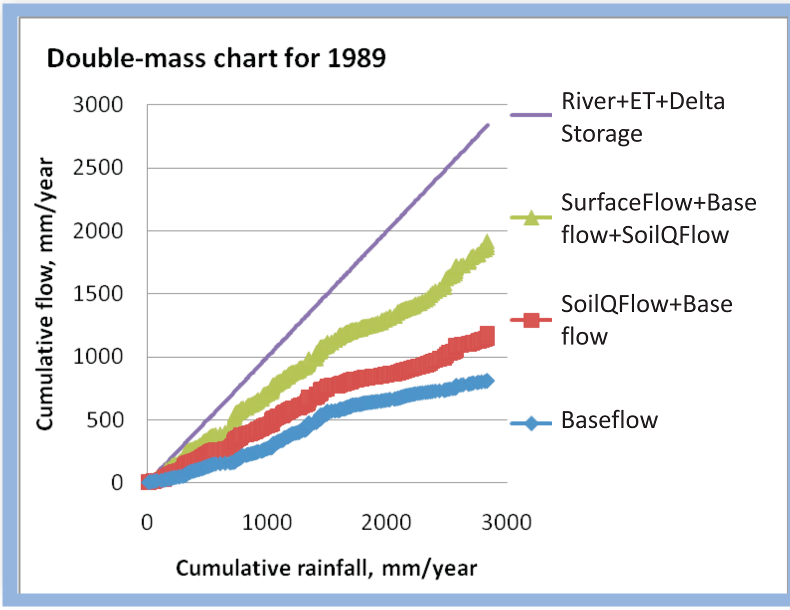


Figure 2.19 Example of a double-mass chart of cumulative river flow components against cumulative rainfall; the change in slope at about 1500 mm indicates start of a relatively dry period

2.2.3. Analysis on indicators of watershed functions: water quantity and quality

The assessment of the hydrological situation of a watershed is determined by the criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (relationship of peak river flow and peak rainfall, linked to flooding risk) and gradual release of (ground) water in the dry season, based on recharge in the rainy season (Table 2.5). These indicators all relate the flows of water to the preceding rainfall and by doing so allow analysis of relatively small land-use effects, superimposed on substantial year-to-year variations in rainfall. We provide a file, IndicatorWatershed, to help you make this analysis.

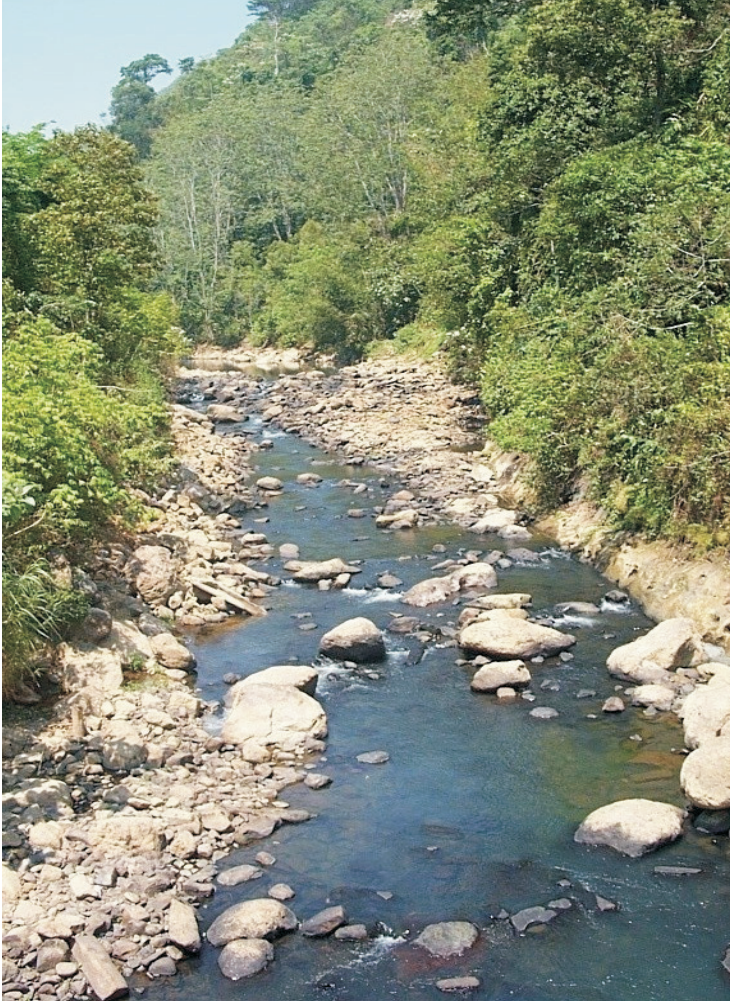
Table 2.5 Criteria and indicators of watershed hydrological functions relevant to downstream stakeholders (van Noordwijk *et al.* 2006)

Criteria	**Indicator**	**Quantitative Indicator**	**Site Characteristics**	**Relevant for**
Water transmition	Total water yield (discharge) per unit rainfall (TWY)	$TWY = \frac{Q}{A \text{ x } P}$ Q = annual river flow A = total watershed area P = annual precipitation	Annual rainfall (mm year^{-1})	Downstream water user
Buffering peak rain event	Buffering indicator for peak flows given peak rain even (BI)	$BI = 1 - \frac{Q_{abs\_Avg}}{A \text{ x } P_{abs\_Avg}}$ where $P_{abs\_Avg} = \sum \max(P - P_{mean}, 0)$ $Q_{abs\_Avg} = \sum \max(Q - Q_{mean}, 0)$	Geomorphology	Communities living along the river and in flood plains
	Relative buffering indicator, adjusted for relative water yield (RBI)	$RBI = 1 - (\frac{P_{mean}}{Q_{mean}} \text{ x } \frac{Q_{abs\_Avg}}{P_{abs\_Avg}})$		
	Buffering peak event (BPE)	$BPE = 1 - \frac{\max(Daily\_Q - Q_{mean})}{A \text{ x } \max(Daily\_P - P_{mean})}$		
	Fraction of total river discharge derived from surface quick flow (run off)	Direct output from model		
	Fraction of total river discharge derived from soil quick flow	Direct output from model		
Gradual water release (water availability during dry season)	Lowest of monthly river discharge totals relative to mean monthly rainfall		Soil type and characteristics	Communities who do not own water harvesting/storing systems (lake, embung)
	Fraction of dish-charge drived from slow flow (> 1 day after rain event)	Direct output from model		

Note: Q (mm.day^{-1}) = {[(m^3.sec^{-1}) x 24 hour x 3600 sec.hour^{-1}]/[A(km2) x 10^{6}m^2.km^{-2})]}x 10^3 (mm.m^{-1})

If there is a shortage of reliable data on river flow, you can first calibrate and validate a water balance model for the area, and then use this for further exploration of scenarios. If no continuous data on sedimentation or erosion exist, you can assess the risk to erosion through level of runoff. This is with an underlying assumption that high run-off would lead to high risk of erosion or you can use the runoff output as the input for other erosion models at the catchment level.

CHAPTER 3



3. Examples of model application

GenRiver model was initially developed to analyze river flow in Way Besai watershed in Sumberjaya, Lampung, Indonesia, where coffee plantation is the dominant land cover. Since then, it has been applied at various sites with specific land cover and characteristics. “GenRiver Database” is a file consisting of data input parameters from all sites that have ever been simulated. This chapter discusses examples of model application based on current default input parameters (Sumberjaya) as well as other sites (Mae Chaem basin, North Thailand).

3.1. Simulation based on default parameter setting (Sumberjaya)

3.1.1. Area description

The Sumberjaya subdistrict is situated between 4° 56” 6” and 5° 11” 25” South and 104° 17” 52” and 103° 33” 51” East. The elevation ranges between 720 m and 1831 m above sea level. The subdistrict is 415 km^2. The upper part of Way Besai watershed is a large caldera with the Bukit Rigis hill as a distinct remnant of the former volcano. The major soils are inceptisols (Dystropepts, Dystrandepts and Humitropepts) with some entisols (Troporthent). Land use in the area is mostly coffee plantation (70%).

3.1.2. Raw data available

Secondary data available in Sumberjaya is presented in Table 3.1.

3.1.3. Data of input parameters

Rainfall data

There are 17 rainfall stations in Way Besai watershed, eight stations with manual and automatic rainfall gauges in the upper part of the watershed and nine stations outside the watershed within a radius of 60 km. We chose eight stations, which have high spatial correlation to interpolate daily rainfall depth for all subcatchments using Thiessen polygons. The daily rainfall data are available for 32 years (1976–2007) (Figure 3.1).

Table 3.1 List data available in Sumberjaya watershed

Data		Timeseries	Sources	Type of Files
Climate	Daily Rainfall	1976-2007	BMG[1], Pu[2], PLN[3]	Excel files
	Daily temperature	BMG (1976-2007)	BMG1	Excel files
DEM	DEM Topographic map 10 m		ICRAF Indonesia[4]	ASC
Vegetation and Land Cover	Landsat MSS & ETM	1973, 2002	ICRAF Indonesia	Shape files ESRI
Geology	Geology 1:250000		ICRAF Indonesia	Shape files ESRI
Soil	Land Unit Map 1:250.000	2003	CSAR	Shape files ESRI
	Daily discharge Petai station	1976-1998	PU2, Pusair	Excel files
Hydrology	Subcatchment Boundaries		ICRAF Indonesia	Shape files ESRI
	River Network		ICRAF Indonesia	Shape files ESRI

[1] Bureau of Meteorological and Geophysics, [2] Public Work Department, [3] National Electricity Company,
[4] World Agroforestry Centre (ICRAF) Indonesia

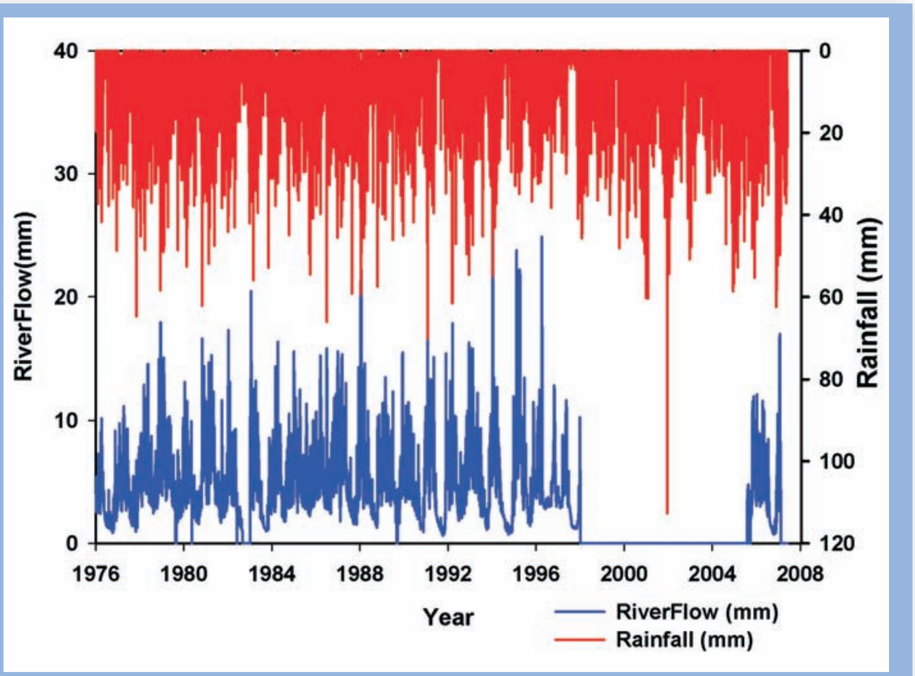


Figure 3.1 Rainfall and river flow in Way Besai, Sumberjaya, West Lampung, for period August 1976–May 2007. There is a gap due to no river flow data available in 1983, 1998 to 2005

River flow data

Daily river flow data are available for from 1976 to 1998 and 2005 and covering 90% of the total area. For the years 1976 – 1998, the daily river flow data were obtained from the Department of Public Works in Kotabumi, Lampung province (local level) and from PUSAIR (Pusat Litbang Sumber Daya Air, the Research Centre for Water Resources, based in Bandung) (national level). The daily river flow data were estimated based on continuous water-level measurements using a drum recorder. For the year 2005, the daily river flow data were obtained from the World Agroforestry Centre (ICRAF) Indonesia. The daily river flow data were measured using automatic water level. Data was extrapolated to hydropower inlet (414.4 km^2) by calculating the fraction area (Figure 3.1).

Evapotranspiration

Monthly average of potential evapotranspiration was calculated using the Thornwaite equation. Air temperature data is one of its input parameters (Figure 3.2). Daily pattern of potential evapotranspiration of each land-cover type was calculated by multiplying this monthly value to multiplier of each land-cover type (Table 3.2).

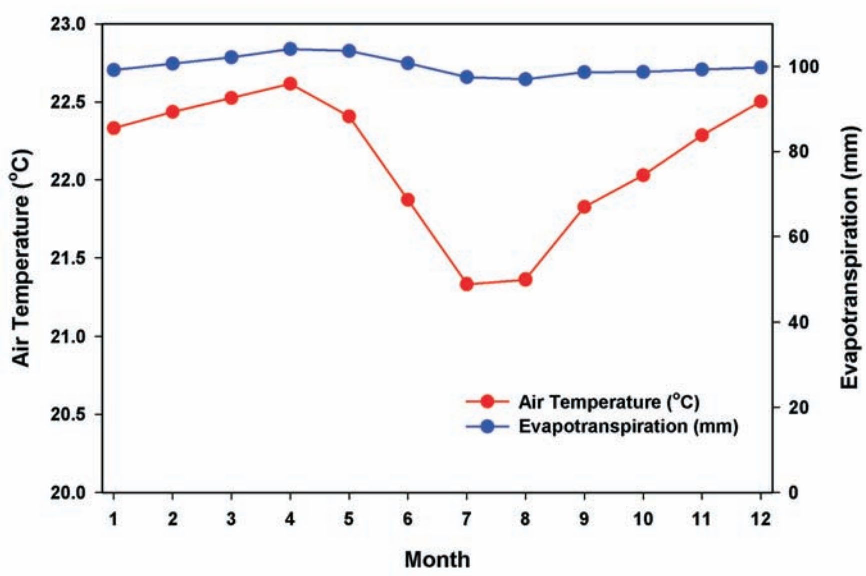


Figure 3.2 Monthly average of potential evapotranspiration calculation using Thornwaite method. This ranged between 97 to 104 mm

Table 3.2 Monthly multipliers of evapotranspiration per land-cover type

Month	Sun coffee	Shrub and Grass	Forest	Simple Shade	Multi-strata	Horti-culture	Rice field	Settlement
1	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
2	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
3	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
4	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
5	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
6	0.5	0.6	0.8	0.6	0.7	1.0	1.0	0.01
7	0.5	0.6	0.8	0.6	0.7	0.7	1.0	0.01
8	0.5	0.6	0.8	0.6	0.7	0.3	1.0	0.01
9	0.5	0.6	0.8	0.6	0.7	0.5	1.0	0.01
10	0.5	0.6	0.8	0.6	0.7	0.5	1.0	0.01
11	0.5	0.6	0.8	0.6	0.7	0.5	1.0	0.01
12	0.5	0.6	0.8	0.6	0.7	0.8	1.0	0.01

Catchment boundaries

A digital elevation model (DEM) was derived from 1:50 000 scale topographic map to delineate the catchment boundaries. Way Besai catchment is about 414.4 km^2 and consists of 20 subcatchments (Figure 3.3).

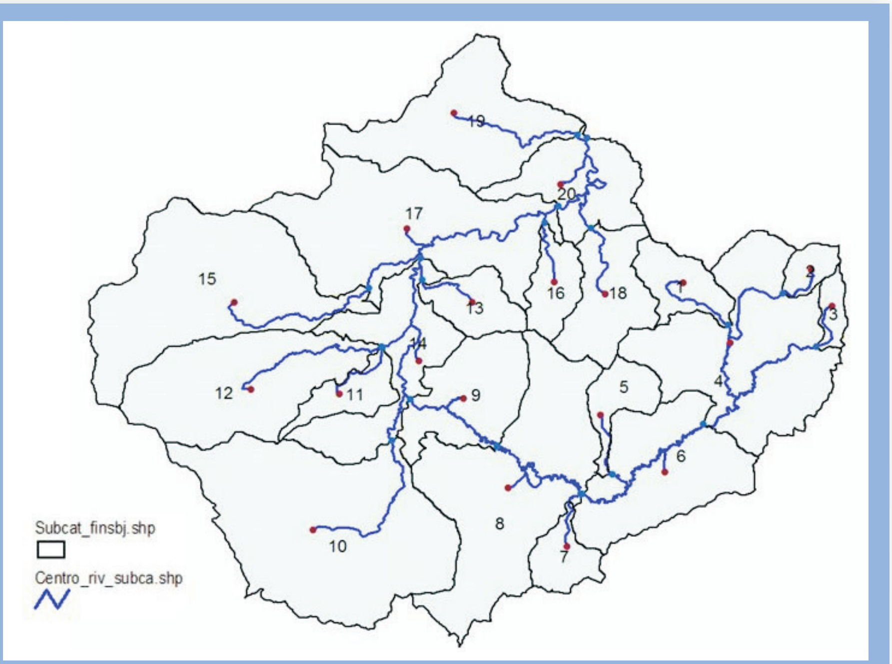


Figure 3.3 Catchment and subcatchment boundaries of Way Besai

Soil types

Soil types in Way Besai are dominated by andisol (48%), inceptisol (30%) and ultisol (22%) (Figure 3.4).

Infiltration

Infiltration capacity in Way Besai was estimated based on soil physical properties. Generally, the topsoil of Way Besai catchment is dominated by clay and silty clay soil, with the average of soil BD/BDref per land cover being quite low (0.67–0.92) (Table 3.3).

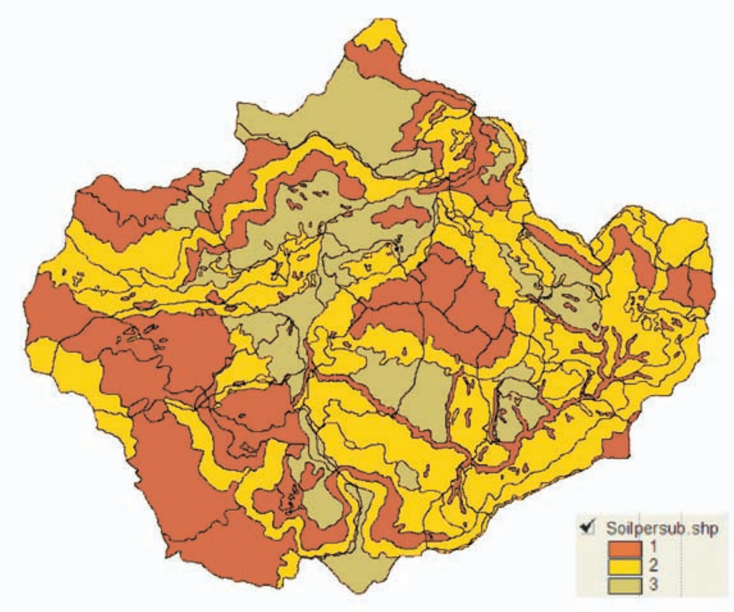


Figure 3.4 Soil map derived from soil survey conducted by CSAR (Kasdi et al. 2005): legend shows the derivation type of soil order:
1) andisol;
2) inceptisol; and
3) ultisol.

Table 3.3 Soil BD/BDref derive from soil physical measurement (Kasdi *et al.* 2004)

Class	Number of samples	Min of BD/BDref$_2$	Average of BD/BDref$_2$	Max of BD/BDref$_2$
Sun coffee	14	0.54	0.88	1.08
Shrub and grass	5	0.74	0.86	1.07
Forest	5	0.51	0.67	0.80
Multistrata	72	0.51	0.87	1.14
Horticulture	7	0.78	0.92	1.07
Rice field	13	0.58	0.85	1.10
Settlement*		**1.1**		**1.30**

Land cover

The various coffee systems increased for 30 years. Forest and shrub cover declined from 60% to 14%, with forest mainly being converted into coffee-based systems (Table 3.4).

Table 3.4 Land-cover classification of Way Besai Sumberjaya (ICRAF Indonesia database)

Land-cover type	**Land-cover change (ALL subcatchments)**			
	1976	**1986**	**2000**	**2007**
Forest	0.43	0.18	0.11	0.1
Simple shade	0	0	0.06	0.13
Multistrata	0.12	0.36	0.44	0.48
Shrub and grass	0.27	0.13	0.14	0.04
Horticulture	0.01	0.01	0.01	0.03
Sun coffee	0.16	0.19	0.2	0.09
Rice field	0.004	0.08	0.01	0.1
Settlement	0.01	0.03	0.02	0.03

Stream routing

The routing distance was calculated by measuring the stream length from the stream segment closest to subcatchment centroid to the targeted outlet (Table 3.5).

Non-measured input parameter

A number of non-measured parameters were used in a model calibration exercise, using the Nash–Sutcliffe Efficiency as criteria (Moriasi *et al.* 2007). The similarity pattern was determined from the coefficient of correlation. Parameters that were used for this calibration included the potential canopy interception and relative drought threshold per land-cover type (Table 3.6) and a number of the catchment response parameters (Table 3.7).

Model calibration was only carried out across the years for which data were available and no year-specific ad hoc adjustments were made. Model calibration was not pursued beyond “coarse tuning” of round numbers. A key parameter for the dry season recession rate (GWreleaseFracVar) was tuned to the overall pattern in dry periods.

Table 3.5 Subcatchment area and stream length

No	Subcatchment	Outlet		Centroid		Area (km^2)
		X	Y	X	Y	
1	WTebu	447790	9441713	450951.5	9443950	7.7
2	WB1	449860	9443057	451731.5	9442500	3.2
3	WB2	451121	9440860	441626.5	9432780	2.7
4	WB3	446839	9437697	438026.5	9442660	38.7
5	Air Ringkih	443369	9435719	441146.5	9443460	6.1
6	WB4	442207	9434911	442916.5	9438090	25.7
7	Air Lingkar	442146	9434909	432941.5	9438950	5.7
8	WB5	438965	9436841	446051.5	9443450	42.8
9	WB6	435686	9438712	443086.5	9442990	16.8
10	Air Hitam	434952	9437048	437671.5	9438755	55.0
11	Air Napalan	434589	9440836	441386.5	9447405	6.0
12	WKabul	434562	9440872	445366.5	9435795	30.4
13	WRingkih	436110	9443545	429566.5	9439140	7.4
14	WB7	436032	9444430	437326.5	9450300	19.7
15	WCampang	434060	9443224	428931.5	9442640	42.6
16	Wlirikan	440783	9445875	435966.5	9440275	6.7
17	WB8	441281	9446547	431951.5	9433445	40.9
18	WPetai	442535	9445669	447846.5	9441005	13.8
19	WCengkaan	442046	9449398	435511.5	9445630	27.3
20	WDAM	442415	9449293	439381.5	9435155	15.1
	Total					414.4

Table 3.6 Final input parameters BD/BDref, potential interception and relative drought threshold

Land-Cover Class	BD/BDref	Potential Interception (mm day^{-1})	Relative Drought Threshold
Sun coffee	1.08	1.00	0.55
Shrub and grass	1.07	3.00	0.60
Forest	0.80	4.00	0.40
Simple shade	1.00	2.00	0.55
Multistrata	1.00	3.00	0.60
Horticulture	1.07	1.00	0.70
Rice field	1.10	1.00	0.90
Settlement	1.30	0.05	0.01

Table 3.7 Final input of non-measured parameter of GenRiver

Acronym	Definition	Value
RainInterceptDripRt (i)	Rain interception Drip Rate	10 mm
RainMaxIntDripDur (i)	Rain interception Drip Duration	0.5 mm
InterceptEffectontrans(i)	Rain Interception Effect on Transpiration	0.8 mm
RainIntensMean	Average rainfall intensity	30 mm/day
RainIntensCoefVar	Coefficient of variation of rainfall intensity	0.3
MaxInfRate (i)	Maximum infiltration capacity per unit i	720 mm day^{-1}
MaxInfSubsoil (i)	Maximum infiltration capacity per unit i	120 mm day^{-1}
PerFracMultiplier (i)	Daily soil water drainage as fraction of groundwater release fraction	0.13
MaxDynGrWatStore (i)	Dynamic groundwater storage capacity	300 mm
GWReleaseFracVar (i)	An option to have a constant groundwater release fraction for each subcatchment or using single value for the whole catchment	0.1
Tortuosity (i)	Stream shape Factor	0.4
Dispersal Factor (i)	Drainage density	0.3
River Velocity (i)	River Flow velocity	0.4 m s^{-1}

3.1.4. Modelling result

Model performance

The model was simulated by using rainfall data from 1 January 1976 to February 2007. The periods where there were no measured data available were discarded and the remaining periods were used for performance analysis. We obtained the result that 16 of the 25 years of the simulation period showed satisfactory-to-good performance (NSE 0.5-0.75). The bias is less than 20% and the minimum coefficient of correlation (r) is 0.55 (Table 3.8)

The model simulation could capture most of the observed pattern across 31 years (Figure 3.5 and Figure 3.6). As shown in Figure 3.5 and Figure 3.6, observed and simulated flows for the first year (1976), tenth year (1986), 16th year (1992) and the last year of simulation (2006) with daily correlation coefficient respectively with daily correlation coefficient, are 0.78, 0.73, 0.84 and 0.83. However, the model still has underestimation prediction if compared to observation data, particularly in the second and at the end of the simulation period.

Table 3.8 Performance of GenRiver based on Nash-Sutcliffe Efficiency (NSE) criteria of Moriasi *et al.* (2007)

Year	n	Biased (%)	NSE	r	NSE
1976	365	14.87	0.64	0.8	satisfactory
1977	365	2.24	0.59	0.8	satisfactory
1978	365	2.73	0.60	0.8	satisfactory
1979	365	1.35	0.70	0.9	good
1980	365	1.07	0.63	0.8	satisfactory
1981	365	2.11	0.70	0.8	good
1982	365	9.92	0.64	0.8	satisfactory
1983	365	8.98	0.64	0.8	satisfactory
1984	365	11.30	0.55	0.8	satisfactory
1985	365	8.14	0.42	0.7	unsatisfactory
1986	365	15.69	0.37	0.7	unsatisfactory
1987	365	10.98	0.68	0.8	good
1988	365	14.86	0.59	0.8	satisfactory
1989	365	5.44	0.42	0.7	unsatisfactory
1990	365	0.88	0.32	0.7	unsatisfactory
1991	365	3.17	0.59	0.8	satisfactory
1992	365	-1.24	0.61	0.8	satisfactory
1993	365	-0.12	0.76	0.9	very good
1994	365	0.07	0.75	0.9	very good
1995	365	27.07	0.34	0.7	unsatisfactory
1996	365	28.23	0.02	0.5	unsatisfactory
1997	365	39.26	0.29	0.8	unsatisfactory
1999	365	40524.54	542.45	0.1	unsatisfactory
2005	365	221.31	3.31	0.2	unsatisfactory
2006	365	-5.87	0.76	0.9	very good

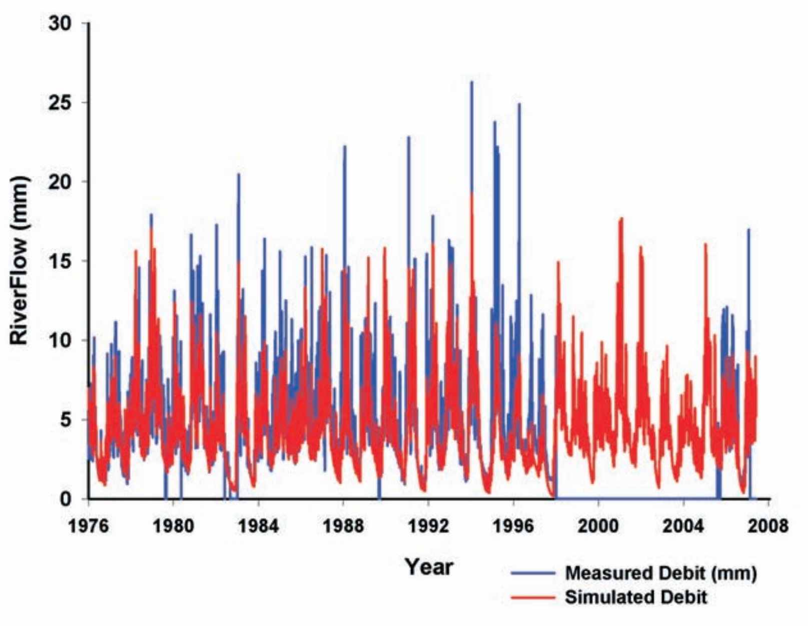


Figure 3.5 Plot of simulation against observation for 1 January 1976–13 February 2007

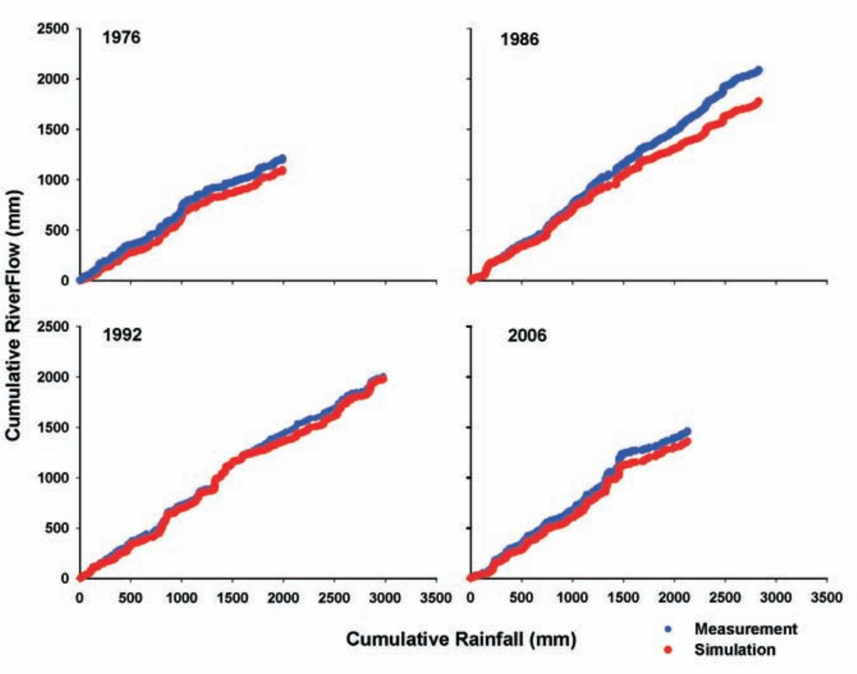


Figure 3.6 Plot of cumulative of simulated and observed rainfall and river flow during 31-year simulation period

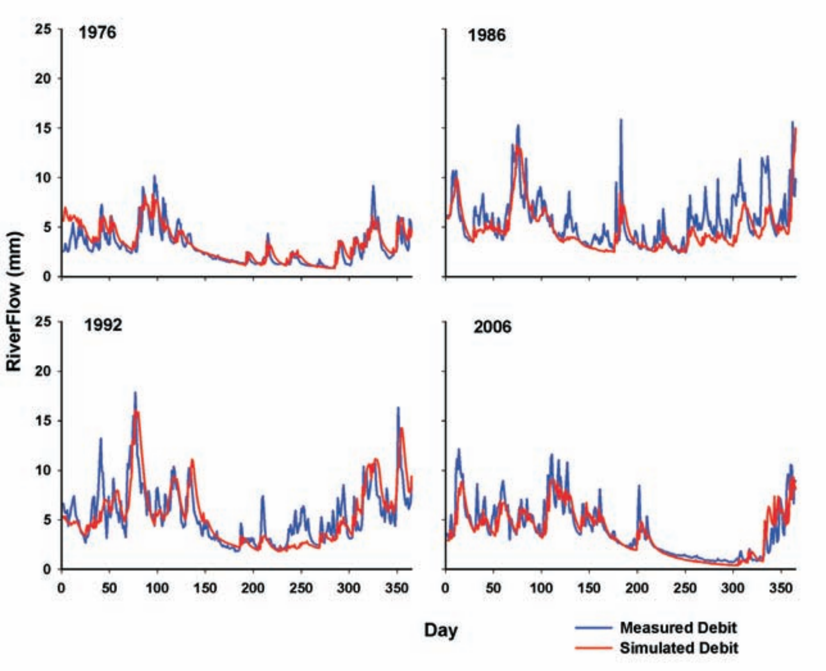


Figure 3.7 Hydrograph of simulated and observed of rainfall and river flow over 31 years

Water balance of Way Besai

The average water balance of Way Besay during 31 years of simulation, excluding the unsatisfactory output and unavailable data, is presented in Table 3.9. The result showed that evapotranspiration in the area was about 34% of annual rainfall and base flow was 36% of annual rainfall. Runoff in the whole catchment area was about 26% of annual rainfall, while soil quick flow is 4% of annual rainfall.

Table 3.9 Average water balance of Way Besai during 10-years simulation

No	**Dynamic of Water**	**Observed**	**Simulated**
		Average	**Average**
1	Precipitation (mm)	2515	2515
2	Evapotranspiration (mm)	-	858 (34)
3	River flow (mm)	1648 (66)	1658 (66)
	Σ Runoff (mm)	-	645 (26)
	Σ Soil Quick Flow (mm)	-	101 (4)
	Σ Base Flow (mm)	-	911 (36)

NB: Values in parentheses are percentages

Analysis of indicators of watershed functions: water quantity due to land-cover change

The assessment of the hydrological situation of a watershed is determined by the criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (relationship of peak river flow and peak rainfall, linked to flooding risk) and gradual release of ground water in the dry season, based on recharge in the rainy season (Table 3.9). These indicators all relate the flows of water to the preceding rainfall and by doing so allow the analysis of relatively small land-use effects, superimposed on substantial year-to-year variation in rainfall.

The watershed function of Way Besai, Sumberjaya, was assessed using criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (peak flow or peak rainfall) and gradual release of ground water (dry season flow) (Table 3.10). To capture the impact of land-use change the indicators are scattered over the 30-year simulation period (Figure 3.8). The main effect of land-cover change seems to increase the total water yield as a fraction of total rainfall, as well as the runoff (overflowfraction) tends to increase. Gradual water release function (slow flow, soil quick flow and lowest monthly fraction) tend to decrease over the years. The buffering capacity (buffering indicator, buffering relative, and buffering peak events) tends to decrease before year 1998 and then tends to increase after year 2005.

The effect of rainfall variation over the year could be evaluated when the indicator was expressed to the discharge fraction. The runoff (overlandflow) has positive correlation. The slow flow indicator has a negative correlation as well as the buffering indicator or buffering relative, while the other indicators tended to be quite stable to the discharge fraction over the year (Figure 3.9).

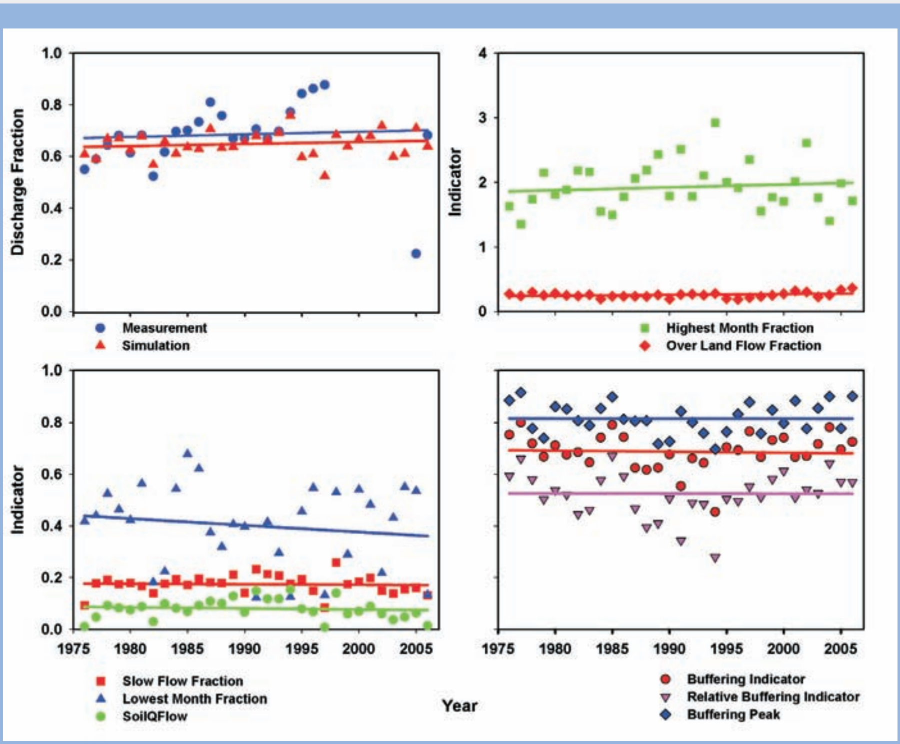


Figure 3.8 Discharge Fraction during 31-year simulation (top left) and Gradual water release function (bottom left). The water transmission function (top right) and Buffering capacity function (bottom right)

Table 3.10 Average of indicators of watershed functions

Indicators	Observed			Simulated		
	Min	Average	Max	Min	Average	Max
Total discharge fraction	0.5	0.7	0.9	0.5	0.7	0.8
Buffering indicator	0.5	0.7	0.8	0.5	0.7	0.8
Relative buffering indicator	0.2	0.4	0.6	0.3	0.6	0.7
Buffering peak events	0.4	0.7	0.9	0.7	0.8	0.9
Highest monthly discharge relative to mean rainfall	1.4	2.3	3.0	1.3	1.9	2.8
Overland flow fraction	-	-	-	0.2	0.3	0.4
Soil quick flow fraction	-	-	-	0.0	0.0	0.1
Slow flow fraction	-	-	-	0.3	0.4	0.5
Lowest monthly discharge relative to mean rainfall	-	-	-	0.0	0.4	0.8

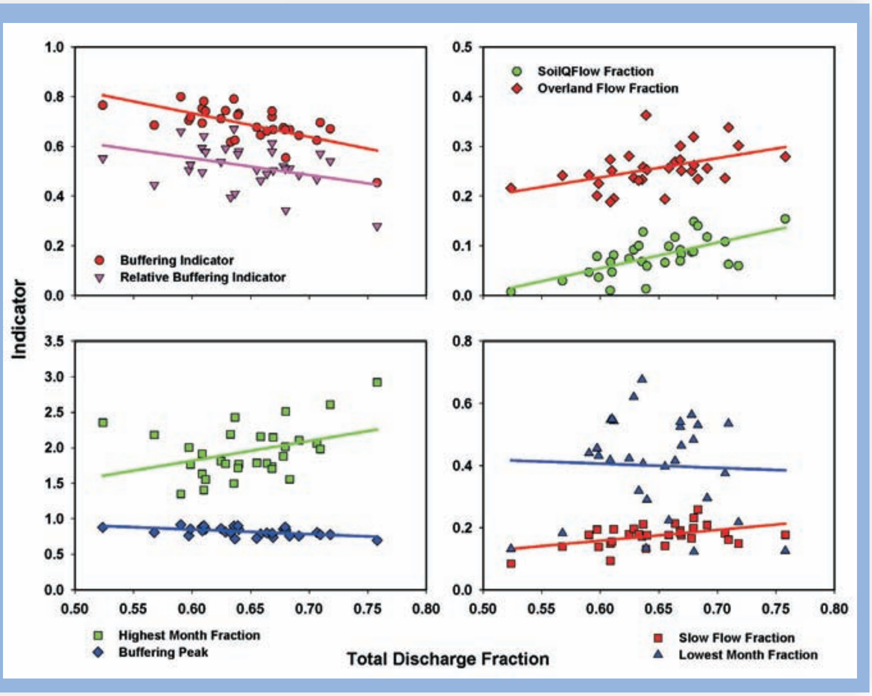


Figure 3.9 Indicators of watershed function of Way Besai, Sumberjaya, expressed in relationship to the total discharge fraction (which is positively correlated with annual rainfall), over a 31-year period

3.1.5. Discussion and conclusion

Using existing data and current hydrological studies of Way Besai to parameterize input of the GenRiver model can increase the model performance. Through several tests over a 25-year simulation GenRiver produced daily hydrographs close to the observation data. The model could simulate more than 60% of the simulation year with satisfactory-to-very good performance (NSE 0.5-0.75), while bias is less than 20% and the coefficient of correlation (r) is more than 0.72 (Table 3.10) (NSE more than 0.5).

The water balance in Sumberjaya indicated that around 66% of rainfall flows into the river, while 34% of annual rainfall is used by the vegetation and lost as evaporation. According to the model, 26% of rainfall comes as surface runoff and 36% as ground water flow with the amount of soil quick flow around 4% of annual rainfall. The estimated water balance of Way Besai watershed did not show the differentiation between the dry and rainy seasons. Almost all of the hydrological years are in saturated condition.

The hydrological function of Way Besai indicator showed an increase of water transmission indicators and a decline of gradual release of water. Average discharge (expressed as a fraction of rainfall) has increased while the slow flow fraction relative to the rainfall tends to be decreasing. This is likely due to reduced canopy interception and evapotranspiration of coffee gardens. However, even though the buffering indicator of the overall hydrological years is not indicative of a change of direction, the Way Besai, as reflected in quantitative indicators, is entering a degraded phase.

3.2. Simulation based on other sites (Mae Chaem Basin, North Thailand)

The Mae Chaem basin in Northern Thailand has been the focus of a number of watershed studies (Croke *et al.* 2004, Thanapakpawin *et al.* 2005). It has physically clear delineation, good land-cover and land-use change data, long-term record of river flow at the outlet of the catchment and a number of rainfall stations. Changes in both forest cover and land-use patterns outside of the forest have been well documented and are subject to considerable interest from downstream water users. We used this basin as a test of the robustness of GenRiver and of the reliability of the model predictions.

Table 3.11 Data available in Mae Chaem basin

Data		Timeseries	Sources	Files
Climate	Daily Rainfall	1989–2002	WRD55,MTD22 RYP48,RYP46 GMT13,WRD 52	MS Excel
	Pan Evaporation	1989–2002	RFD, Airport	MS Excel
DEM	DEM	1989–2002	ICRAF SEA[1)]	Asc
Spatial Data	Land Cover Landsat TM5 BSQ 30 1989 Landsat TM7 HDF 15 2000		ICRAF Chiang Mai[2)]	GRID
	Geology		TRFIC.MSU.EDU	Vector (shp)
	Soil		TRFIC.MSU.EDU	Vector (shp)
	Subcatchment Boundaries		TRFIC.MSU.EDU	Vector (shp)
	River Network		TRFIC.MSU.EDU	Vector (shp)
Discharge	Daily discharge P 14	1954–2003	ICHARM	MS Excel

1) World Agroforestry Centre (ICRAF) Southeast Asia Program,
2) World Agroforestry Centre (ICRAF) Thailand office

3.2.1. Area description

Mae Chaem watershed is geographically positioned at 18°06″ – 19°10″ North and 98°04″ – 98°34″ East. The basin area is about 3890 km^2. The elevation varies from 475 to 2560 m above sea level and slopes range from 0 to 78°.

The climate of this basin has seasonal variations influenced by Pacific-born typhoons, which, superimposed on the south-west monsoon orographic effect induces an increase of rainfall with elevation, depending on the dominant compass direction of the rain front (Dairaku *et al.* 2000). The rainy season mostly occur May to October, with average temperature range of 20–34°C.

Deciduous forest is still the largest amount of land cover (43%), followed by evergreen forest (11%) at higher elevations and a considerable range of other classes ranging from urban, field crop, shrub, scrub–crop mosaic, rice field, fallow, orchard, degraded forest and hill pine forest (Thomas *et al.* 2006).

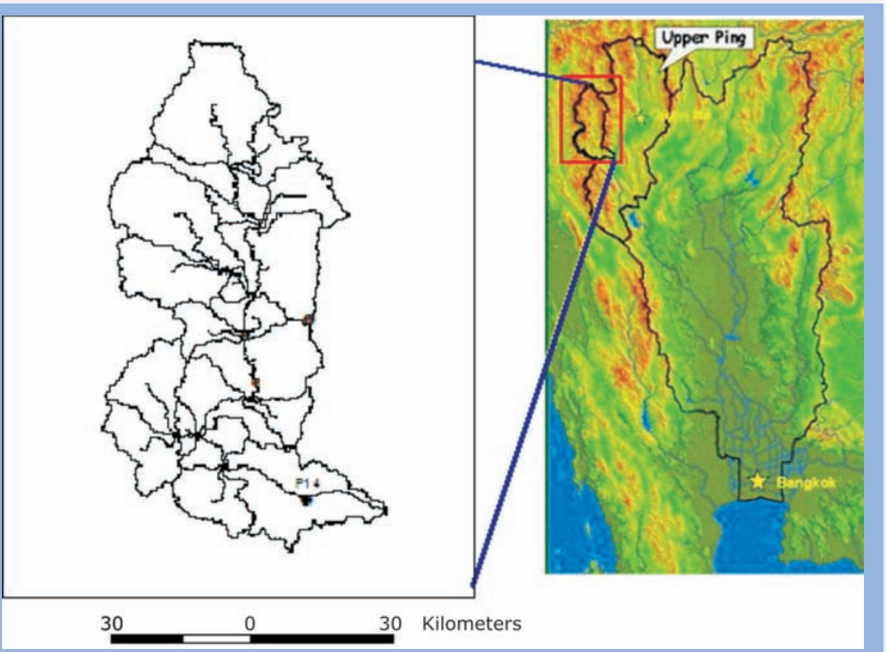


Figure 3.10 Mae Chaem Watershed as part of the upper Ping Basin, contributing to the Chao Phraya

3.2.2 Data on input parameters

Rainfall

There are more than 20 rainfall stations in the Mae Chaem basin. We chose six stations which had the same series of data to interpolate daily rainfall depth for all subcatchments (Table 3.12). We used Thiessen interpolated rainfall data for the whole basin area (Figure 3.11, Figure 3.12 and Table 3.13) as the basic rainfall data.

Table 3.12 Rainfall stations and description data available in the area

Rainfall station	Name	X	Y	Elevation (m)	Source	Rainfall Data	Weighting Area
WRD55	Mae Chaem (MAE)	434894	2039919	454	Water Resource Dept.	1989–2003	0.30
MTD22	Wat Chan (WA)	425936	2108176	960	Met Dept	1989 2003	0.18
RYP48	Doi Inthanon (DO)	445494	2054637	2565	Royal Project	1989–2003	0.04
RYP46	Research Station (RE)	426124	2047327	1100	Royal Project	1989–2003	0.18
GMT13	Ban Kong Kan	432146	2050808	446	Game-T data	1989–2003	0.05
WRD 52	Ban Mae Mu	437312	2070460	660	Water Dept	1989–2003	0.26

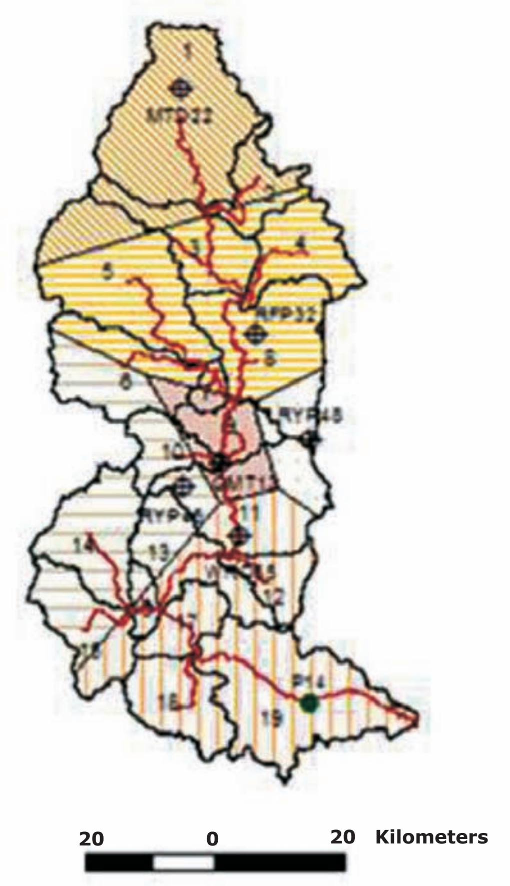


Figure 3.11 Thiessen polygon to determine the area rainfall map

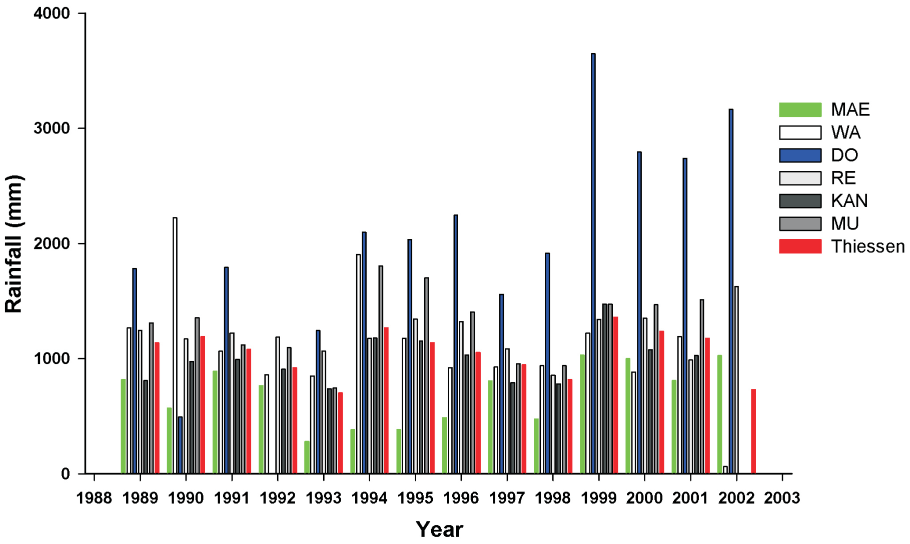


Figure 3.12 Annual rainfall in Mae Chaem basin

Table 3.13 Annual rainfall 1989–2003 recorded in Mae Chaem basin

Year	Mae Chaem (MAE)	Wat Chan (WA)	Doi Inthanon (DO)	Research Station (RE)	Ban Kong Kan	Ban Mae Mu	Average Thiessen
1989	816	1267	1781	1245	809	1310	1137
1990	569	2224	492	1172	974	1357	1195
1991	891	1064	1793	1223	991	1119	1079
1992	765	861		1187	908	1097	957
1993	281	849	1243	1065	738	745	702
1994	383	1904	2097	1176	1180	1804	1271
1995	384	1176	2033	1344	1155	1701	1139
1996	487	922	2245	1322	1032	1404	1064
1997	808	927	1559	1086	790	956	948
1998	476	938	1916	855	781	939	816
1999	1033	1220	3648	1341	1473	1474	1377
2000	999	883	2796	1352	1076	1469	1266
2001	809	1191	2740	988	1027	1513	1177
2002	1026	63	3165	1627			1381
2003	877	670	2161	985			921

River flow data

River flow data was obtained from the Royal Irrigation Department (RID) river gauge station P.14 in Ob Luang, which has an area of about 3740 km^2. The data was taken from ICHARM web site, which publishes discharge data recorded 1954–2003 (Figure 3.13). (http://www.icharm.pwri.go.jp/html/network/pub_dabase_top_files/maecham_q.txt). We used data from 1 January 1989 to 30 March 2003 for the simulation owing to time availability of land-cover classification. The observed data was adjusted to the whole basin area by calculating the fraction area of contributed area (Table 3.14).

Table 3.14 Annual river flow data recorded in P14 station (mm/year)

Year	River flow	Year	River flow
1989	251	1997	223
1990	240	1998	126
1991	278	1999	324
1992	219	2000	319
1993	169	2001	252
1994	362	2002	342
1995	377	2003	33
1996	301		

Evapotranspiration

Evapotranspiration in the Mae Chaem basin was obtained from pan evaporation data recorded at Airport TM (meteorology department) and Mae Chaem Watershed Research Station (RFD) (Table 3.15). The Airport Station was located outside the basin, thus daily evapotranspiration data was taken from the average of both stations (Table 3.16). The actual data of evapotranspiration per land-cover type was provided by multiplying this average data to evapotranspiration multiplier per land-cover type (Table 3.17).

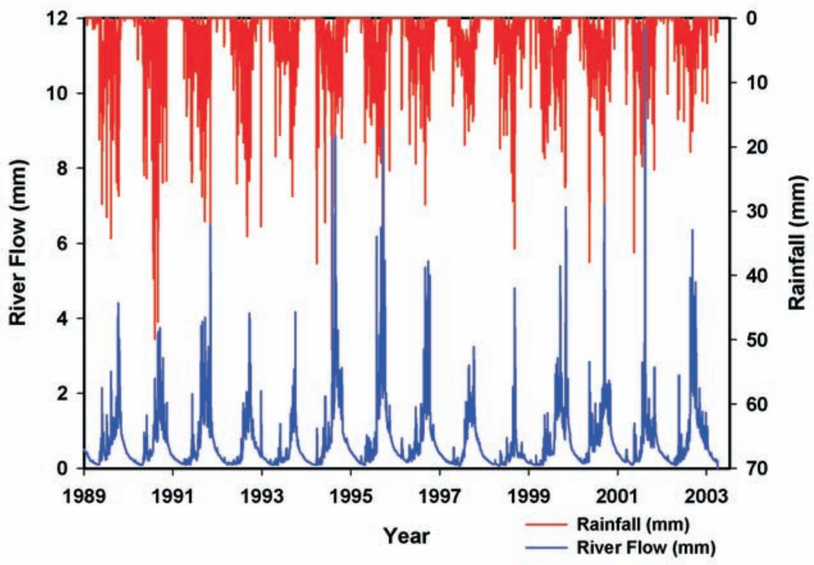


Figure 3.13 Temporal pattern of observed rainfall (spatially averaged over the Mae Chaem catchment) and river flow at the P14 station

Table 3.15 Locations of available weather station data

Id	Name	Elevation (m)	X	Y	Source	Available Data
MTD17	Airport CM	304	498946.3	2077423.4	Met Dept	1973–2003
RFD44	Research Station	1100	426123.7	2047326.7	RFD	1986–2002

Table 3.16 Monthly average of daily potential evapotranspiration (pan evaporation) record in Mae Chaem 1989–2003

Month	Airport Station			Research Station			Average		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
1	3.13	3.47	3.74	2.38	3.29	4.15	2.76	3.38	3.95
2	4.15	4.45	4.62	3.66	4.87	5.76	3.91	4.66	5.19
3	4.88	5.46	5.93	4.73	5.51	6.64	4.81	5.49	6.29
4	5.65	6.24	6.91	4.64	5.64	6.62	5.15	5.94	6.77
5	5.20	5.89	6.74	2.79	4.11	5.20	4.00	5.00	5.97
6	4.07	4.56	5.07	1.63	2.65	4.07	2.85	3.61	4.57
7	3.83	4.12	4.52	0.99	2.24	3.83	2.41	3.18	4.18
8	4.01	4.30	4.97	1.33	2.22	4.11	2.67	3.26	4.54
9	3.80	4.32	4.81	1.94	2.61	3.80	2.87	3.47	4.31
10	3.84	4.18	4.34	2.37	2.88	3.84	3.11	3.53	4.09
11	3.56	3.72	3.78	2.06	3.00	4.72	2.81	3.36	4.25
12	3.07	3.31	3.47	1.99	2.56	3.18	2.53	2.94	3.33