

ICIMOD

MANUAL

Application of the J2000 Hydrological Model in the Panjshir catchment of the Hindu Kush Himalayan region



Copyright © 2020

International Centre for Integrated Mountain Development (ICIMOD)

This work is licensed under a Creative Commons Attribution Non-Commercial, No Derivatives 4.0 International License

<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Note

This publication may be reproduced in whole or in part and in any form for educational or nonprofit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. ICIMOD would appreciate receiving a copy of any publication that uses this publication as a source. No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from ICIMOD.

The views and interpretations in this publication are those of the author(s). They are not attributable to ICIMOD and do not imply the expression of any opinion concerning the legal status of any country, territory, city or area of its authorities, or concerning the delimitation of its frontiers or boundaries, or the endorsement of any product.

This publication is available in electronic form at www.icimod.org/himaldoc.

Published by

International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal

ISBN 978 92 9115 695 5 (electronic)

LCCN 2020-325701 (electronic)

Production team

Nagraj Adve (Consultant editor)

Samuel Thomas (Senior editor)

Rachana Chettri (Editor)

Dharma R Maharjan (Graphic designer)

Photos:

Shiva Hari Khatri: Cover

Jitendra Bajracharya: pp iv

Kabi Raj Khatiwada: pp x, 22

Nakul Chettri: pp ii

Nawraj Pradhan: pp vi, 60

Santosh Nepal: pp ix, 106

Citation

Nepal, S., Khatiwada, K.R., Pradhananga, S., Kralisch, S. (2020).

Application of the J2000 Hydrological Model in the Panjshir catchment of the Hindu Kush Himalayan Region, Training Manual. ICIMOD.

MANUAL

Application of the J2000 Hydrological Model in the Panjshir catchment of the Hindu Kush Himalayan region

Authors

Santosh Nepal¹, Kabi Raj Khatiwada¹, Saurav Pradhananga¹, Sven Kralisch²

¹ International Centre for Integrated Mountain Development

² Friedrich Schiller University, Jena, Germany



Contents

PAGE iii

Abbreviations and acronyms

PAGE iii

Acknowledgements

PAGE iv

About SWaRMA

Strengthening Water Resources Management in Afghanistan (SWaRMA) is a two-year project supported by the governments of Australia and Afghanistan, and implemented by the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australia.

PAGES v-vi

About this manual

This tutorial manual has been prepared with an aim to assist the implementation of the J2000 hydrological model in catchments of the Hindu Kush Himalayan region.

Part I | PAGES 1-21

Hydrological modelling system theory and processes

Hydrological models are simple representations of real world systems and represent our understanding of hydrologic processes, and current and future water-related challenges. They are crucial for effective planning and management of water resources.

Part II | PAGES 22-58

Applying the J2000 model in the Panjshir catchment

This manual contains systematically represented information on the application of the J2000 model in the Panjshir catchment of the Kabul River basin to enable users to set up the application and understand the hydrological processes characteristic of the basin.

PAGES 59-107

Exercises

PAGES 108-110

References

Abbreviations and acronyms

actET	Actual evapotranspiration
DEM	Digital Elevation Model
DPS	Depression storage
ET	Evapotranspiration
GLUE	General Likelihood Uncertainty Estimation
HKH	Hindu Kush Himalaya
HRUs	Hydrological response units
JADE	JAMS Adaptable Data Explorer
JAMS	Jena Adaptable Modelling System
JUICE	JAMS User Interface Model Editor
LAI	Leaf area index
LPS	Large pore storage
MCA	Monte-Carlo analysis
MPS	Middle pore storage
potET	Potential evapotranspiration
refET	Reference evapotranspiration
RSA	Regional sensitivity analysis
soilMaxDPS	Maximum depression storage
snowCritDens	Critical density of snowpack
SWAT	Soil and water assessment tool
Tbase	Threshold temperature for ice melt
tmean	Mean air temperature

Acknowledgements

This training manual was initially prepared as part of a training programme on hydrological modelling in New Delhi, India in 2018. This programme was a part of the Strengthening Water Resources Management in Afghanistan (SWaRMA) Initiative, and the participants represented different government institutions from Afghanistan. We would like to acknowledge the feedback and inputs provided by the participants during the training workshop.

We express our gratitude to the Ministry of Energy and Water (MEW); Ministry of Agriculture, Irrigation, and Livestock (MAIL); Ministry of Foreign Affairs (MoFA); Afghanistan National Disaster Management Authority (ANDMA); National Environmental Protection Agency (NEPA); Afghanistan Meteorological Department (AMD); Kabul University (KU), Kabul Polytechnic University (KPU); Aga-Khan Agency for Habitat (AKAH); and other Afghan ministries for their feedback and support in creating this manual. During the training programme, the manual was successfully applied and tested in the Panjshir catchment of the Kabul River basin. It has been further adapted to make it applicable to different mountain basins of the Hindu Kush Himalayan region.

We would like to take this opportunity to express our thanks to Fayez Azizi, Director, Water Resources Department, Ministry of Energy and Water, Afghanistan and Tayib Bromand, Water Resources and Climate Change Adaptation Specialist, Water Resources Department, Ministry of Energy and Water, Afghanistan for their support and encouragement from the inception to the finalization of this manual.

We would also like to thank the coordinator of the SWaRMA initiative, Neera Shrestha Pradhan, ICIMOD; Arun B Shrestha, Regional Programme Manager, River Basins and Cryosphere, ICIMOD; and Sanjeev Bhuchar, Theme Leader, Water and Air, ICIMOD for their guidance.

Finally, we express our gratitude to members of the SWaRMA steering committee for their support.



About the SWaRMA project

Strengthening Water Resources Management in Afghanistan (SWaRMA) is a two-year project supported by the governments of Australia and Afghanistan, and implemented by the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australia. The project works to create learning opportunities to strengthen water resources management in Afghanistan. It has done so by assessing water resources at various levels, monitoring the cryosphere and floods at the community level, developing and using water information systems, fostering integrated river basin management, and supporting Afghanistan's engagement in regional forums to showcase result-based outcomes.

SWaRMA's focal partner in Afghanistan is the Ministry of Energy and Water (MEW). SWaRMA also works closely with the Ministry of Agriculture, Irrigation, and Livestock (MAIL); Ministry of Foreign Affairs (MoFA); Afghanistan National Disaster Management Authority (ANDMA); National Environmental Protection Agency (NEPA); Afghanistan Meteorological Department (AMD); Kabul University (KU); Kabul Polytechnic University (KPU); Aga-Khan Agency for Habitat (AKAH); and other ministries.

SWaRMA has seven thematic areas for capacity enhancement, co-creating knowledge, and facilitating learning platforms. They are:

- Water availability analysis
- Cryosphere monitoring
- Flood monitoring and early warning systems
- Water resources management
- Water resources planning at the basin scale
- Water information systems
- Regional cooperation



About this manual

This tutorial manual has been prepared with an aim to assist the implementation of the J2000 hydrological model in catchments of the Hindu Kush Himalayan region.

It has been prepared in such a way that the J2000 hydrological model can be applied independently to other basins.

The manual is divided into two parts, each with a key objective.

This tutorial manual has been prepared with an aim to assist the implementation of the J2000 hydrological model in catchments of the Hindu Kush Himalayan (HKH) region. The tutorial was successfully applied during a training programme on hydrological modelling in New Delhi, India, from 25 October to 4 November 2018. The training programme was organized by SWARMA in collaboration with the Ministry of Energy and Water (MEW), Afghanistan and the Friedrich Schiller University of Jena, Germany. Other concerned ministries and universities in Afghanistan, including the Ministry of Agriculture, Irrigation, and Livestock (MAIL); Afghanistan National Disaster Management Authority (ANDMA); National Environmental Protection Agency (NEPA); Kabul University (KU); and Kabul Polytechnic University (KPU) participated in the training programme. Participants were provided with a theoretical description of hydrological processes, with a focus on the JAMS/J2000 modelling system. During the second week, they themselves set up the J2000 model for the glaciated Panjshir catchment in the Kabul River basin, Afghanistan.

This manual is prepared in such a way that the J2000 hydrological model can be applied independently to other basins. It is divided into two parts, each with a key objective. The first part is dedicated to theoretical bases, designed to get the manual's users familiar with the different aspects of the J2000 modelling system. Most of the examples are supplied with a test dataset of the Dudh Koshi River basin in Nepal (Nepal et al., 2014). The second part is concerned with the strategy for facilitating setting up the model in new river basins/catchments and performing analyses. The dataset used as an example in this second part pertains to the Panjshir catchment of the Kabul River basin. It is followed by exercises relevant for an assessment of the different water balance components of the HKH region. The examples, and the exercises, are based on the Panjshir catchment.

1.1 Who can use the manual?

This manual can be used by students, practitioners, and researchers to carry out hydrological system analysis for basins at different scales. It is useful for anyone interested in getting familiar with model application and, simultaneously, preparing their own datasets to simulate the hydrological behaviour of river basins/catchments in the HKH region.

Detailed explanations of the hydrological modelling can also be found at the online platform, 'Applying the J2000 model', at < http://jams.uni-jena.de/ilmswiki/index.php/Applying_the_J2000_model >.

1.2 Objective of this manual

The main objective of the manual is:

- To familiarize readers with the JAMS modelling framework and J2000 modelling system.
- To enable readers to set up a new J2000 model in the catchment/basin of their interest, based on the model of Panjshir catchment.

1.3 Software and test dataset

The JAMS/J2000 modelling system can be downloaded from the website <<http://jams.uni-jena.de>>.

The model source code is open access. Further details can be accessed from < http://jams.uni-jena.de/ilmswiki/index.php/Tutorial_Model_Developers >.

The test dataset of the Dudh Koshi region (Nepal, Krause, Flügel, Fink, & Fischer 2014) was also supplied to the participants of the training programme to test the different features of the J2000 hydrological model, before applying it to the Panjshir catchment. The model can be downloaded from < http://jams.uni-jena.de/ilmswiki/index.php/File:J2000_DudhKoshi_Tutorial.zip > and further details regarding the dataset can be accessed at < http://jams.uni-jena.de/ilmswiki/index.php/Applying_the_J2000_model#Description_of_the_test_dataset >.





PART I

Hydrological modelling system theory and processes

Hydrological models are simple representations of the real-world system that aid in the different phases of understanding, planning, and implementation of water resources management, at both the global and local levels.

An understanding of the hydrological system dynamics of any river basin is very crucial for the planning and management of its water resources. There exists a significant information gap for many watersheds, regarding the baseline status of their different components. Hydrological models are simple representations of the real-world system, that aid in the different phases of understanding, planning, and implementation of water resources management, at both the global and local levels.

Hydrological models are among the tools available to gain an adequate understanding of the characteristics of a river basin (Tessema 2011). The role of hydrological modelling is ever increasing (Flügel 2009; Refsgaard, van der Sluijs, Højberg, & Vanrolleghem 2007). The application of hydrological models is of great significance in extrapolating information in both space and time from available measurements; understanding the hydrological dynamics, the interaction of the different system components (for example, the soil, groundwater, streamflow, snow, and glaciers) of a watershed (Uhlenbrook, Seibert, Leibundgut, & Rodhe 1999); and forecasting (referring to certain periods in real time) or predicting (independent of a specific time reference) the behaviour of this real-world system based on one or more sets of underlying resource development or physical setting (such as climate change) assumptions or behaviour (Anderson & Burt 1985; DeCoursey, Shaake Jr, & Seely 1982).

The application of these models contributes essential information to strengthen decision-making regarding water management (Beven 2001; Beven & Freer 2001), for basic research (Lutz, Immerzeel, Shrestha, & Bierkens 2014; Nepal, et al. 2014, Wijngaard et al. 2017), and to overcome the constraints of the limited availability of data given complex topographies.

Water-related challenges are expected to increase in the future in the HKH region (Scott et al. 2019). In the context of climate change and other environmental changes, securing water for different uses will be a major challenge. Hydrological models play an important role in understanding, analysing, and exploring a range of solutions for sustainable water management to support decision makers and operational water managers (Immerzeel, Van Beek, & Bierkens 2010).

2.1 Hydrological modelling systems

Hydrological models represent the real world in a simplified way (Refsgaard & Knudsen 1996). Hydrological modelling systems can be grouped into many categories based on the modelling approaches used. Many attempts have been made to classify hydrological models (Jajarmizadeh, Harun, & Salarpour 2012). However, due to their overlapping characteristics, they are not strictly classified.

A key distinction among models involves stochastic and deterministic approaches. Stochastic models have statistical characteristics; these types of models allow random variation in one or more inputs, and therefore provide simulated results with a certain amount of randomness. Deterministic models, on the other hand, are based on mathematical relationships in which results are achieved through known state-to-event relationships.

Physically-based models are entirely based on the laws of physics and are also known as ‘white box’ models. They consist of a complex set of mathematical equations representing a catchment’s hydrological processes. Examples include the MIKE-SHE model (Jayatilaka, Storm, & Mudgway 1998), ISBA surface scheme model, and the HSPF (Bicknell, Imhoff, Kittle Jr, Donigian Jr, & Johanson 1996). Likewise, ‘gray box’ models, also known as conceptual models, are a combination of an empirical approach and simple functions of physical processes. They are often preferred because they require less extensive input data than physically-based models. Examples of such models are SWAT (Arnold, Srinivasan, Muttiah, & Williams 1998), HBV (Bergstrom 1976), QUAL-2K (Chapra, Pelletier, & Tao 2003), the PRMS/MMS model (Leavesley, Lichty, Troutman, & Saindon 1983), and J2000 (Krause 2001). ‘Black box’ models, also known as empirical models, do not take into account any physical processes. They consist of simple functions for approximating or fitting the data available (for example, simple regression models or water-balance/water-quality spreadsheet models).

The spatial variability of system variables and parameters are considered under another classification—distributed, semi-distributed, and lumped models. Most physically-based hydrological models rely either on

spatially distributed or lumped characterizations of topography or other spatial variables (Cunderlik & Simonovic 2003; Daniel et al. 2011; Singh & Frevert 2002).

Lumped models describe the watershed as a single entity, that is to say, do not vary spatially and usually based on the concept of the unit hydrograph. The lumped approach is often implemented in conceptual models. Similarly, semi-distributed models have a more physically-based structure than lumped models. They occur between the lumped and distributed models, and require less input data than distributed models do, for example, SWAT (Arnold et al. 1998) and J2000, which are based on hydrological response units (HRUs). The distributed model incorporates the spatial variation of a watershed’s characteristics with stated variables (such as precipitation, temperature, soil, geology, and land use) by disaggregating the system into a large number of elements or grid squares (Beven 2001). These are based on physical processes of the catchment, need a large amount of data for parameterization in each modelling unit, and provide the highest degree of accuracy (for example, the ISBA hydrological model) (Noilhan & Mahfouf 1996; Noilhan & Planton 1998).

There are hence a wide variety of hydrological models and what is a suitable type of model would vary, based on the specific questions asked, available datasets, facility of the computational processes, and the flexibility of the model to answer the question. For example, to answer the question regarding the contribution of melt run-off from a glaciated area requires a model that has a snow and glacier module in its framework.

2.2 The JAMS/J2000 hydrological model

J2000 is a process-oriented, distributed hydrological model for meso- and macro-catchment hydrological simulations. It is implemented in the Jena Adaptable Modeling System (JAMS), a software framework for the development of component-based models and application of environmental simulation (Kralisch & Krause 2006; Kralisch, Krause, Fink, Fischer, & Flügel 2007). The simulation of the various hydrological processes takes place in encapsulated process modules, which are to a great extent independent of each other. This enables single modules or processes to be changed, replaced or added, without having to restructure the model from the start. So for instance, with this flexibility, a glacier module has been integrated as part of the study carried out by Nepal (2012) in the Himalayan region.

JAMS is a modular, structured environment modelling framework developed to address current challenges in environmental problems. It can simulate environmental processes at discrete points in time and/or space.

2.2.1 Installing JAMS

JAMS can be downloaded from the website <<http://jams.uni-jena.de>>. The latest available version is displayed in Figure 1. The link currently opens to version 3. Its installation for a Windows operating system is carried out by an executable file. For Linux, a *tgz*-archive is available, which includes all the files needed. However, for the execution of JAMS on Linux, an existing Java installation is required. This tutorial provides examples rooted in Java 8.

The model is installed in C:\jams.

The model library component files are installed in C:\jams\components.

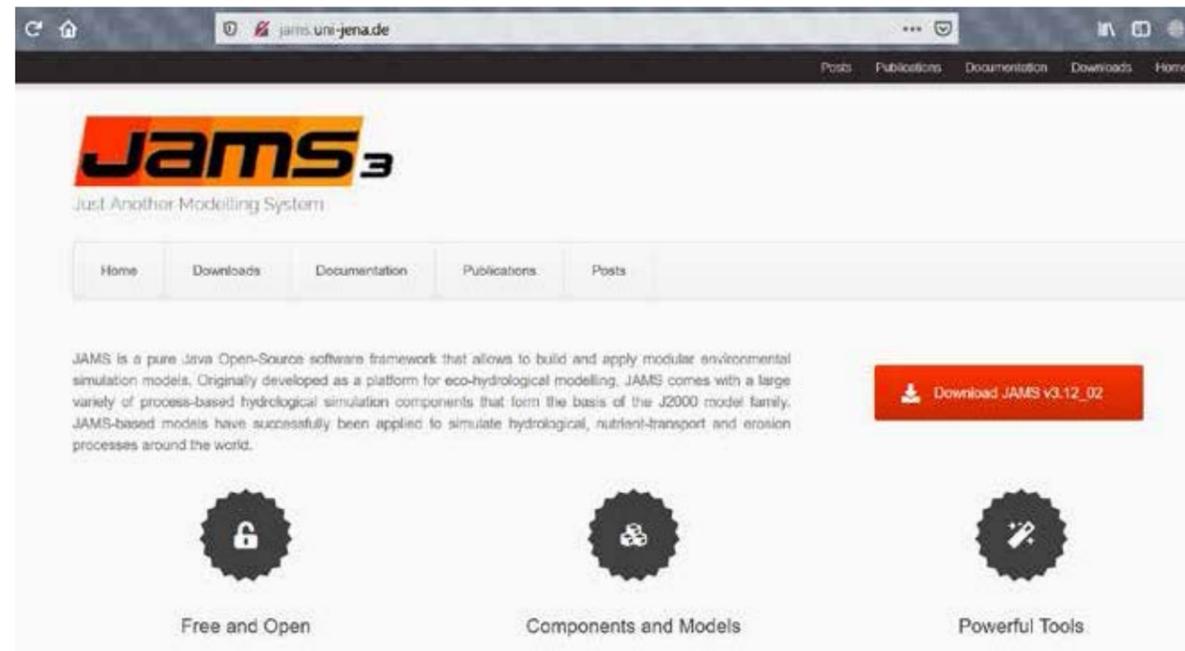
The standard J2000 model installation comes with J2K_gehlberg and j2k_dudh_koshi model files, which are provided as an example test dataset. They are available in C:\jams\data\. These two example datasets support two different purposes: J2k_ghelberg is a standard J2000 model file provided for the Gehlberg catchment in Germany. The j2k_dudh_koshi is a standard J2000 model file adapted to a glaciated basin of Mt Everest region in Nepal, known as the Dudh Koshi catchment of the Himalayan region. The catchment has sufficient input data to use the inverse distance weighted (IDW) method for regionalization.

The model can be run by double-clicking on the ‘jam (eg. j2k_ghelberg.jam) file in the model folder.

2.2.2 JAMS interfaces

Graphical user interfaces of some of the major components of the model are presented below.

FIGURE 1 WEB PLATFORM FOR DOWNLOADING THE JAMS MODELLING SYSTEM



2.2.2.1 JAMS LAUNCHER

JAMS Launcher is a software tool that facilitates the loading, parameterization, and execution of the model, and visualization of the results. The total run-off at the catchment outlet, evapotranspiration, soil water, snow water equivalent, the map of the catchment area, etc can all be visualized.

The Launcher (Figure 2) can be started from the Start menu or from the shortcut on the desktop. Under the menu item 'File', you can load, save, and close models. The menu item 'Edit' can change settings, and load and save preferences. Under the menu item 'Model', you can start the modelling (*Run the Model*), go to JAMS Data Explorer, or switch to 'JUICE' (*JAMS Builder*), see the current workspace (*Browse Workspace Directory*) or see the docket of all ongoing processes (*Show Process List*). Under the menu item 'Logs', you can open the *Info Log* and *Error Log*. Info Log contains information about the model's author, version, user, as well as information on the model's efficiency and runtime. Error Log records any errors that may have occurred during the model run.

After starting JAMS Launcher with a model, the main window opens, which contains several tabulators. The main window includes the workspace directory which sets the time interval. You can set the time period for the model run here. It also includes modules such as Initializing, Regionalization, Radiation, Interception, SoilWater, Groundwater, among others. The details of each module are described in subsection 3.6 (see page 50).

2.2.2.2 JAMS BUILDER

As you open the model using JAMS Builder (Figure 3), the window to the left shows the location of model library files that are required to run a model. All the model source codes are in the *.jar file. For the J2000 model, a J2K_base.jar file is used. These library files can be found in <C:\jams\components>.

The window in the middle provides information about the modules used in the model xml file of the model you are using (Figure 3 pertains to the Dudh Koshi model). These are provided in a logical manner, wherein the output

of one module is provided as input for the next. A detailed description of these different modules will be provided in the next subsection. An example of the Entity Reader in JAMS Builder is shown in Figure 3. By clicking on 'EntityReader', or any other module, detailed information about it gets displayed in the window to the right.

FIGURE 2 JAMS LAUNCHER

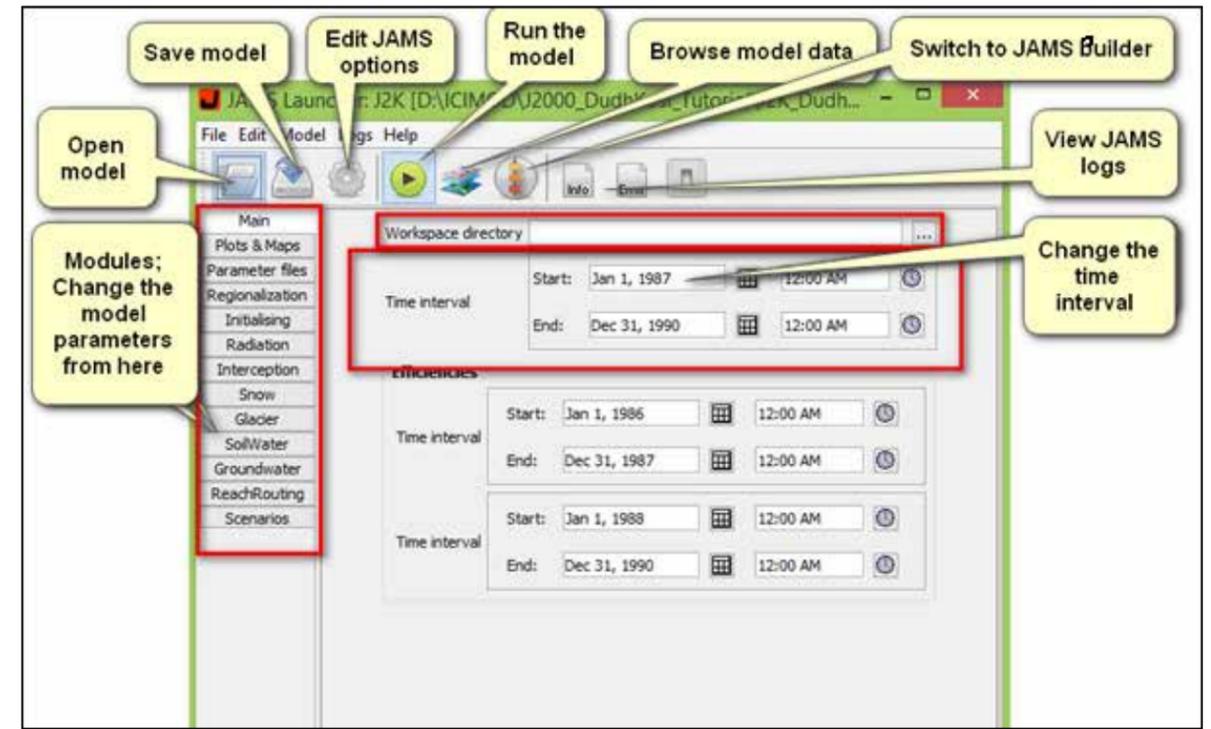
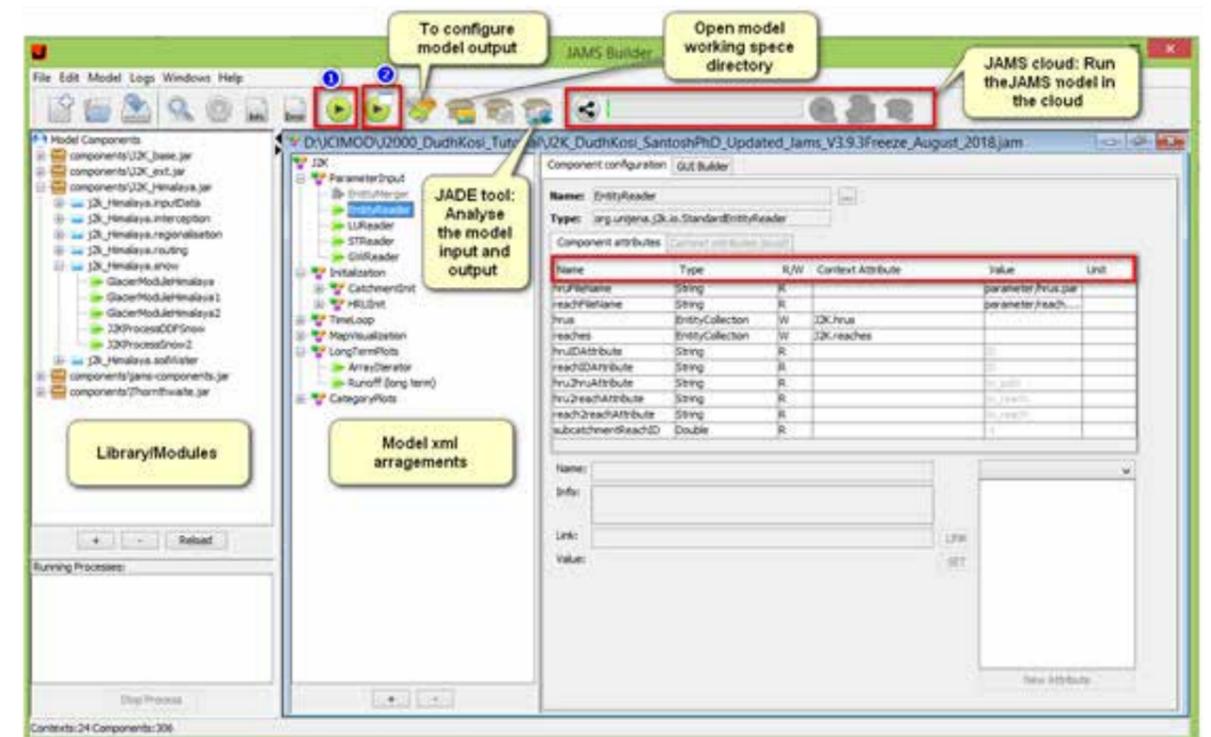


FIGURE 3 JAMS BUILDER



All the variables used in the modules are provided under the column 'Name' (Figure 3). The column 'Type' describes their characteristics, in terms of the information (such as data or quality) they store. The column 'R/W' determines the nature of their input and output. 'R', which denotes 'Read', is used for inputs and 'W' denotes 'Write', which is the output value from this module. 'hruFileName' is an input which reads the HRU file name whereas 'hrus' is an output which stores the HRU information from the hrus.par file. The calibration parameters, if any, are provided in the column 'Value'. This value can be changed directly from JAMS Builder. Upon clicking the variable, the information on 'attribute configuration' will be filled. This information can be changed. Please click on 'SET' to save the information.

The model can be run from JAMS Builder by clicking the 'Run Model' button ([1] shown in Figure 3) or 'Run Model from JAMS Launcher' ([2] shown in Figure 3). Clicking the box [1] will run the model directly, whereas box [2] will launch the JAMS Launcher, which provides options to change the model parameters (such as parameter values, time period), etc. Table 1 highlights some major differences between the JAMS Launcher and JAMS Builder.

TABLE 1 DIFFERENCES BETWEEN JAMS LAUNCHER AND JAMS BUILDER	
Launcher (jams.exe)	Builder (juice.exe)
Loads/saves model definitions and model parameters	Loads/saves model definitions and model parameters
Edits model parameters	Builds models
Runs models	Automated model calibration
Browses model input and result data	Generates model documentation

2.2.3 Model workspace directory

The workspace directory has three main folders: input, parameters, and output. The input folder has all the required climate input data to run the model, in a folder named 'local'. The parameter folder has five parameter files, hru.par, hgeo.par, landuse.par, soil.par, and reach.par, which contain information on topography, geology, land use and soil, and their role in controlling the hydrological processes of a catchment. The output folder stores all output files in a folder named 'current' after the model is successfully run.

2.2.3.1 FOLDER: INPUT

Into the input folder of your model, copy and paste the 12 xml files, for all input data from the input folder 'J2k_gerlberg'. They connect the real input data located inside the folder 'local' with the model.

Subfolder: local

The 'local' folder inside the input folder contains input data for all variables (rain.dat, rhum.dat, sunh.dat, tmax.dat, tmean.dat, tmin.dat, wind.dat). Additionally, ahum.dat is created by the model when the model is run for the first time by using the existing data. Create a subfolder named 'gis' in this folder.

Sub-subfolder: gis

This folder contains the hrus.shp file derived from the hru-web tool. This file is used to display the spatial distribution of some output variables, for example, the spatial distribution of precipitation in a catchment (in 2D and 3D). For this, you need to put the Digital Elevation Model (DEM) file of a catchment (data format: *.asc) in this folder. The resolution of the DEM should be the same as the input DEM used for the HRU delineation process. Copy the styles.sld file from the test dataset, needed to display a map. Additionally, streams and station data files (*.shp) can also be put in a separate folder to display the variables in a map component. The names of these files and folders have to be defined in a model xml file.

Subfolder: dump

Create a folder with the name 'dump', and use it to dump temporary files.

2.2.3.2 FOLDER: OUTPUT

The folder named 'output' stores two .dat files (TimeLoop.dat and HRULoop.dat) inside the folder 'current' after the model has successfully run.

2.2.3.3 FOLDER: PARAMETER

This folder contains parameter files (hgeo.par, hru.par, landuse.par, reach.par, soils.par). Do remember that these names should be the same in the model xml file.

2.2.3.4 FOLDERS: EXPLORER AND TMP

These two folders inside the workspace are used to dump temporary files generated while running the model.

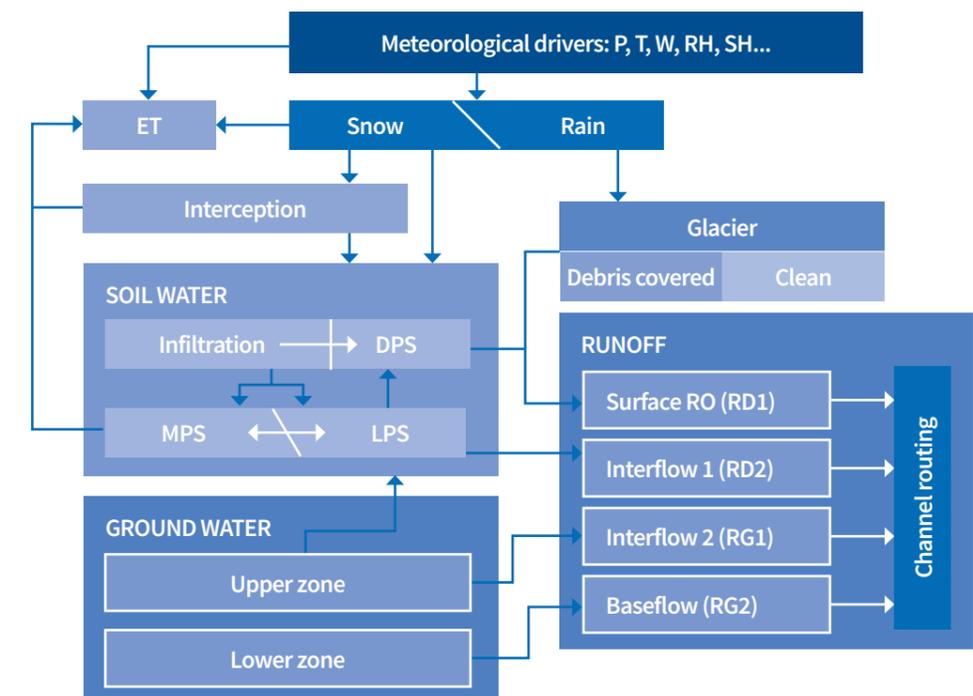
2.2.3.5 MODEL XML FILE

The workspace directory contains a model xml file. The model files can be read as *.xml or *.jam. The model .jam file contains the logical structure of the model framework and modules used in the model. It is organized in a systematic way, such that the output from one module is supplied as an input for the next one. For example, snowmelt (output from the snow module) is an input for the soil water module. This file also contains information about the display of different variables and outputs in the JAMS framework. The model xml can be viewed using the JAMS Builder to understand the different components of a specific model. Exercise 16 (see page 104) is a dedicated exercise to check how the precipitation variable is passed through different modules in the model.

2.2.4 Layout of the J2000 hydrological model

The application of modelling represents a river catchment's significant hydrological processes. The principal layout of the J2000 hydrological model is provided in Figure 4. The layout includes important hydrological dynamics, including the glacier module, which has been applied in the Himalayan region.

FIGURE 4 PRINCIPAL LAYOUT OF THE J2000 MODEL



Note: ET = evapotranspiration, P = precipitation, T = air temperature, W = wind speed, RH = relative humidity, SH = sunshine hours, LPS = large pore storage, MPS = middle pore storage, DPS = depression storage, RO = runoff

Adapted from Krause (2002) and Nepal (2014)

The JAMS/J2000 modelling system differentiates run-off among the four components according to their specific origin. The fast direct run-off (RD1), also known as surface run-off, is the component with the highest temporal dynamics. It consists of the run-off from impermeable areas and surface run-off resulting from saturation and infiltration. Likewise, the slow direct run-off component (RD2), also known as Interflow 1, corresponds to the lateral hypodermic run-off within the soil and this process reacts slightly more slowly than RD1.

Two additional components of base flow run-off are distinguished. The relatively fast baseflow run-off (RG1), also known as Interflow 2, simulates run-off from the upper part of an aquifer, which is more permeable than the lower zone of the aquifer due to weathering. The slow base flow run-off component (RG2), also known as base flow, refers to the flow within fractures of solid rocks or matrices in homogeneous, unconsolidated aquifers.

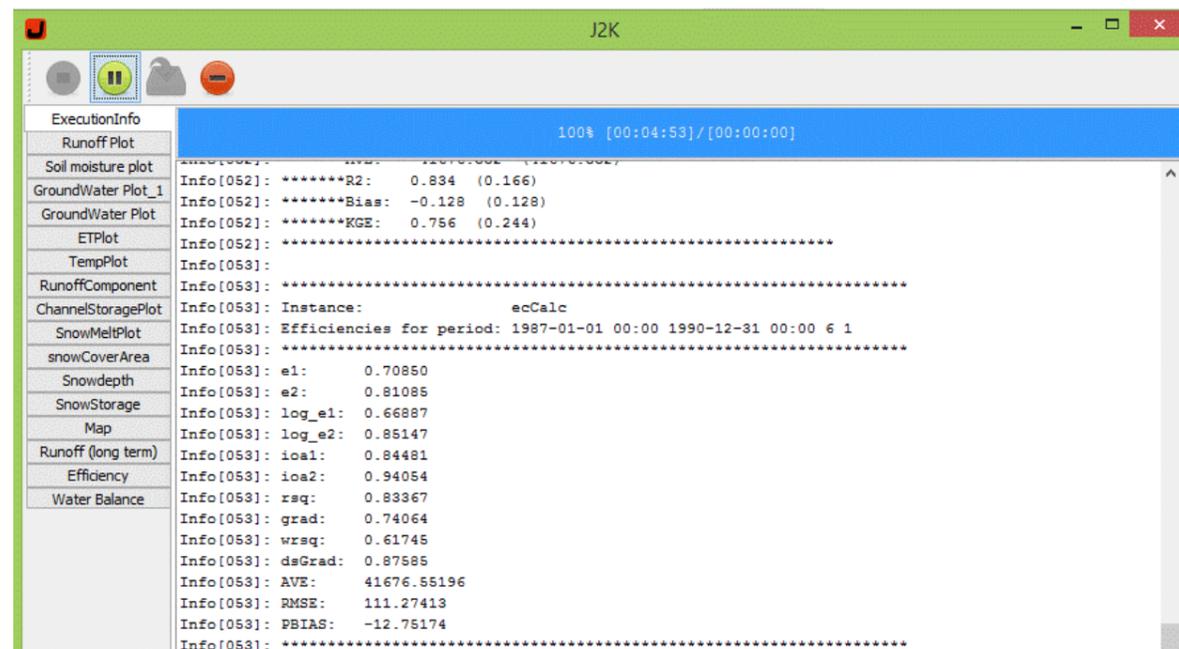
Detailed descriptions are presented in section 2.3.

2.2.5 Visualization of modelling results

Once the model is successfully run (Figure 5), The model's results and efficiency are provided in three ways:

- Graphical display
- Numerical output
- Efficiency measurement

FIGURE 5 DISPLAY OF THE EFFICIENCY CRITERIA AFTER THE MODEL RU



After the model run, a new window opens automatically, which includes varied, relevant information. 'ExecutionInfo' (Figure 5) contains information about the model's author, its version, and the model's efficiency (Figure 6) (or any error message during the model run). While the other tabs include the plots and graphs for the different outputs, such as run-off, evapotranspiration, groundwater, etc.

The model provides the graphical display output for many variables. The spatial distribution of certain output variables (such as precipitation and evapotranspiration) can be displayed at the end of the model run, including a 3D map (Figures 7 and 8). You can also visualize the long-term run-off and water balance components of your model by clicking on the 'Runoff (long term)' tab.

FIGURE 6 DISPLAY OF DIFFERENT EFFICIENCIES FROM THE MODEL

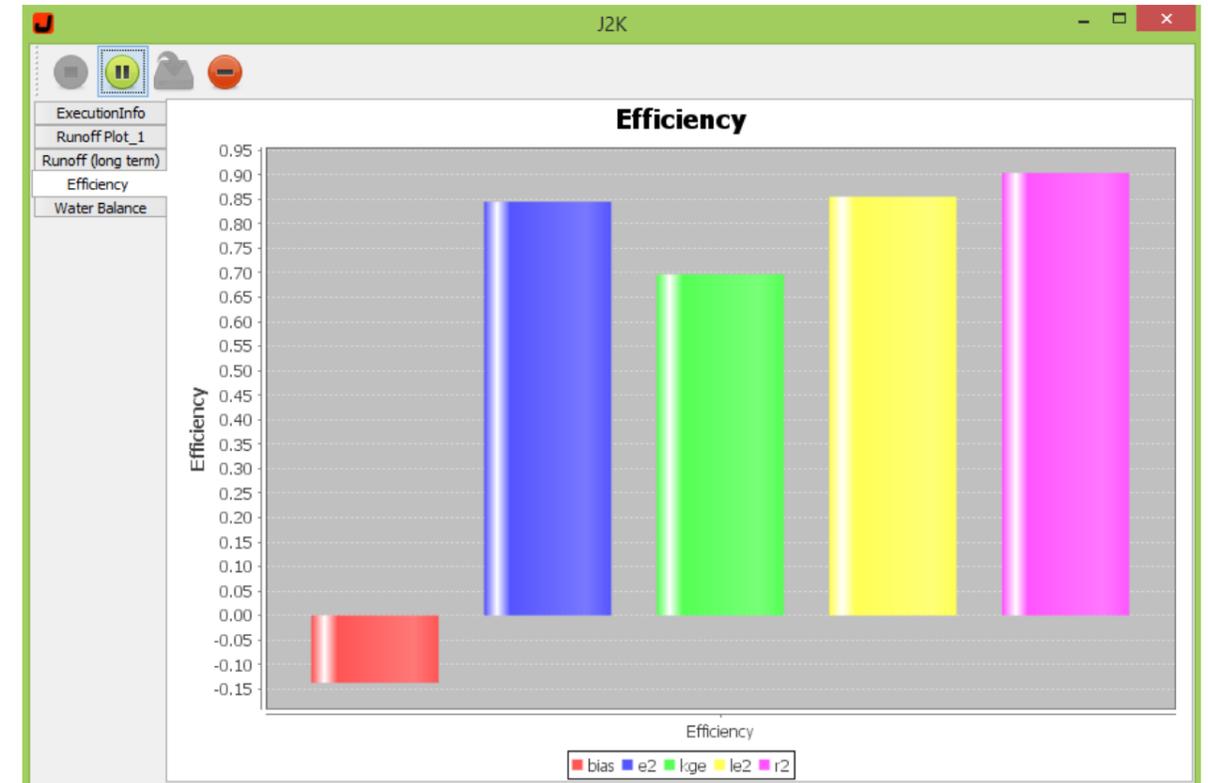


FIGURE 7 GRAPHICAL DISPLAY OF RUN-OFF PLOT WITH PRECIPITA

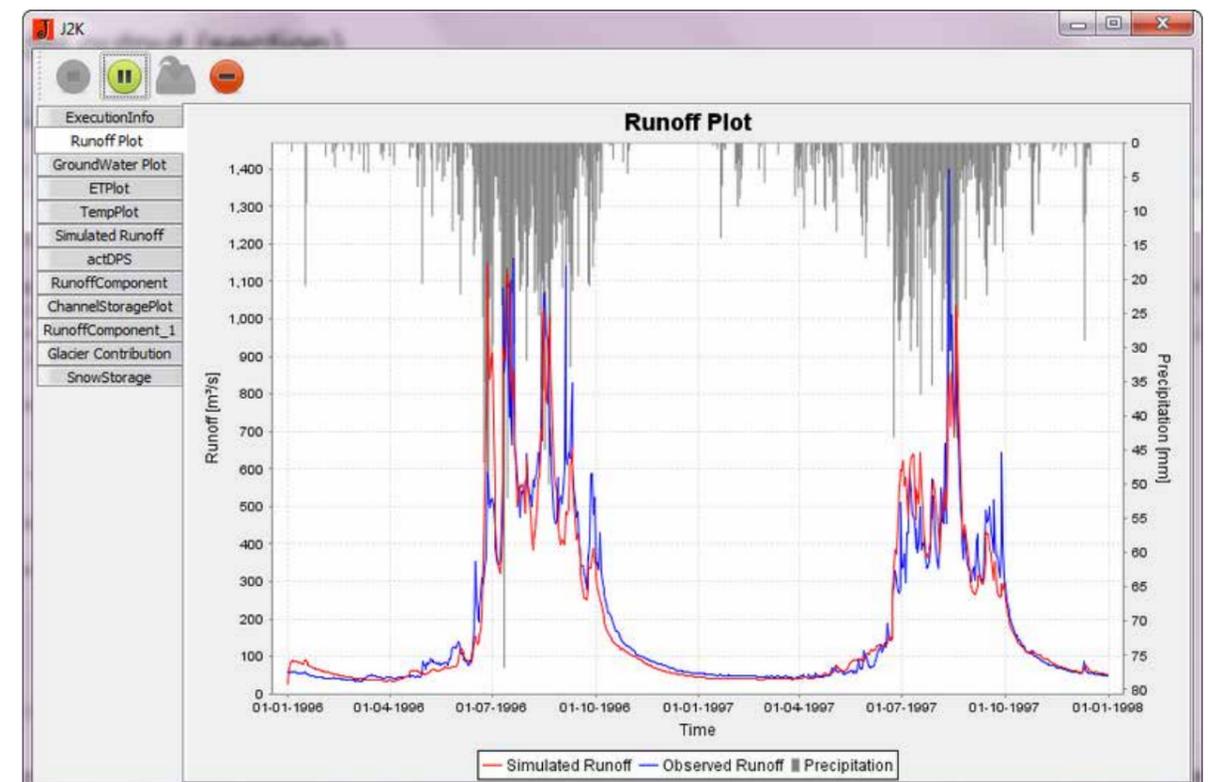
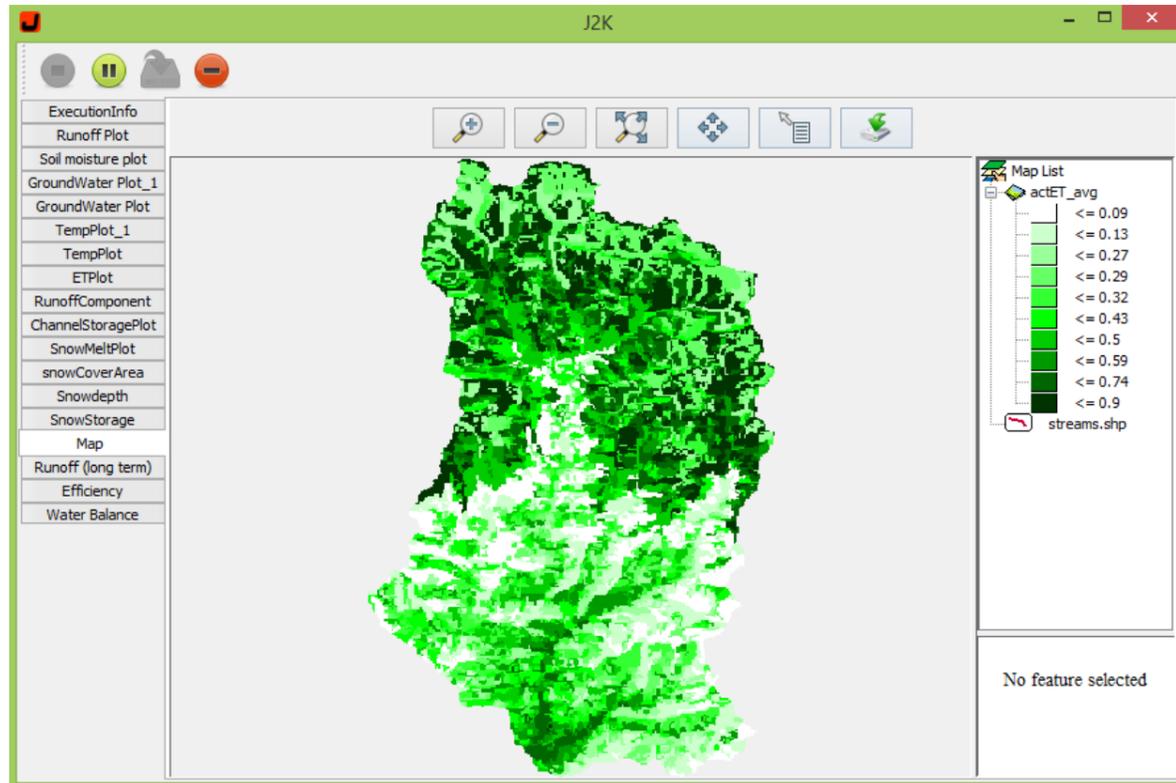


FIGURE 8 VISUALIZATION OF THE SPATIAL DISTRIBUTION OF ACTUAL EVAPOTRANSPIRATION VARIABLES IN THE BASIN MAP



The model efficiency results are also provided after the model run. Efficiencies such as Nash-Sutcliffe efficiency, log Nash Sutcliffe, or the coefficient of determination are used to show how the results of the model match with the observed time series, usually with the discharge from the catchment. The prioritized efficiency can differ, depending on the objective of the work. In the J2000 model, the different efficiency criteria are displayed in ExecutionInfo after each model run (Figures 5 and 6). The 13 criteria provided by the model are as follows:

- e1: Nash-Sutcliffe efficiency with power 1.0
- e2: Nash-Sutcliffe efficiency with power 2.0
- log_e1: logarithmic Nash-Sutcliffe efficiency with power 1.0
- log_e2: logarithmic Nash-Sutcliffe efficiency with power 2.0
- ioa1: Willmot's index of agreement with power 1.0
- ioa2: Willmot's index of agreement with power 2.0
- rsq: coefficient of determination (r^2)
- grad: gradient of linear regression
- wrsq: weighted rsq
- dsGrad: gradient of double sum regression
- AVE: absolute volume error (same as values)
- RMSE: root mean square error (same as values)
- PBIAS: percentage bias (unit: %)

The daily output from the model can be found in the output folder with the filename 'Timeloop.dat'. This file can be opened in any text editor (for instance, Notepad ++) or MS Excel. Exercise 6 shows the selected model output variables in Excel for further analysis.

2.2.6 Running the test dataset Dudh Koshi model

In this manual, a test dataset of the Dudh Koshi river basin has been used. This river basin's data was used as a part of PhD research for hydrological system analysis (Nepal 2012). This data is from virtual stations of the basin with regionalization, and was further processed with random error. The Dudhkoshi model is available at: http://jams.uni-jena.de/ilmswiki/index.php/File:J2000_DudhKoshi_Tutorial.zip. (Since April 2020, the j2k_dudh_koshi model has been available as a test dataset while installing the standard JAMS model. Please refer to Section 2.2.1).

The Dudh Koshi river basin is a sub-catchment of the Koshi river basin in Nepal, located in the Everest region. This dataset will help facilitate understanding of different aspects of the J2000 modelling system, and help users prepare their own datasets to run the model. In addition, for running the model in the glaciated basin, one needs to ensure that the 'J2K_Himalaya.jar' file available in the readme folder is copied to the components folder. This will enable the model to run the glacier melt process. (If you installed the JAMS software after 22 April 2020, you do not require the J2K_Himalaya.jar file. Please refer to Section 2.2.1).

You can visualize the new plots in the J2000 hydrological model by making some changes in the JAMS Builder. How to create a new plot through JAMS Builder is shown in Exercise 1 (page 62). Similarly, Exercise 2 helps in understanding detailed information about the input variables. For the ease of the user, Exercise 3 is dedicated to using the PivotTable, which can be an asset in the later exercises.

2.3 J2000 modules

This section describes the different modules within the J2000 hydrological model. The calibration parameters applicable to each module are also described, with a focus on how they influence streamflows. The important modules in the J2000 hydrological model are:

- Precipitation distribution module
- Regionalization of datasets
- Interception module
- Snow module
- Glacier module
- Soil module
- Groundwater module; and
- Routing module

2.3.1 Precipitation distribution module

In the J2000 modelling system, precipitation is first distributed between rain and snow, depending upon the air temperature. Two calibration parameters, Trans and Trs, are used. 'Trs' is the base temperature for snow and rain (global range: -5 to +5) and 'Trans' is a temperature range (the upper and lower boundaries) above and below the base temperature (global range: 0 to -5). In order to determine the amount of snow and rain, it is assumed that precipitation below a certain threshold temperature occurs entirely as snow, and precipitation exceeding a second, higher threshold temperature entirely as rain. In the range (Trans) between those threshold temperatures, mixed precipitation occurs, as snow or rain.

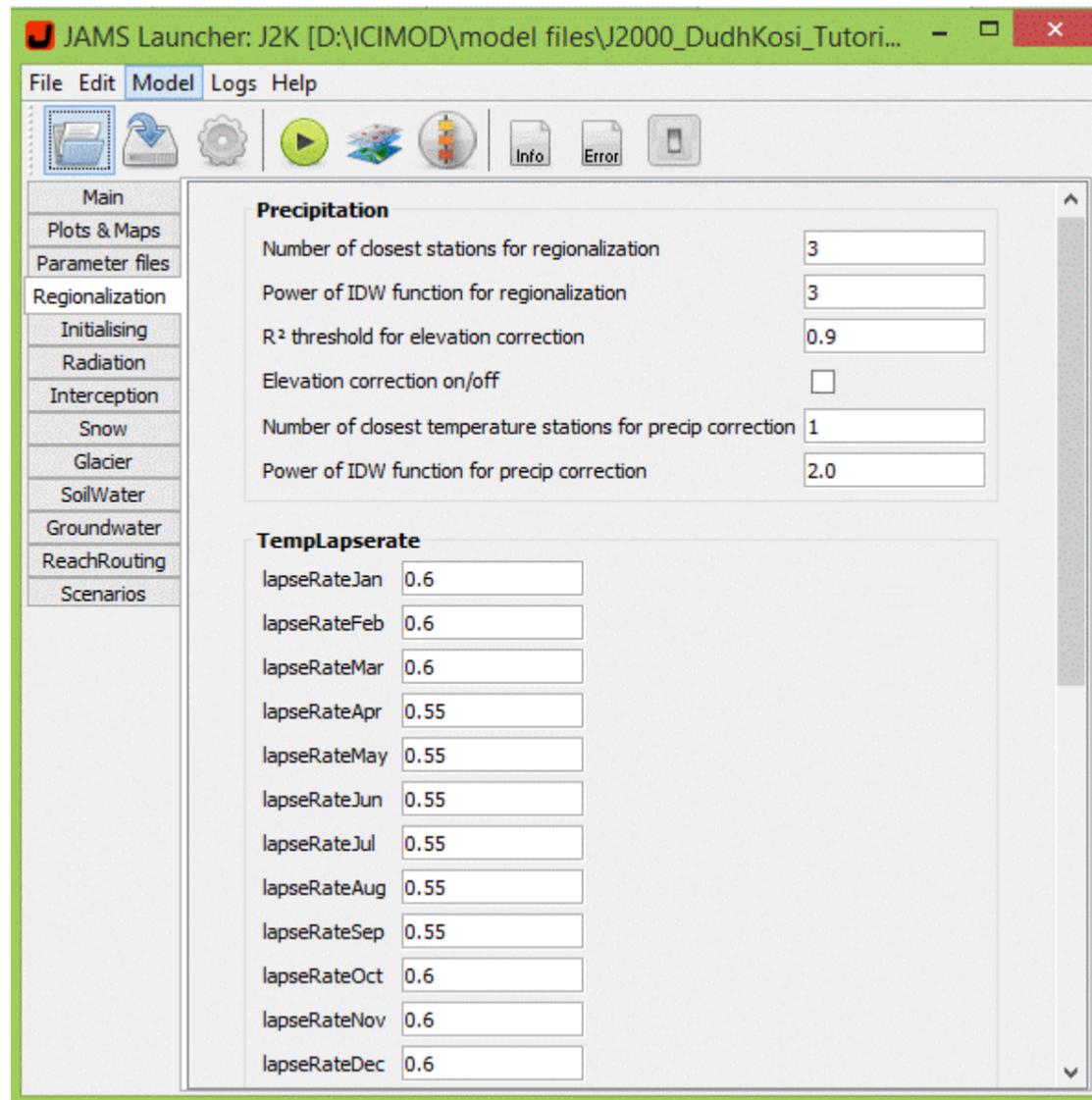
'Trs' values below zero (e.g. -2) will bring precipitation more in the form of 'rain' than 'snow' than if the value were above zero. Details of the module are provided at http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Precipitation_distribution_module

2.3.2 Regionalization of datasets

Regionalization in the J2000 model is carried out by a combination of linear regression and Inverse Distance Weighting (IDW), which consider the horizontal and vertical variability of climate and lapse rates. Figure 9 shows the calibration parameters for the lapse rate, which are displayed in the JAMS framework.

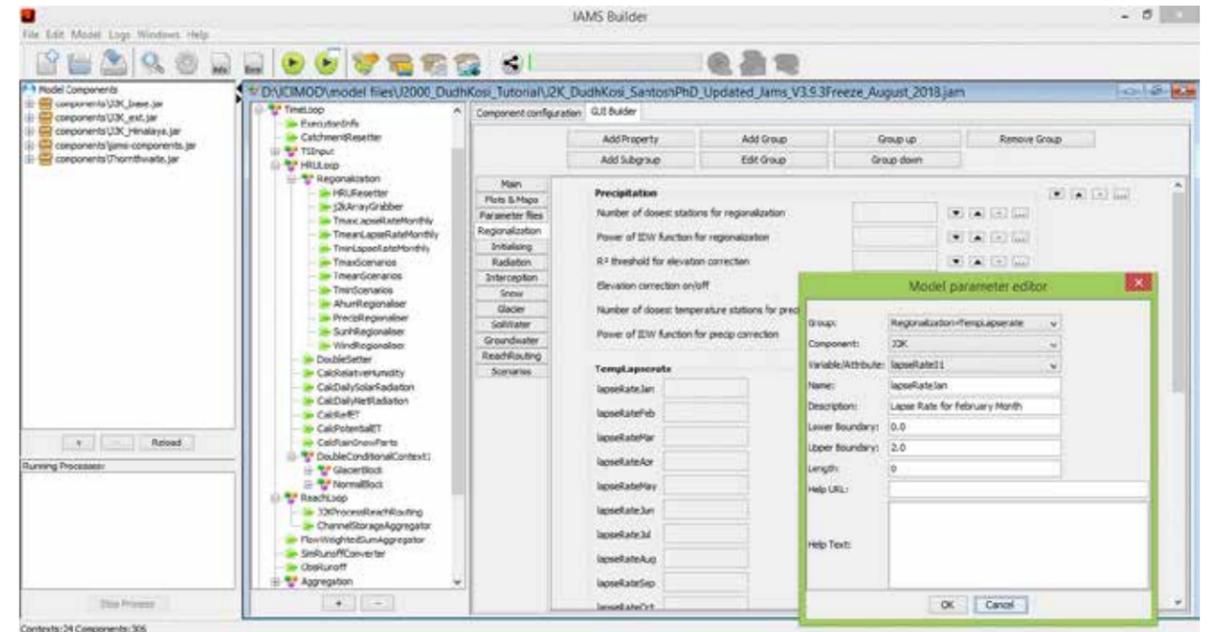
Figure 9 shows the parameters of the regionalization approach for the Dudh Koshi river basin. The values and ranges for the parameters can be changed from the JAMS Launcher.

FIGURE 9 REGIONALIZATION IN THE JAMS LAUNCHER



In the example in Figure 10, the temperature lapse rate has been shown, which is under the group 'Regionalization'. To manually edit the model components of the Regionalization, or any, module, the following steps are to be adopted. First, click on 'JAMS Builder' and choose the group 'Regionalization' and then click on 'Add properties'. A new window 'Model parameter editor' will appear, where the information of the model component can be changed.

FIGURE 10 JAMS LAUNCHER WITH THE REGIONALIZATION MODULE



For example, in 'Group', choose 'Regionalization>>TmaxLapseRate'. In the box next to Component, choose 'J2K'. In 'Variable/Attribute', choose 'lapseRate01'. The name and description of the parameter also have to be filled, along with its lower and upper boundary. One can choose the calibration parameter value in between the boundary range. One can also put extra information in the box 'Help Text' to provide detailed information about the parameter. When all the information has been filled in, clicking 'OK' will bring the parameter in the modelling framework. Likewise, in the next step, you can choose 'lapseRate02' for the second month of the year as shown in Figure 10.

Regionalization is a useful tool, it helps to distribute the information from the point data over the region based on the method or formula provided. The details are provided in the tutorial <http://jams.uni-jena.de/ilmswiki/index.php/Hydrological_Model_J2000#Calculation_of_Evapotranspiration>

All the meteorological input data needed might not be available in some catchments. Normally, temperature and precipitation data are commonly available. If there are only a few stations (less than three) for some parameters, the IDW does not work properly. In that case, the same input value is applied for the entire catchment. This approach would introduce a large amount of error/uncertainty for certain variables, such as temperature. In such cases, the regionalization approach based on a lapse rate is suggested. Likewise, if there is no other station data available, data regarding the sunshine hours and wind speed from one station can be assumed to suffice. In such cases, the same station value is applied for a whole catchment.

Data pertaining to the relative humidity, wind, and sunshine hours are not frequently available in some catchments, or parts of some catchments. These values are used to estimate evapotranspiration while using the Penman–Monteith approach. In case this data (pertaining to relative humidity, wind, and sunshine hours) is not available the Penman–Monteith approach cannot be used. Instead, a more empirical approach based on temperature—such as Hargreaves–Samani—can be used to calculate evapotranspiration.

A dedicated exercise on how to change the Penman–Monteith approach of calculating evapotranspiration to Hargreaves–Samani is shown in Exercise 4 (see page 73). The exercise that follows (Exercise 5) shows us how to adapt the results from these two approaches by using calibration parameters (page 77). Exercise 6 tells us how to calculate the long-term average of actual and potential evapotranspiration, and Exercise 7 helps us get insights into how the change in temperature will affect evapotranspiration.

2.3.3 Interception module

Interception is a process by which precipitation is stored in leaves and other open surfaces of vegetation. It is an important component of the hydrological cycle and can affect the water balance (components). Interception by the canopy and residue interception are considered losses to the system, as any rainfall intercepted by either of these components will subsequently be reduced by the evapotranspiration process.

The interception module uses a simple storage approach according to Dickinson (1984), which calculates a maximum interception storage capacity based on the Leaf Area Index (LAI) of the particular type of land cover. The model gets the LAI information of different seasons from the land-cover parameter file. The algorithm for maximum interception capacity (Intmax) is calculated according to the following formula:

$$\text{Intmax} = \alpha \cdot \text{LAI} \text{ [mm]}$$

where α is storage capacity per squared metre (m²) leaf area against the precipitation type [in millimetres/mm]. When the maximum storage is reached, the surplus is passed as throughfall to the soil module.

The calibration parameters (Table 2) of the interception module in the JAMS Launcher is provided in Figure 11:

TABLE 2 PARAMETERS OF THE INTERCEPTION MODULE

Parameters	Description	Global range	Dimension
α_{rain}	Storage capacity (m ²) of particular land cover for rain	0 to +5	(mm)
α_{snow}	Storage capacity (m ²) of particular land cover for snow	0 to +5	(mm)

Relevance in modelling:

- Having a high value for the parameters ('a_snow' and 'a_rain') will store more water on leaf surfaces. This leads to higher evapotranspiration and less water available for the soil module, and the opposite for a lower value.

Exercise 8 shows the effects on evapotranspiration by changing the value of the interception parameter (see page 82).

Further details regarding the module are described at < http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Interception_module >

2.3.4 Snow module

Precipitation in high-altitude areas, where the average temperature is below the threshold temperature, occurs as snow, mostly in the mountains. Snowpack forms from layers of snow that accumulate over time on the land surface. It stores water (in the form of snow) and gradually melts when the temperature increases. This water storage in snowpacks is crucial for communities downstream as they rely on these resources for drinking and irrigation purposes. However, in some contexts, the excessive melting of the snowpack can be the cause of or contribute to flooding.

The J2000 snow module is executed according to the method described in Knauf (1976), including some changes and extensions. The module estimates variables of the snowpack, such as snow depth, snow density and snow water equivalent, which can be used for the validation. The module mainly describes the phases of accumulation, melting, and subsidence of a snowpack.

The calibration parameters (Table 3) of the snow module in the JAMS Builder is provided in Figure 12. The snow cover can store liquid water in its pores until a certain critical density (critDens). This storage capability is lost nearly completely and irreversibly when a certain amount of liquid water in proportion to the total snow water equivalent is reached (typically, 40%). This is taken into account in the modelling exercise by calculating the maximum water content (WSmax) of the snow cover:

$$\text{WSmax} = \text{critDens} \cdot \text{snowDepth} \text{ [mm]}$$

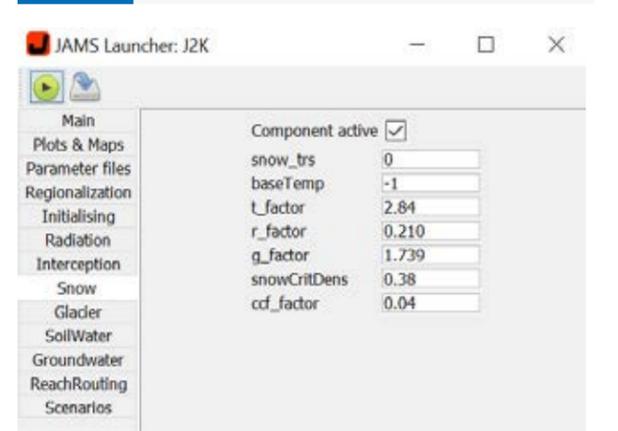
The critical density (critDens) values are provided by the user. The stored water in the snow cover that goes beyond this threshold gets drained.

TABLE 3 PARAMETERS OF THE SNOW MODULE

Parameters	Description	Global range	Dimension
snowCritDens	Critical density of snowpack	0 to 1	%
snowColdContent	Cold content of snowpack	0 to 1	NA
baseTemp	Threshold temperature for snow to melt	-5 to 5	(oC)
t_factor	Melt factor by sensible heat	0 to 5	(NA)
r_factor	Melt factor by liquid precipitation	0 to 5	(NA)
g_factor	Melt factor by soil heat flow	0 to 5	(NA)

Note: NA = Not Applicable

FIGURE 12 CALIBRATION PARAMETERS IN THE SNOW MODULE



Relevance in modelling:

- 'baseTemp' is a threshold temperature for snow melt. Melting only occurs if the air temperature is higher than baseTemp. Keeping its value high will mean more snow to store and less snowmelt, and the opposite for a lower value. This parameter is particularly important in case the basin has seasonal snow storage and snowmelt.
- 'snowCritDens' is an important calibration parameter as it allows liquid water from the snowpack to melt when the critical density is higher than this value. Keeping this parameter value low will mean that the liquid water from snowpack gets released faster (as the critical density of snow is reached earlier) with a lesser amount of snow and related depth. A higher value implies more time to reach critical density, which requires more fresh snow to occur.
- 'snowColdContent' helps cold content of a snowpack reach close to zero so that the melting process starts. A higher value will help the cold content of a snowpack reach zero faster than a lower value.
- 't_factor' is one of the most important and sensitive parameters for melt run-off from a snowpack. A higher value of the t-factor will produce higher snowmelt, and the opposite for a lower value. A higher t_factor value along with r_factor and g_factor will provide heat energy to melt the snowpack and produce run-off.

The detail of the snow module and its different parameter is explained in the following link <http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Snow_module>

Quantification of the snowmelt from the basin is done in Exercise 9. Through Exercise 10, the different sensitive parameters of the basin are analysed. Likewise, Exercise 12 shows how a temperature change in a warming scenario will affect the extent of snowmelt in the basin (see pages 85, 87, and 93).

2.3.5 Glacier module

A glacier is a persistent body of dense ice that constantly moves downslope under its own weight. Glaciers form from the accumulation of snow, where the accumulation exceeds its ablation (melting and sublimation). Snow turns into firn as it prevails for several years. Upon compaction due to its own weight, the firn eventually becomes glacier ice after it has reached a thickness of several tens of meters. This glacier ice typically persists for centuries. It deforms under its own weight and moves downslope due to gravity. No matter whether a glacier is advancing or retreating, glacier ice always moves from the upper part of the glacier towards its lower end, the snout. In the context of climate change, with increasing air temperatures, there is a high probability that glacial melt in general will accelerate.

The glacier module is treated as a separate module within J2000, in which the snow and ice melt (SIM) run-off are estimated and the output directly provided to a stream as overland flow (RD1). The approach suggested by Hock (1999) has been implemented in the J2000 model and further adapted for ice melt estimation (Nepal 2012).

The calibration parameters (Table 4) for the glacier module are provided in Figure 13. You can choose the method to calculate the glacier ice melt, by opting either for simple degree-day factor [1] or for enhanced degree-day factor [2] in 'melt formula'. The melt rate for glacier ice (iceMelt) (mm/day) is obtained by the following equation:

$$\text{iceMelt} = 1/n * \text{meltFactorIce} + \text{alphaIce} * \text{radiation} * (\text{meltTemp} - \text{tbase})$$

Where:

radiation = actual global radiation

meltFactIce = generalized melt factor for ice as a calibration parameter

alphaIce = melt coefficient for ice

n = time step (for a daily model, n=1)

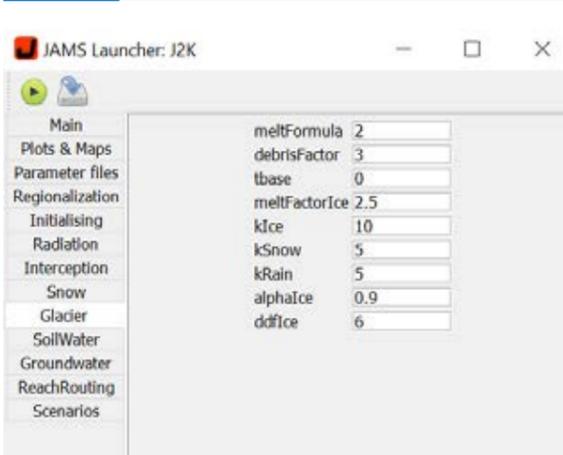
The iceMelt is further adapted with the slope and aspect of the particular HRU with glacier present in the landuse type.

TABLE 4 PARAMETERS OF THE GLACIER MODULE

Parameters	Description	Global range	Dimension
meltFactorIce	Melt factor for ice	0 to 5	(NA)
tbase	Threshold temperature for ice melt	-5 to 5	(°C)
debrisFactor	Debris cover factor for ice melt	0 to 10	(NA)
alphaIce	Radiation melt factor for ice melt	0 to 5	(NA)
klIce	Routing coefficient for glacier ice melt	0 to 50	(NA)
kSnow	Routing coefficient for snow melt	0 to 50	(NA)
kRain	Routing coefficient for rain run-off	0 to 50	(NA)

Note: NA = Not Applicable

FIGURE 13 CALIBRATION PARAMETERS IN THE GLACIER MODULE



Relevance in modelling:

- 'meltFactorIce' is one of the sensitive parameters of the glacier module. A higher value causes higher glacial ice melt and the opposite for a lower value.
- tbase is a threshold temperature for snow melt. Melting only occurs if the air temperature is higher than tbase. Keeping its value high will cause more snow to be stored and less snowmelt to occur. The opposite happens if you keep its value low.

- 'debrisFactor' affects the ice melt. A higher value (for example, 4) means ice melt is reduced by 40% in a debris-covered glacier.
- 'alphaIce' brings the radiation factor for snowmelt. A higher value will cause higher glacial ice melt.
- 'kIce', 'kSnow', and 'kRain' are routing coefficients. Lower values represent short residence times of the potential melt run-off. It is assumed that rain on the glacier's surface drains faster than snowmelt and ice melt.

Details of the glacial module, along with the algorithm, are available at < http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Glacier_module >

Exercise 9 is a dedicated exercise for the quantification of glacial melt from the basin. Exercise 11 is dedicated to show how the change in different factors such as 'alphaIce' and 'meltFactorIce' will affect the glacial run-off in the basin.

2.3.6 Soil water module

Soil types play an important role in the hydrological cycle, especially in water storage and distribution. Part of the rainfall is stored in the soil surface and is retained in the form of soil moisture. The capacity of the soil to hold water depends upon the soil texture (the proportion of sand, silt, and clay) and depth. Whereas loamy and clayey soil can hold more water, sandy soil can retain it for a lesser time. Similarly, the more the soil depth, the higher is the soil water volume. The extent of saturation of the soil profile also affects water flows over its surface which determines saturation and infiltration excess run-off.

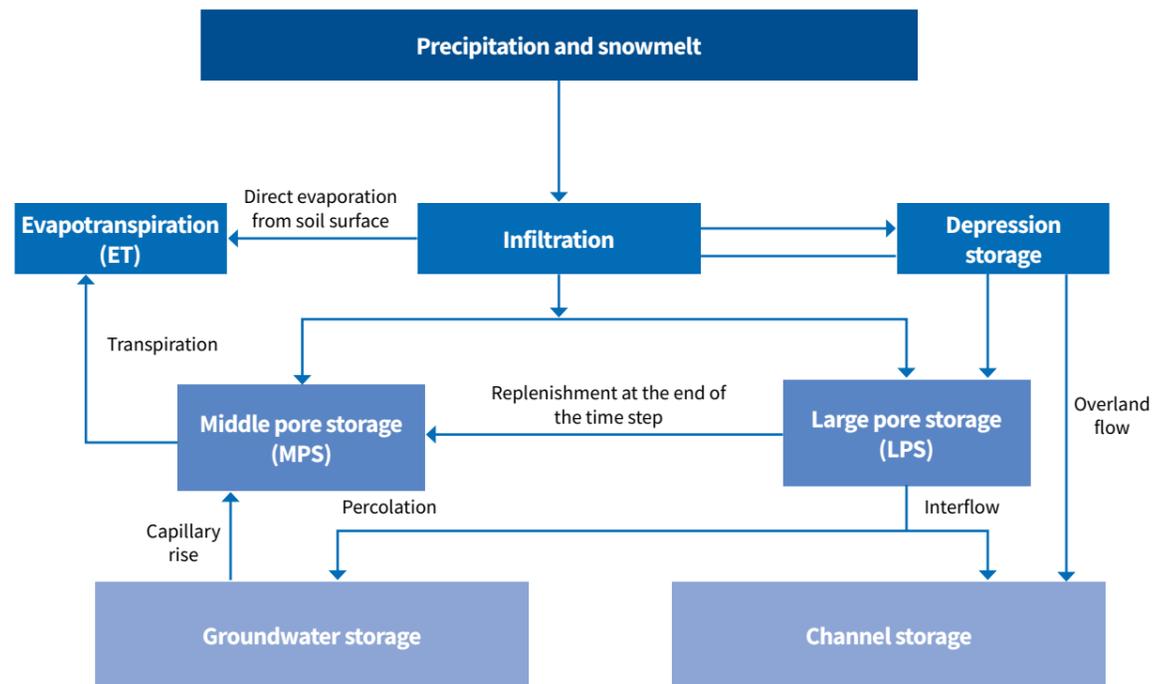
The soil details, its depth, water-holding capacity, and other important characteristics of the basin can be visualized through the parameters file in the model. Exercises 13 to 15 also provide some insights into the significance of soil parameters in the model. The role of infiltration is captured more in Exercise 13, whereas the significance of the recession coefficient for the overland flow and interflow is shown in Exercise 14 (see pages 96 and 99).

Similarly, the vegetative cover influences hydrological processes in many ways. First, evapotranspiration and infiltration processes are influenced by the presence of vegetation (grass, forests, and rangeland) and by root depth. Exercises 4 to 7 of this manual help in understanding how evapotranspiration is affected by different factors. Exercise 4 demonstrates the applicability of the J2000 hydrological model to calculate evapotranspiration, using the two different equations of evapotranspiration. Exercise 5 shows how one can calculate the long-term average evapotranspiration rate of an area. Exercise 6 deals with how the change in temperature will affect the evapotranspiration rate of a basin. Also, part of the rainfall is intercepted by the leaves and vegetative surface. The intercepted water is depleted by evaporation. Exercise 8 is dedicated to reflect how the change in interception will change the evapotranspiration value.

The soil module is the most complex part of the J2000 hydrological model, which reflects the central role of the soil zone as a regulation and distribution system. The inputs for the soil module are snowmelt and precipitation in the form of rain. Middle pore storage (MPS) and large pore storage (LPS) represent the water-holding capacity of the soil. The water in the MPS represents the field capacity, in which water is held against the force of gravity but can be subtracted by an active tension, for example, plant transpiration. The inputs to the soil module are first used to fill the MPS and LPS, which determine the current soil moisture.

Figure 14 shows that infiltration storage, which contains net precipitation and water from snowmelt, precedes soil storage. From infiltration storage, the water is distributed to middle and large soil storage, and the remaining water is cached in the depression storage in case the maximum infiltration capacity of the corresponding soil is exceeded, or the large pore storage saturated. Emptying the depression storage is done by evaporation, the generation of surface run-off, and/or seepage at a later point in time. The middle pore storage is emptied by evapotranspiration, and the large pore storage by generating interflow or by groundwater recharge. In addition, at the end of the time step, a certain amount of water stored in large pores can be transferred to the middle pore storage. The middle pore storage can, in addition to this water and from infiltration, receive water from the saturated zone due to capillary motion.

FIGURE 14 HYDROLOGICAL PROCESSES WITHIN THE SOIL WATER ZONE



Source: Krause, 2002

The calibration parameters are presented in Figure 15 while Table 5 contains descriptions of the same. ‘SoilDistMPSLPS’ and ‘soilDiffMPSLPS’ are mainly responsible for the distribution and diffusion of water between the MPS and LPS. ‘soilOutLPS’ influences the Interflow 2 (RD2) component. ‘soilLatVertLPS’ distributes the inflow (after infiltration) between RD2 (interflow 1) and percolation. ‘soilMaxPerc’ controls the percolation rate to the groundwater per time step. ‘soilConcRD1’ and ‘soilConcRD2’ are recession coefficients for overland flow (RD1) and Interflow 1 (RD2); the value represents the retention time (per time step) for overland flow. The ‘soilConcRD1flood’ parameter replicates the run-off behaviour, especially during the period of severe flooding in the monsoon-dominated Himalayan region. This parameter is only activated when the input for overland flow crosses the parameter ‘soilConcRD1floodthreshold’. In principle, the value of ‘soilConcRD1flood’ should be lower than ‘soilConcRD1’ as the retention time of the overland flow is smaller during the period of high flooding.

FIGURE 15 CALIBRATION PARAMETERS IN THE SOIL WATER MODULE

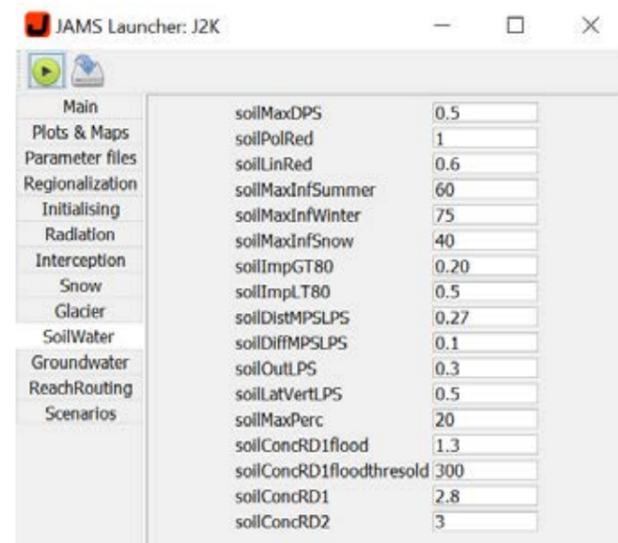


TABLE 5 PARAMETERS OF THE SOIL WATER MODULE

Parameters	Description	Global range	Dimension
soilMaxDPS	Maximum depression storage	0 to 10	(mm)
soilLinRed	Linear reduction coefficient for AET	-5 to 5	
soilMaxInfSummer	Maximum infiltration in summer	0 to 200	(mm)
soilMaxInfWinter	Maximum infiltration in winter	0 to 200	(mm)
soilMaxInfSnow	Maximum infiltration in snow-covered areas	0 to 200	(mm)
soilImpGT80	Infiltration for areas greater than 80% sealing	0 to 1	(NA)
soilImpLT80	Infiltration for areas lesser than 80% sealing	0 to 1	(NA)
soilDistMPSLPS	MPS–LPS distribution coefficient	0 to 10	(NA)
soilDiffMPSLPS	MPS–LPS diffusion coefficient	0 to 10	(NA)
soilOutLPS	Outflow coefficient for LPS	0 to 10	(NA)
soilLatVertLPS	Lateral vertical distribution coefficient	0 to 10	
soilMaxPerc	Maximum percolation rate to groundwater	0 to 100	(mm)
soilConcRD1flood	Recession coefficient for flood event	0 to 10	(NA)
soilConcRD1floodthreshold	Threshold value for soilConcRD1flood	0 to 500	(NA)
soilConcRD1	Recession coefficient for overland flow	0 to 10	(NA)
soilConcRD2	Recession coefficient for Interflow	0 to 10	(NA)

Note: NA = Not Applicable

Relevance for modelling:

- ‘soilLinRed’ reduces the rate of evapotranspiration. A lower value will increase the actual evapotranspiration (that is, the actET rate will be slow).
- ‘soilMaxInfSummer’, ‘soilMaxInfWinter’, and ‘soilMaxInfSnow’ influence the maximum infiltration rate at which rain and snowmelt enter the saturated (soil water) and unsaturated (groundwater) zones. Lower values for these parameters imply that only a part of the rainfall and snowmelt is allowed to enter the unsaturated zone (for instance, a value of 20 means that only 20 mm of rainfall and snowmelt is allowed to go through the soil water module per unit of time step). In such cases, the overland flows would be higher as most of the input drains as surface run-off. It is usually assumed that the ‘soilMaxInfSummer’ is slightly lower than ‘soilMaxInfWinter’ because the soil is more saturated during the rainy/summer period. ‘soilMaxInfSnow’ is considered the lowest among the three because of the frozen soil conditions in an environment in which snowfall occurs.
- ‘soilMaxPerc’ controls the percolation rate to the groundwater per time step. A higher value, for example, 20, indicates that a maximum equivalent of 20 mm of water is allowed to enter the groundwater. The higher value will increase the groundwater contribution (RG1 and RG2) and at the same time decrease the RD2 component at a higher magnitude. This also decreases the RD1, but to a lesser extent.
- ‘soilConcRD1’ and ‘soilConcRD2’ are recession coefficients for overland flow (RD1) and Interflow 1 (RD2) and are among the sensitive parameters in the module. The value represents the retention time (per time step) for overland flows. A higher value indicates that the retention period is high and therefore, less water flows as overland flows. In principle, the retention period for RD1 should be less than that for RD2.

Further details of the module including its algorithm are provided in the link < http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Soil_water_module >

2.3.7 Groundwater module

The model structure of the groundwater module in J2000 allows the presentation of the groundwater run-off of all geological formations existing in the catchment area by considering their storage and run-off behaviour. The geological units are subdivided into the upper groundwater storage (RG1)—with weathered, loose material with high permeability and a short retention time—and the lower groundwater storage (RG2) with fissures and ravines of the bedrock with low permeability and a relatively long retention time. Correspondingly, two basic

run-off components are generated, a fast one from the upper groundwater storage and a slow one from the lower groundwater storage.

The groundwater module (Figure 16) receives inputs from unsaturated soil zones in a two-storage compartment of a groundwater zone, namely the upper groundwater zone (RG1) and the lower groundwater zone (RG2). The input is then between these two zones in which its distribution is carried out by the calibration parameter 'gwRG1RG2dist'. The water discharge from the upper and lower storage areas (RG1 and RG2) is carried out according to the current storage amount in the form of a linear function, using the storage retention coefficient for two storages, 'gwRG1Fact' and 'gwRG2Fact'. There is also a possibility that the water from groundwater is transferred to the soil water zone through capillary action with the parameter 'gwCapRise'. The details are explained further in Table 6.

The storage retention coefficients (kRG1 and kRG2), which are considered as the amount of time water rests in the specific storage, are a factor of the current storage volume (actRG1 and actRG2) used for the calculation of the groundwater outflow (outRG1 and outRG2) as follows:

$$outRG1 = \frac{1}{gwRG1Fact \cdot kRG1} \cdot actRG1 \text{ mm}$$

$$outRG2 = \frac{1}{gwRG2Fact \cdot kRG2} \cdot actRG2 \text{ mm}$$

Relevance in modelling:

- 'gwRG1RG2dist' distributes input water to RG1 and RG2. A higher value for this parameter increases the proportion of input water to the RG2 zone.
- 'gwRG1Fact' and 'gwRG2Fact' influence the outflow from the RG1 and RG2 storage units. The parameter values represent the retention time in these units. A higher value will lead to less outflow and more water remains in them.
- 'gwCapRise' influences the distribution of water between soil water and the groundwater module. A higher value implies a higher flow in the volume of water from the groundwater to the soil water zone.

Details about the module are available at < http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Groundwater_module >

2.3.8 Routing module

The routing inside the channel network is simulated by connecting each entity to the channel storages and receiving water from the stream channel. This is done by using the commonly applied kinematic wave approach and the calculation of velocity according to Manning and Strickler (Krause 2002).

The J2000 hydrological model has two routing components. The lateral routing serves to simulate lateral flow processes in the catchment area from one model entity (HRU) to the next until the water finally reaches to a reach. The routing parameters are represented in Figure 17, while Table 7 contains descriptions of the same.

FIGURE 16 GROUNDWATER-RELATED PARAMETERS

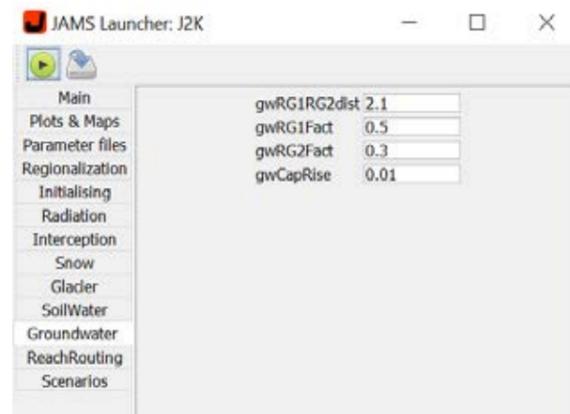


TABLE 6 PARAMETERS OF THE GROUNDWATER MODULE

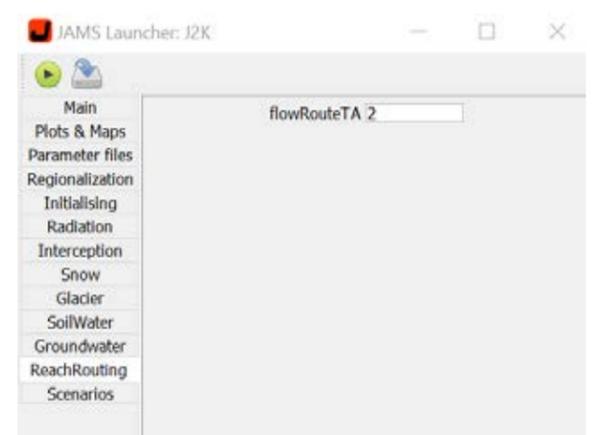
Parameters	Description	Global range	Dimension
gwRG1RG2dist	RG1-RG2 distribution coefficient	0 to 10	(NA)
gwRG1Fact	Adaptation for RG1 flow	0 to 10	(NA)
gwRG2Fact	Adaptation for RG2 flow	0 to 10	(NA)
gwCapRise	Capillary rise coefficient	0 to 10	(NA)

Note: NA = Not Applicable

TABLE 7 PARAMETERS OF THE ROUTING MODULE

Parameters	Description	Global range	Dimension
flowRouteTA	Calibration parameter for adapting velocity of flow waves	0 to 100	(NA)

FIGURE 17 REACH ROUTING-RELATED PARAMETERS



Relevance in modelling:

- 'flowRouteTA' influences the run time of run-off waves in the stream channel. A higher value increases the velocity of run-off waves and more water flows from the channel.

Further details regarding the module are available at < http://jams.uni-jena.de/ilmswiki/index.php/J2000_modules_in_detail#Routing_module >

Exercise 15 observes the effect of the flood routing coefficient (page 101).

2.4 Application of the J2000 model in the Hindu Kush Himalayan region and beyond

JAMS-based models have successfully been applied to better understand hydrological dynamics, and simulate hydrological, nutrient-transport, and erosion processes in river basins around the world. The main idea behind the J2000 model is to bridge the gaps between models developed for small catchments and those for large-scale basins (Krause 2002). It was initially built to reproduce the hydrological dynamics of large river basins in Germany.

The model has been applied to understand the water balance assessment of Java Island, Indonesia (Julian, Fink, Fischer, Krause, & Flügel 2013); the Koshi river basin (Nepal 2012; Nepal, 2014, the Marshyangdi River basin (Tuitui 2017), and the Karnali River basin, Nepal (Khatiwada et al. 2016); and Pendjari river basin, West Africa (Ahouansou, Agodzo, Kralisch, Sintondji, & Fürst 2015). The J2000 model has been applied in the Qugaqie glaciated catchment of the central Tibetan Plateau, to understand hypothetical climate change scenarios in order to grasp run-off and glacier melt processes. (Gao, Kang, Krause, Cuo, & Nepal 2012). The model has also been successful in reflecting water balance for different types of glacial coverage in the Hunza basin (Shrestha & Nepal 2019). Likewise, the model was applied in the Upper Gera watershed located in Thuringia, Germany (Fink, Krause, Kralisch, Bende-Michl, & Flügel 2007) to capture its semi-distributive nature. Similarly, in order to assess the impacts of climatic and land use changes, the model was applied in the Vu Gia-Thu Bon watershed catchment located in central Vietnam (Fink, Fischer, Führer, Firoz, & Laux 2013).

Comparison of the J2000 and ISBA hydrological models for surface flow at a local scale in the Everest region shows that soil processes and snowpack are the main drivers behind differences in the results generated by the two models (Eeckman et al. 2019). The J2000 model has also been applied in ungauged catchments of the Himalayan region to assess the spatial transferability of the model (Nepal et al. 2017). A study by Fink et al. (2007) shows that J2000 serves as an adequate tool to support catchment-related work that has to be done within the scope of the EU Water Framework Directive – integrated river basin management for Europe. The model has been successfully applied in different locations of the globe to simulate the water balance, assess the impacts of climatic and land use changes (Fink et al. 2013; Julian et al. 2013; Nepal et al. 2014) and also understand temperature incremental scenarios (Gao et al. 2012). The model has been applied together and independently with other models such as SWAT, GR4J, etc to understand its strengths and weaknesses, and the results show its better performance. It produced results better than those of the SWAT model in Fink et al. (2007) and Nepal et al. (2017).



PART II

Applying the J2000 model in the Panjshir catchment

The Panjshir catchment is one of the dynamic catchments in the HKH where much of the hydrological cycle is dominated by snow.

Winter precipitation falls in the form of snow in the catchment as the temperature dips below zero in the basin. The accumulated snow melts during the summer.

This section of the manual focuses on the application of the J2000 model in the Panjshir catchment. Its contents are systematically arranged so that the user can follow it to set up and understand the hydrological processes of the new basin.

3.1 Characteristics of the Panjshir catchment and basin

Panjshir River is one of the tributaries of the Kabul River. It is one of the dynamic catchments in the HKH where much of the hydrological cycle is dominated by snow. Winter precipitation falls in the form of snow in the catchment as the temperature dips below zero in the basin. The accumulated snow melts during the summer and generates the peaks in the hydrograph. The climatology of the Panjshir catchment is shown in Figure 18. It reflects the precipitation, discharge, and temperature of the basin. The figure shows that most of the precipitation occurs during February, March, and April and discharge is heavier during May, June, and July. The maximum temperature peaks at 20°C during July and dips to -20°C during January.

FIGURE 18 CLIMATOLOGY OF THE PANJSHIR CATCHMENT

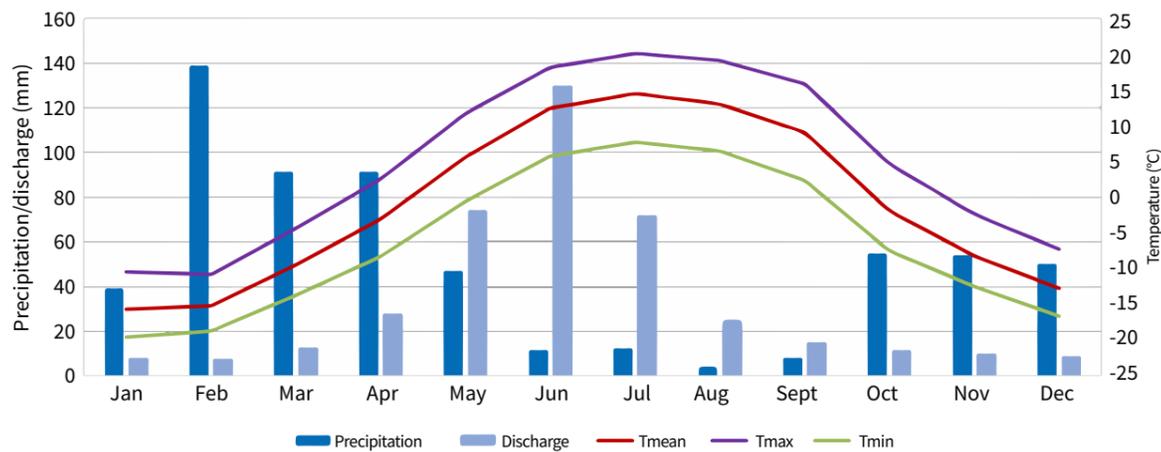
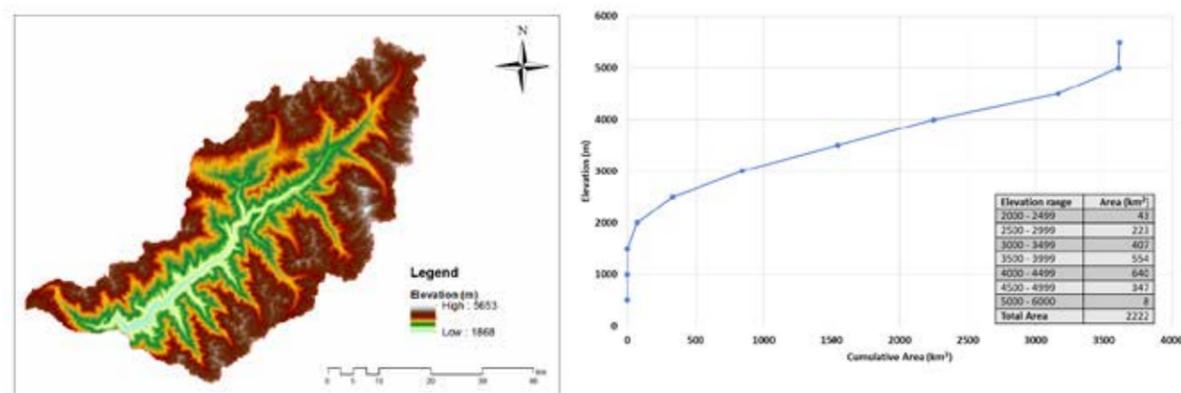


Figure 19 presents the digital elevation model of the area, which ranges from 1,868 metres (m) to 5,653 m. Similarly, the hypsometric curve shows the elevation with respect to the cumulative area distribution. It shows us that the most area in the catchment is at an elevation range of 3500 m–4500 m.

FIGURE 19 DIGITAL ELEVATION OF THE PANJSHIR CATCHMENT (LEFT) AND ITS HYPSEMTRY CURVE (RIGHT)



3.2 Setting up the J2000 model

The input data required to run the J2000 hydrological model has to be provided in a specific folder considered as a 'workspace directory'. This directory also contains the parameter files and model output files.

To set it up in the new basin, the requirements for running the J2000 hydrological model are discussed below.

3.2.1 Preparation of spatial parameters files

The spatial parameter files, also known as model parameter files, are prepared and quantified inside the GIS environment.

3.2.1.1 LAND COVER PARAMETER FILE

The land use parameter file (landuse.par) (Figure 20) includes information (Table 8) about the land use and land cover of a catchment which control the different aspects of hydrology. This information is derived from the literature of spatial information or can be estimated from remote sensing images.

FIGURE 20 LAND USE PARAMETER FILE OF THE MODEL

TABLE 8 DETAILED INFORMATION REQUIRED FOR THE LAND COVER PARAMETER FILE

Parameter	Description
LID	Land use ID
albedo	Albedo in %
RSC0_1 to RSC0_12	Minimum surface resistance for water-saturated soil in January to December
LAI_d1 to LAI_d4	Leaf area index (LAI) at the beginning of the vegetation period (Jan-Mar) to end of the vegetation period (Oct-Dec)
effHeight_d1 to effHeight_d4	Effective vegetation height at the beginning of the vegetation period (Jan-Mar) to the end of the vegetation period (Oct-Dec)
rootDepth	Root depth
sealedGrade	Sealed grade of the surface

The detailed land use parameter file and its information can be accessed at < http://jams.uni-jena.de/ilmswiki/index.php/Land_use_parameter >

3.2.1.2 SOIL PARAMETER FILE

The soil parameter file (soils.par) (Figure 21) is an important parameter file that helps produce a comprehensive characterization of soil types at different horizons including their water-holding capacity (Table 9).

The soil parameter file looks as follows:

FIGURE 21 SOIL PARAMETER FILE OF THE MODEL

#	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	# soil parameters for the Panjshir basin																						
2	SID	soil depth	kf_min	depth_min	kf_max	cap_rise	aircap	fc_sum	fc_1	fc_2	fc_3	fc_4	fc_5	fc_6	fc_7	fc_8	fc_9	fc_10	fc_11	fc_12	fc_13	fc_14	
3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	-9999	mm	-9999	-9999	-9999	0/1	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
5	n/a	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
6	16 LP	100	1	0.5	2	0	49.02	297.28	28.08	28.08	28.08	30.17	30.17	30.17	30.17	30.17	30.17	30.17	30.17	30.17	30.17	30.17	0
7	19 HV	100	1	0.5	2	0	56.93	264.83	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	28.84	0
8	9 FL	100	1	0.5	2	0	56.06	282.3	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	28.53	0
9	22 GQ	100	1	0.5	2	0	78.51	318.43	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	0

TABLE 9 DETAILED INFORMATION REQUIRED FOR THE SOIL PARAMETER FILE

Parameter	Description
SID	Soil type ID
depth	Soil depth
kf_min	Minimum permeability coefficient
depth_min	Depth of the horizon above the horizon with the smallest permeability coefficient
kf_max	Maximum permeability coefficient
cap_rise	Boolean variable, that allows (1) or restricts (0) capillary ascension
aircap	Air capacity (equivalent to large pore storage)
fc_sum	Usable field capacity (equivalent to middle pore storage)
fc_1 ...22	Usable field capacity per decimetre of profile depth

Further details concerning the method of deriving the soil parameter file, including all the input variables, are provided at < http://jams.uni-jena.de/filmwiki/index.php/Soil_parameterization

3.2.1.3 HYDROGEOLOGICAL PARAMETER FILE

The hydrogeological parameter file (hgeo.par) (Figure 22) mainly includes maximum storage capacity and the storage coefficient of both the upper and lower groundwater reservoirs. The required information for this parameter file is provided in Table 10.

FIGURE 22 HYDROGEOLOGICAL FILE OF THE MODEL

#hgeo.par	RG1_max	RG2_max	RG1_k	RG2_k	RG1_active
GID	mm	mm	d	d	n/a
1	0	0	0	0	0
-9999	-9999	-9999	-9999	-9999	1
n/a	mm	mm	d	d	n/a
1	0	0	0	0	0
2	200	825	50	572	1
3	300	1050	50	677	1

TABLE 10 DETAILED DESCRIPTION OF THE HYDROGEOLOGICAL PARAMETER FILE

Parameter	Description
GID	Hydrogeology ID
RG1_max	Maximum storage capacity of the upper groundwater reservoir
RG2_max	Maximum storage capacity of the lower groundwater reservoir
RG1_k	Storage coefficient of the upper groundwater reservoir
RG2_k	Storage coefficient of the lower groundwater reservoir

The storage capacity of the upper (RG1) and lower (RG2) groundwater reservoirs can be estimated by analysing geological information of the area. This capacity is normally controlled by the nature of geological formation, rock types, the origins and nature of rocks, and permeability. These values are expressed as maximum storage volume in mm/day of each storage type. The storage coefficient values (RG1_k and RG2_k) are used as a general recession coefficient of these two storages. These are expressed as retention time (in number of days) in the particular storage. The recession is further controlled by a flexible calibration parameter within the model.

More details about the hydrogeological parameter file are available at < http://jams.uni-jena.de/filmwiki/index.php/Hydrogeo_parameter >

3.2.1.4 HRUS AND REACH PARAMETER FILES

Hydrological Response Units (HRUs) are the modelling entities for the J2000 hydrological model. HRUs are “spatial model entities which are distributed, heterogeneous structured entities having a common land use, soil, and geology controlling their hydrological dynamics” (Flügel 1995). Areas that display similar properties, such as topography (slope, aspects), land use, soil, and geology, and behave similarly in their hydrological response, are merged to develop an HRU. Multiple HRUs are topologically connected for lateral routing – from one HRU to another, and are further connected to a nearby reach for reach routing (Figure 23).

During the delineation of HRUs, the required input data pertains to:

- Digital Elevation Model (DEM)
- Soil
- Land use; and
- Hydrogeology

This input data has to be in the raster format (*.tiff data format). The resolution of the dataset mainly controls the number of HRUs to be formed without losing the heterogeneity of a catchment. Therefore, the resolution of input data depends on the catchment to be modelled. For example, if the catchment is small (for example, 1,000 km²), a resolution between 30–90 m is suitable depending on the resolution of the available dataset. Similarly, for a mesoscale catchment (for example, 4,000 km²), a resolution between 250–500 m is suitable. In addition, a catchment with a flat topography, that is, with a low gradient, needs fine resolution data to characterise the features of a catchment.

HRUs can be delineated via HRUweb, online (< <http://intecral.uni-jena.de/hruweb-qs/> >). The HRUweb is a web-based tool implemented in Python. It calculates HRUs using open-source GRASS-GIS algorithms. After every processing step, the results are provided as a raster or vector file, which are all compatible with established GIS formats.

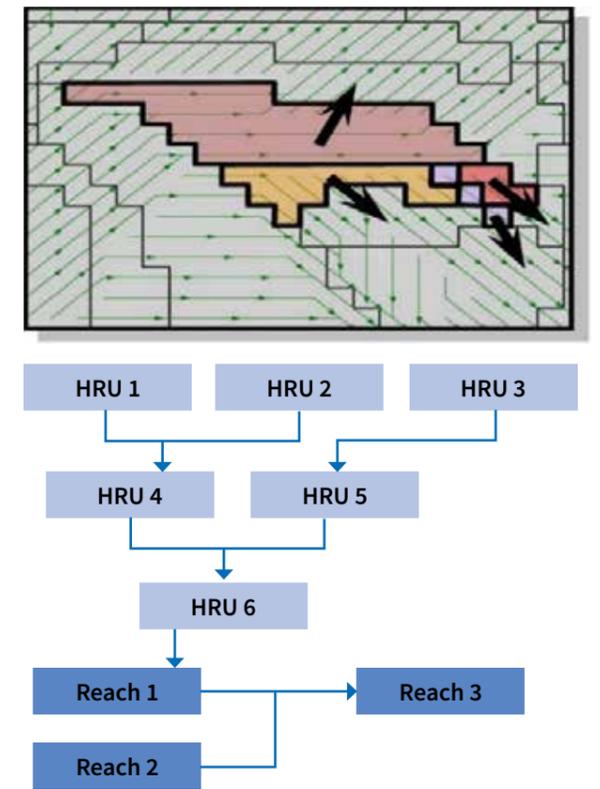
The input data and its format for the preparation of HRUs are explained in Table 11. The following steps are to be applied for the preparation of HRUs:

[The generic process of deriving HRUs is provided in http://jams.uni-jena.de/filmwiki/index.php/WebHRU_Tutorial. The steps below are more specific to the Panjshir catchment.]

TABLE 11 INPUT DATA AND ITS FORMAT FOR THE PREPARATION OF HRUS

Input data	Description	Format	Remarks
DEM	Raster of Digital Elevation Model	Tiff (.tif) or .zip-file	Mandatory
Gauges	Layer of gauging stations	.zip-file	Mandatory
Land use	Raster of land use map	Tiff (.tif) or .zip-file	Optional
Soil	Raster of soil map	Tiff (.tif) or .zip-file	Optional
Geology	Raster of geology map	Tiff (.tif) or .zip-file	Optional

FIGURE 23 SCHEMATIC DIAGRAM OF THE HRU AND REACH CONNECTIONS

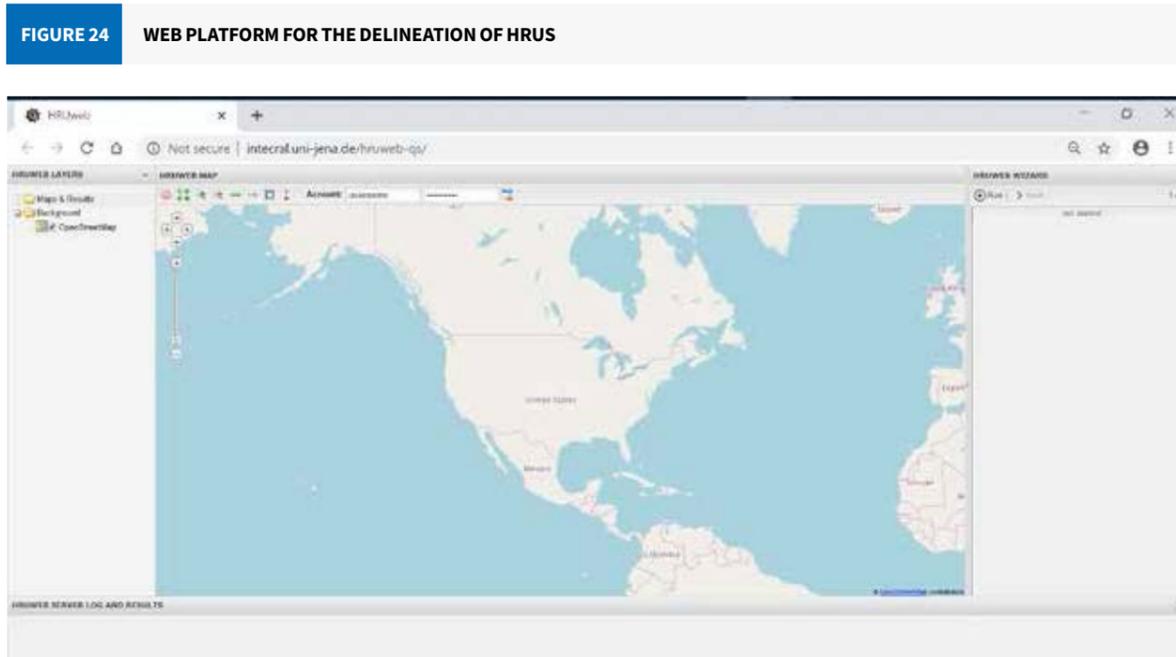


Source: <http://jams.uni-jena.de/jamswiki>

Step 1: Starting the HRUweb tool

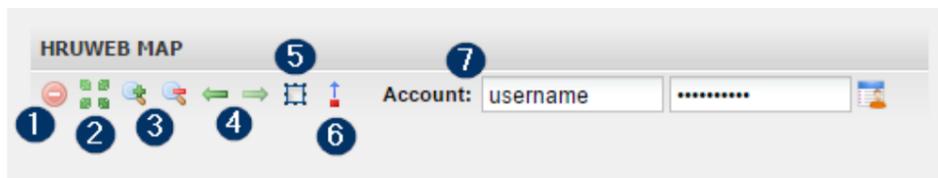
Procedure: Access the website < <http://intecral.uni-jena.de/hruweb-qs/> >

The map window is located in the centre (Figure 24). The view can be set manually by using the arrow buttons or the '+/-' toolbar to the top left. The remaining items are located around the map:



- Table of layers
 1. You can change the order of layer visibility by changing the order of the layers
 2. Select a layer by clicking on it. Now the layer can be edited by using the map legend at the top.
- Map legend

The following tools are available in the map legend:



1. Remove layer
 2. Zoom to map extent: Restores smallest possible scale of the map
 3. Zoom in () or zoom out of the map ()
 4. Zoom to the previous map extent (backward ← forward →)
 5. Create a bounding box of interest (applied in Step 3)
 6. Relocate gauge (applied in Step 7)
 7. User login
- HRUweb Wizard: Includes processing step description and manual input/settings. Includes the buttons for 'Run' and 'Next'.
 - Server Log and Results: Shows the uploading process and provides the resulting layer as a raster or shape file. (click on ⬆ to reveal the item and to hide it again)

Step 2: Uploading the input data

Procedure: First, sign in using both username and password as 'Student6' in < <http://intecral.uni-jena.de/hruweb-qs/> >. All the input files [Figure 25, box 2] need to be of the same UTM projection.

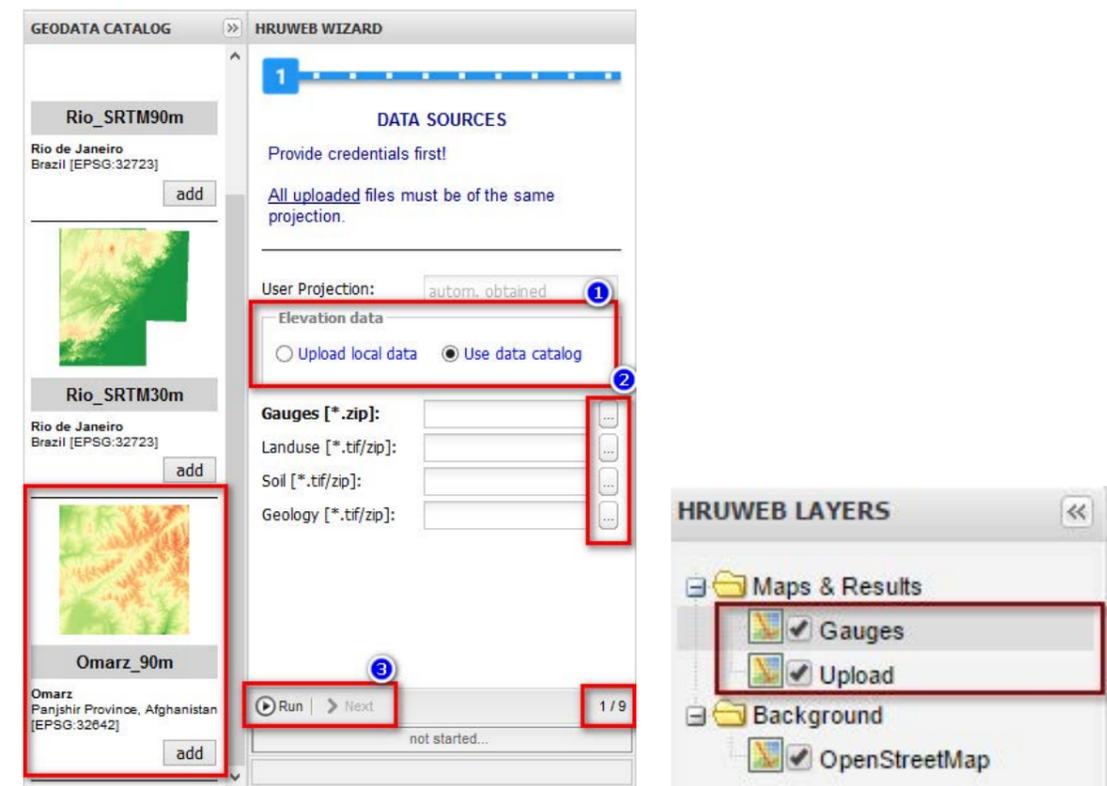
The user can manually input the DEM or choose data via catalog [Figure 25, box 1]. The required DEM can be chosen by clicking on 'add' on the side of the DEM.

The projection of the map will be set automatically on the basis of the input data.

For starting the uploading process, click on 'Run' in the Wizard (Figure 25, box 3).

Zoom into your area of interest. The gauges are shown as light blue dots. The extent of the DEM is marked automatically in a red bounding box. When the process is finished, click on 'Next'. As the process ends, the

FIGURE 25 DATA SOURCES, THEIR INPUTS FOR HRU, AND HRUWEB LAYERS



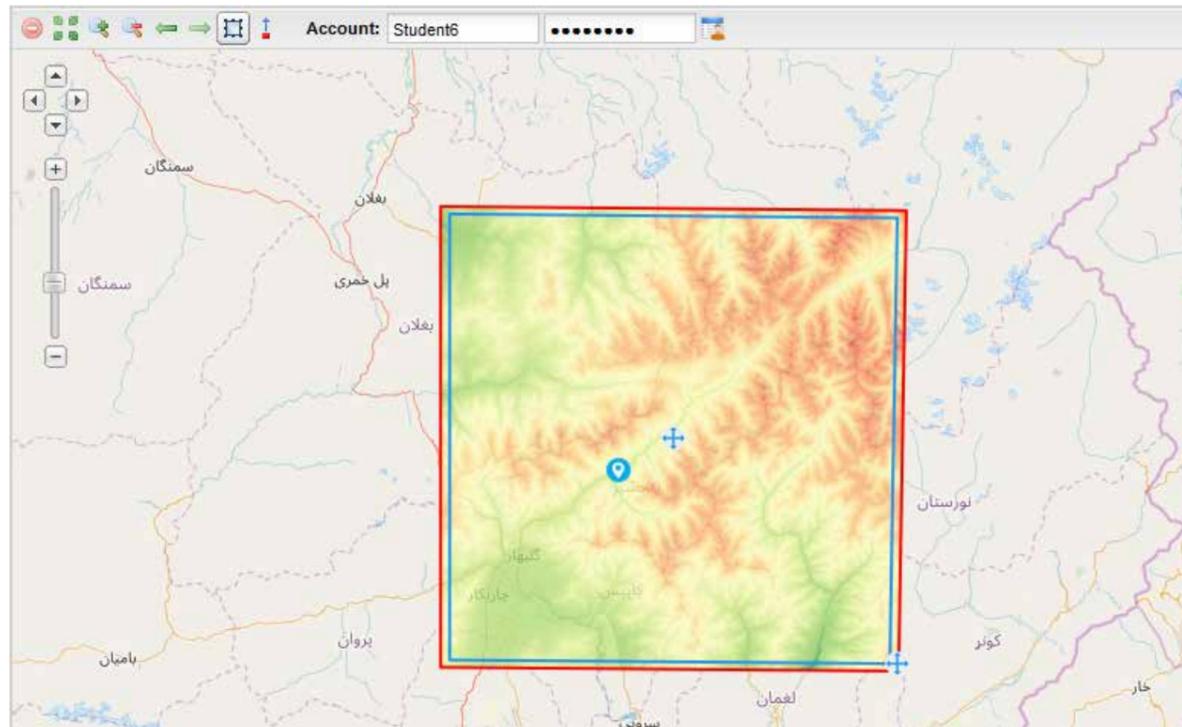
overlays 'Upload' and 'Gauges' are created in the Map View as well as the table of Layers.

Step 3: Define the area of interest for delineating HRUs

Procedure: In this step, the region of interest is defined. To specify the region of interest, the symbol in the map legend needs to be clicked. By doing so, an overlay layer called 'Region' is created.

The red box marks the maximum extent of the analysis. The blue box marks the area that is used for delineating HRUs. The extent of the blue box should be fitted to the gauges' position as only this extent is delineated (Figure 26).

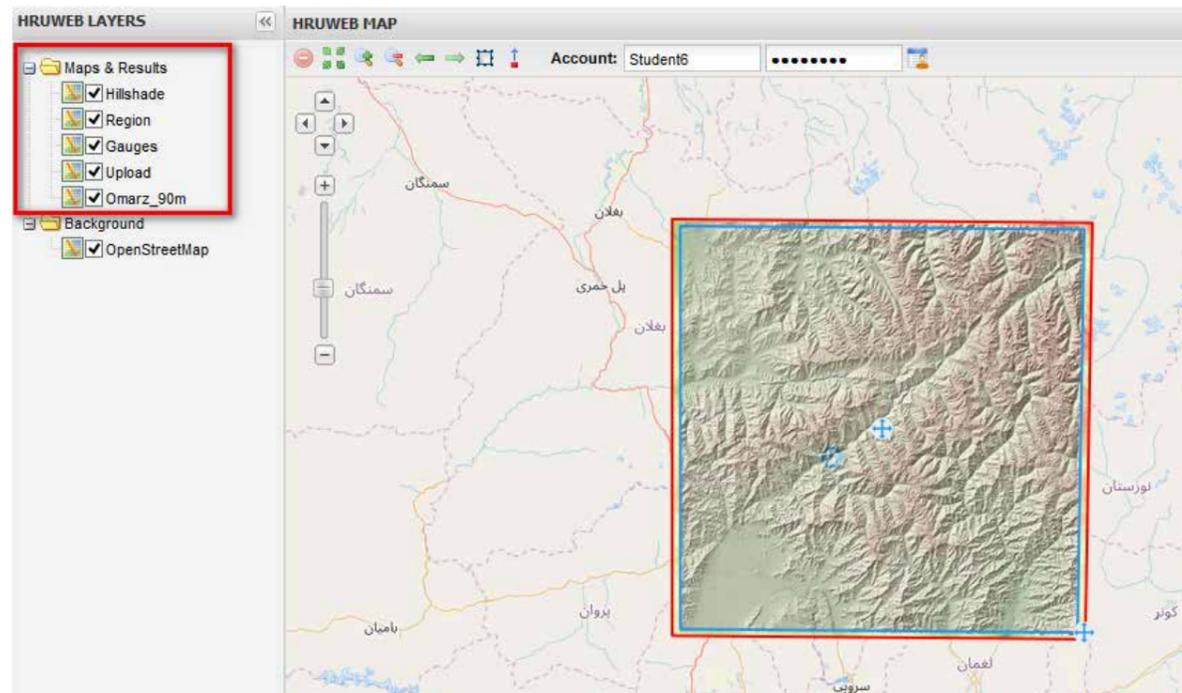
FIGURE 26 SELECTION OF THE SUBREGION THAT HOLDS THE ENTIRE CATCHMENT



In order to shift the whole box, drag and drop it by the blue cross in the centre. In order to resize the box, use the cross at the side. Complete the process by clicking on the symbol  again, and then on 'Run'.

A 'Hillshade' overlay is created in the table of Layers and shown in the map, as shown in Figure 27. Click 'Next'.

FIGURE 27 DISPLAY OF HILLSHADE FROM THE HRU DELINEATION



Step 4: Preprocessing the DEM

Procedure: Choose 'default filling' in the Wizard window if the sinks should be filled, or 'no filling' if the file is already filled (Figure 28).

Click 'Run' to start the process.

A DEM with filled sinks is created (Figure 29). Single maps of sinkless elevation, slope and aspect can be downloaded from the Server Log. If a filling fails, no maps for slope and aspect are available.

FIGURE 28 SELECTION OF A METHOD FOR SINK FILLING THE DEM

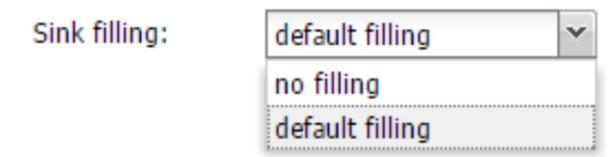


FIGURE 29 OUTPUT FROM SINK FILLING IN THE SERVER LOG

	1	Sinkless elevation map	tiff
	2	Slope map	tiff
	3	Aspect map	tiff

When the process is finished, click 'Next'.

Step 5: Reclassification of terrain attributes

Procedure: In this step, the class ranges of slope and aspect can be reclassified and renamed.

In order to change the table entries, click in the concerning field and type in the desired value. 'Old' lists all existing class ranges. 'New' assigns IDs to the classes. The group of 'old' class ranges can be reclassified with 'New' values (Figure 30) based on expert judgement.

Click on 'Run' to start reclassification.

After the reclassification is complete, the reclassified layers 'aspect' and 'slope' are shown as maps and listed in the table of Layers (Figure 31). These maps can be downloaded from the Server Log as well.

When the process is finished, click 'Next'.

Step 6: Defining the resolution of the stream network/ river system

Procedure: In this step, the maximum number of cells (pixels) for a sub-basin of the smallest size has to be specified. With each sub-basin, one river segment is created. This will determine how detailed the stream network is in the basin. Decreasing the value will produce a more detailed stream network.

FIGURE 30 RECLASSIFICATION OF SLOPE AND ASPECT DATA

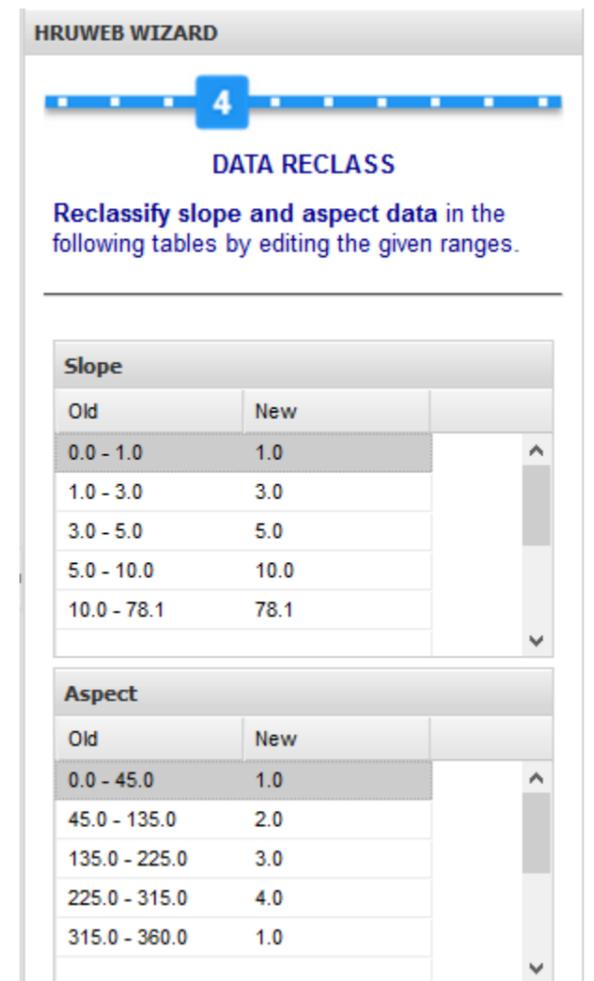
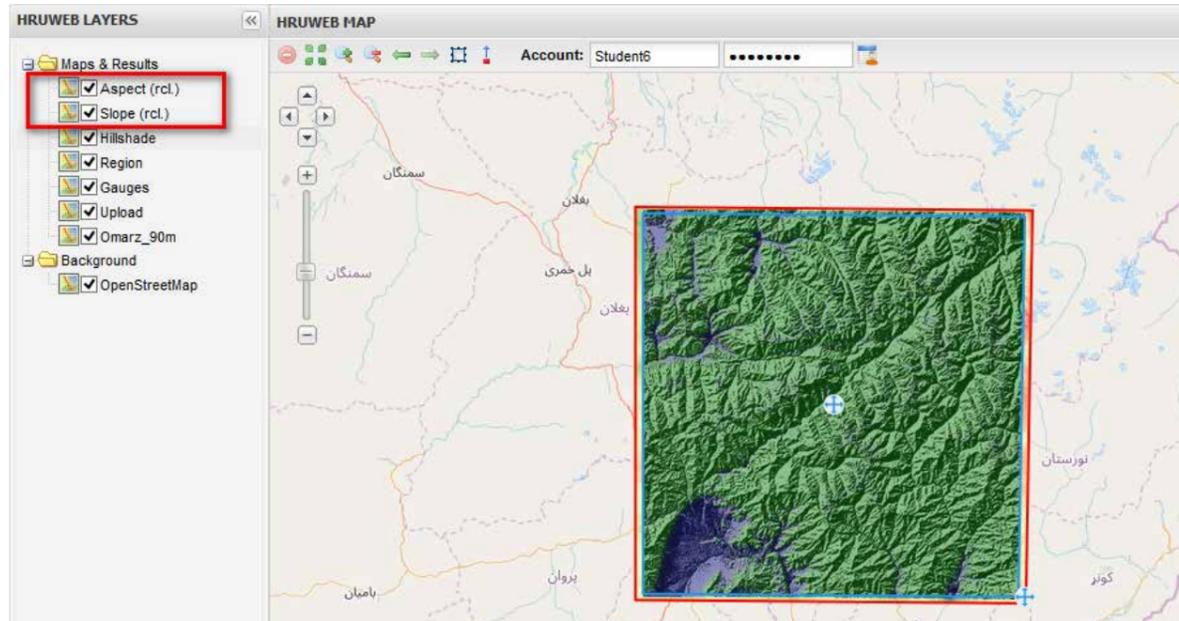


FIGURE 31 DISPLAY OF THE RESULT FROM RECLASSIFICATION



In this tutorial, the cell size was defined as 500 (Figure 32). For starting the process, click 'Run'. The layers 'Subbasins' and 'Streams' are created and shown in the map view (Figure 33).

You can download a map of the sub-basins in raster and shape format, and a vector zip file of the stream network from Server Log.

FIGURE 32 DEFINING THE SUB-BASIN SIZE FOR RESOLUTION OF THE STREAM NETWORK

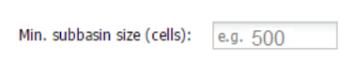
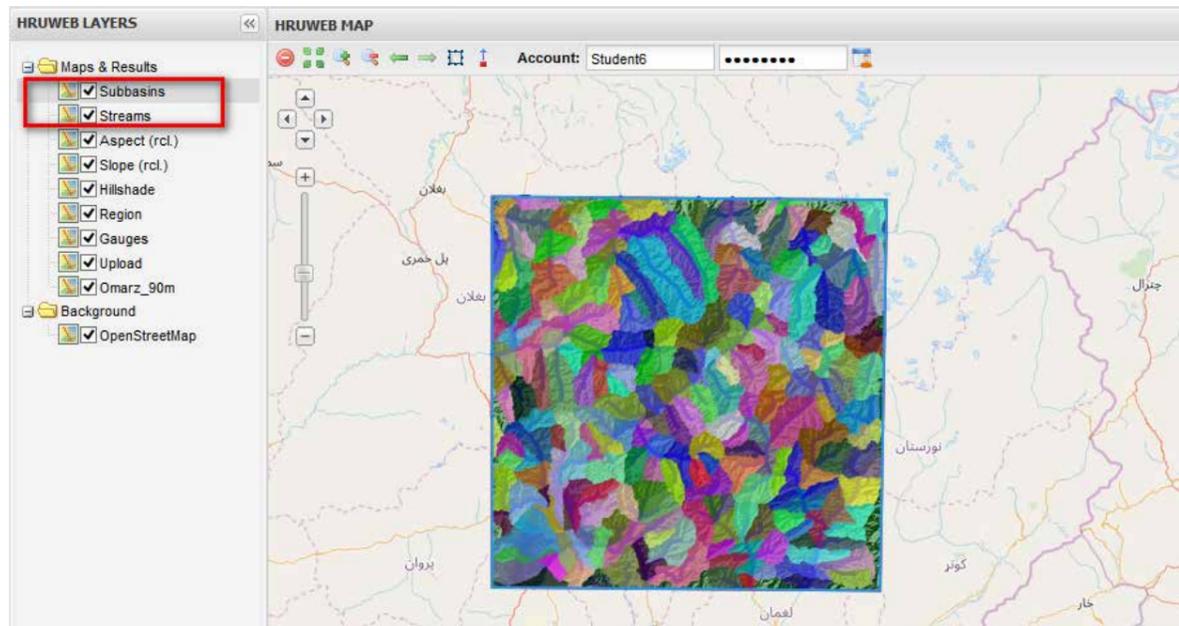


FIGURE 33 RESULTS FROM THE SUB-BASIN-MAKING PROCESS



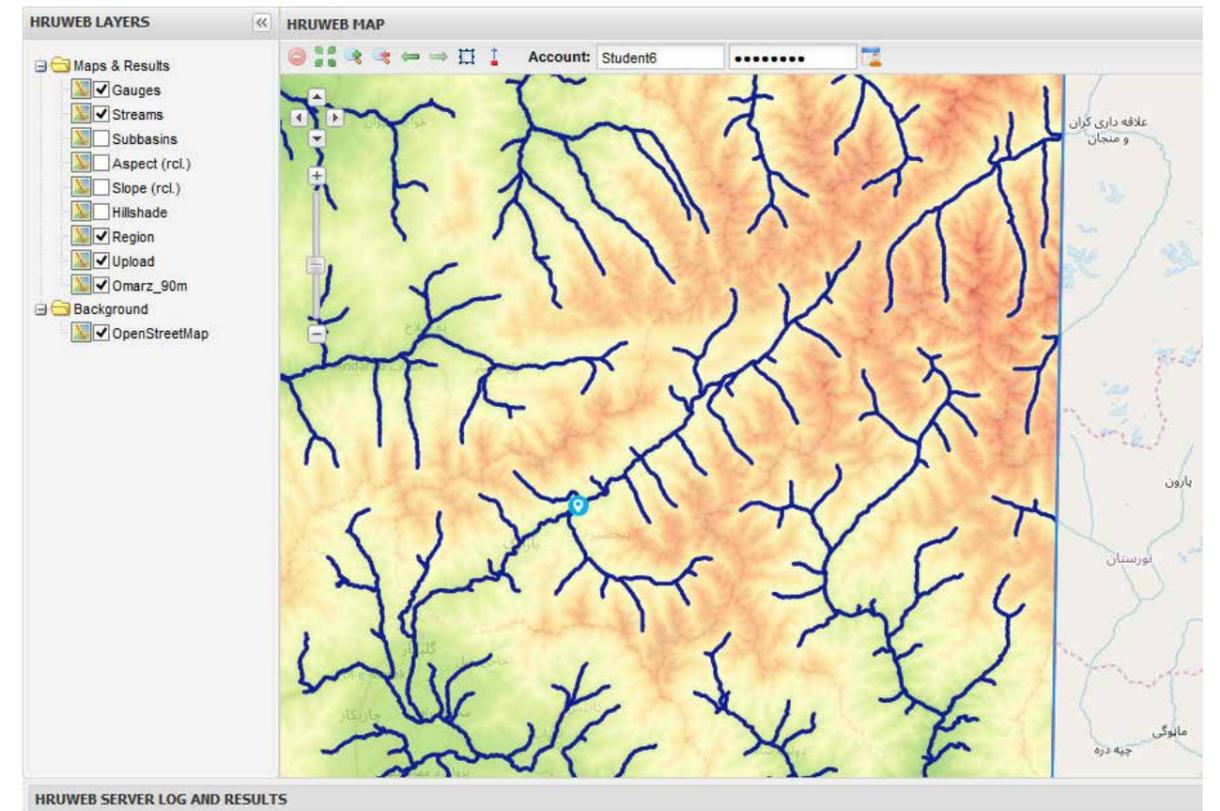
When the process is completed, click 'Next'.

Step 7: Positioning the outlets and delineating catchments

Procedure: First of all, use the drag-and-drop mechanism to change the visibility of the layers in the layer view. Place the layer of gauges on top, followed by the layer of streams and the sub-basins. You can unselect some of the layers, such as slope and hillshade, for better visibility.

Click on  in the legend at the top to activate it (Figure 34). In order to relocate a gauge, click on it and drag it to the nearest river segment. You can zoom into the map for better alignment. When you are finished, click on  again to deactivate the tool.

FIGURE 34 PROCEDURE FOR MAKING OUTLET/DISCHARGE POINT



To start the catchment delineation process, click 'Run'.

After the process is completed, a new layer, 'Watersheds', is listed in the table of Layers. A map of the watersheds is shown in the Map View (Figure 35) and can be downloaded from the Server Log.

Step 8: Delineation of an HRU

Procedure: In this step, the maximum number of cells (pixels) for an HRU of the smallest size has to be specified. A lower value will produce a larger number of HRUs and a higher value will reduce them. The number of HRUs will determine the computational time of the model run. Therefore, specify the number of cells for the smallest HRU in the wizard depending on the resolution of the input data (DEM, land use, soil, and geology). In this manual, the number of cells for the smallest HRU has been defined as 10.

To start the process, click 'Run'. The layer 'HRU' is created in the layer overview and shown in the map view after the completion of the process (Figure 36). A map of the HRUs created can be downloaded from the Server Log.

FIGURE 35 MAP OF THE WATERSHED

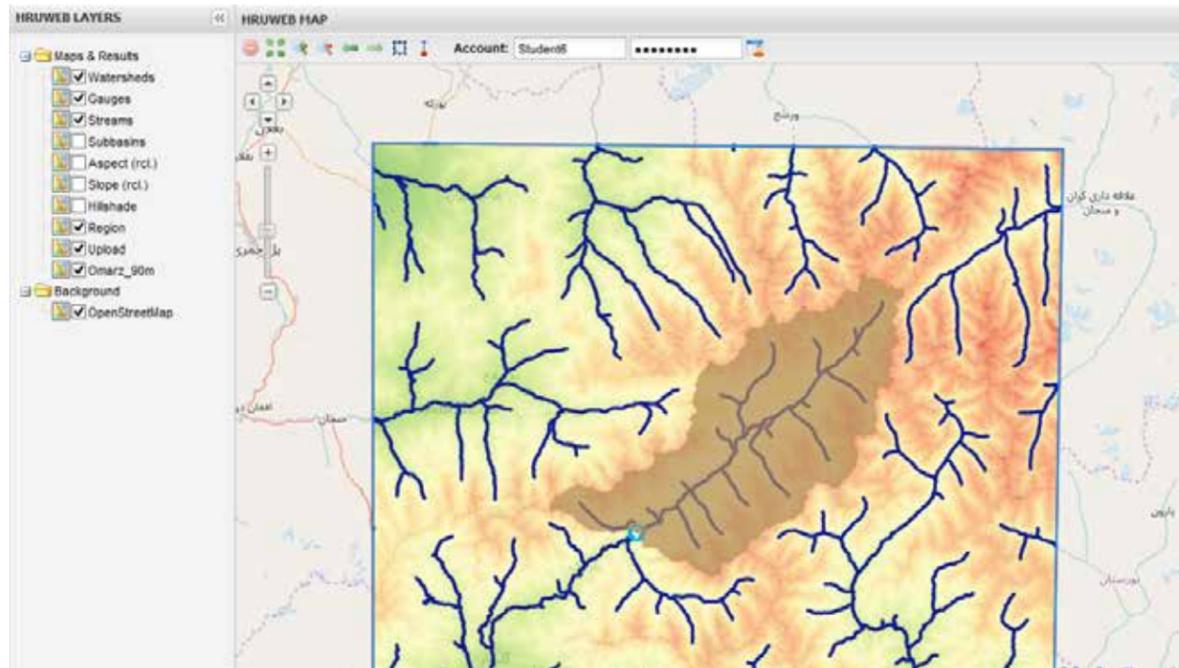
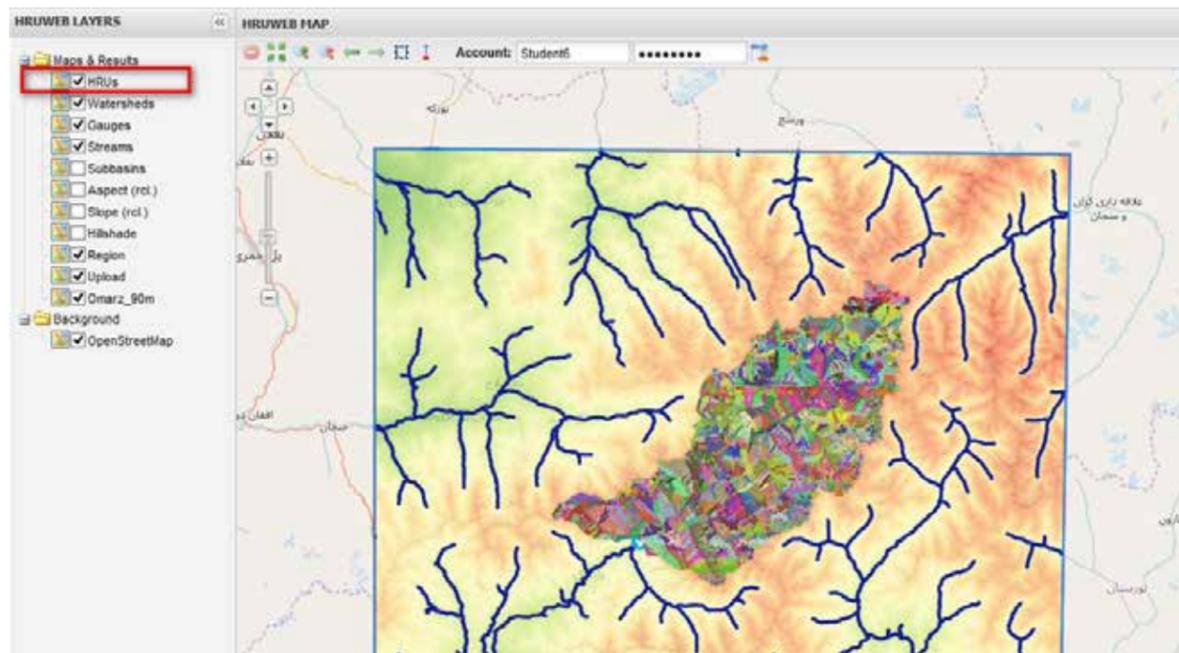


FIGURE 36 DISPLAY OF DELINEATED HRUS



Step 9: Creating topological information

Procedure: In this step, all calculations of the routing parameter are done by the WebTool. No user action is required. Just click 'Run' to initiate the process. After the process is completed, the routing parameters would be available in the Server Log as .csv tables (Figure 37).

FIGURE 37 RESULTS FROM THE ROUTING

↓	14	Reach parameter	CSV
↓	15	Routing (n:m) parameter	CSV
↓	16	Routing rates (n:m) parameter	CSV

When the process is finished, click 'Next'.

Step 10: Downloading the parameter files

Procedure: In this step, post-processing is done by the WebTool. To start the process, click 'Run' and to see the results, click 'Next'.

Shapefiles of the HRUs and the parameter files can be downloaded from the Server Log (Figure 38) after the process is completed.

FIGURE 38 RESULT FROM STEP 10

↓	17	HRU parameter	csv
↓	18	HRU shapefile	zip
↓	19	HRU shapefile (WGS84)	zip

The results of all steps can be downloaded in a zip file.

[Download results \(Zip\)](#)

If you want to delineate a new catchment, click on:

[Run new HRU delineation](#)

The process is fully described in the tutorial:

< http://jams.uni-jena.de/ilmswiki/index.php/WebHRU_Tutorial >

By downloading the results from the delineation of HRUs, you can get the HRU parameter file (hrus.par) and the Reach parameter file (reach.par) for your model.

A sample HRU parameter file is provided in Figure 39, and the description is presented in Table 12. Likewise, the description of the REACH parameter file is presented in Table 13.

The HRU parameter file stores the spatial attributes of the catchment, such as elevation, area, aspect, coordinates, land use type, hydrogeology, and soil through each HRU unit. For example, in the HRU parameter file, HRU ID 1 has all the necessary information, including land use, soil type, and hydrogeological type. The interactions between soil, land use, and hydrogeological parameter files are done through the corresponding value of a given HRU in the HRU parameter file and respective value in their respective parameter files.

FIGURE 39 SAMPLE HRU PARAMETER FILE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	# hru.par created Sat													
2	ID	area	elevation	slope	aspect	x	y	watershed	subbasin	landuseID	soilID	hgeolID	to_poly	to_reach
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	999999	9999999	10000	90	360	9999999	9999999	999999	999999	9999	9999	999999	999999	999999
5	n/a	m2	m	deg	deg	m	m	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	1	77440	5062	27.112	265	607779	3972208	1	2162	56	16	1	0	1
7	2	77440	4974	23.628	294	607424	3972208	1	2162	56	16	1	0	1
8	3	85184	5046	32.044	327	607247	3972030	1	2162	56	16	1	0	118
9	4	131648	4990	27.354	200	607779	3971853	1	2162	55	16	1	0	2
10	5	363968	4788	24.557	278	609996	3971409	1	2162	56	16	1	0	2
11	6	162624	4929	26.769	340	609686	3971321	1	2162	56	16	1	0	2
12	7	263296	4792	8.525	312	607646	3971055	1	2162	56	16	1	0	118
13	8	201344	4858	27.078	214	608356	3971321	1	2162	56	16	1	6	0
14	9	131648	4857	30.943	320	609553	3970611	1	2162	56	16	1	0	1
15	10	565312	4803	22.569	206	610439	3970877	1	2162	56	16	1	0	1

TABLE 12 HRU PARAMETER FILE

Parameter	Description
ID	HRU ID
x	Easting of the centroid point
y	Northing of the centroid point
elevation	Mean elevation
area	Area in m ²
to_poly	ID of the underlying HRU
to_reach	ID of the adjacent channel part
slope	Slope of the HRU
aspect	Aspect of the HRU
watershed	Watershed ID
soilID	ID of the soil class
landuseID	ID of the land use class
hgeolID	ID of the hydrogeological class

TABLE 13 REACH PARAMETER FILE

Parameter	Description
ID	Channel part ID
length	Length
to-reach	ID of the underlying channel part
slope	Slope
rough	Roughness value according to Manning's roughness coefficient
width	Width

From Figure 39, we can visualize that the water from HRU ID 1 (shown as ID in figure 39) contributes directly to REACH ID 1 (shown as to_reach in figure 39) whereas from HRU ID 8, it contributes water to HRU ID 5 which then contributes to REACH ID 2.

The HRUs are topologically connected for lateral routing to simulate lateral water transport processes from one HRU to another. They are further connected to a nearby reach for reach routing. The reach parameter file stores the information about stream characteristics as well as the relationship between stream networks to accomplish reach routing. This file also contains information on the structure of the flow topology by noting the ID for every reach into which it transfers.

A sample reach parameter file is provided in Figure 40.

FIGURE 40 SAMPLE OF A REACH PARAMETER FILE

# reach.par: Reach-Parameter fuer den Pegel in RabDud (400 Reliefeinheiten)						
ID	length	to-reach	slope	rough	width	
0	0	0	0	0	0	
99999999	99999999	99999999	90	9999	99999999	
n/a	m	n/a	%	n/a	m	
1	10571	11	3.935	30	3.1	
2	5017	6	17.597	30	2	
3	6949	8	4.95	30	2.8	
4	3267	6	12.914	30	2.5	
5	7139	16	5.183	30	3	
6	2414	8	3.852	30	3.6	
7	4371	14	3.454	30	2.2	
8	3517	12	2.054	30	5.1	

3.2.2 Preparation of climate input data files

The J2000 hydrological model requires the following input data (Table 14) for model initialization:

The input data (example in Figure 41) must be saved with the extension '.dat' (for example, rain.dat for precipitation). An easier way to do so is to save the data from Excel as tab delineated (.txt) and then manually change the extension from '.txt' to '.dat'. The last line of each dataset must end with "#end of data.dat".

TABLE 14 INPUT CLIMATE DATA FOR MODEL INITIALIZATION

Name	Description	Unit
ahum.dat	Absolute humidity	g/cm ³
orun.dat	Measured flow passage at the run-off	m ³ /s
rain.dat	Measured amount of precipitation	mm
rhum.dat	Relative humidity	%
sunh.dat	Duration of sunshine	hr
tmax.dat	Maximum temperature	°C
tmean.dat	Mean air temperature	°C
tmin.dat	Minimum temperature	°C
wind.dat	Wind speed	m/s

FIGURE 41 EXAMPLE OF INPUT DATA

@dataValueAttribs							
precip 0	9999	mm					
@dataSetAttribs							
missingDataV	-9999						
dataStart	1/1/2009 0:00						
dataEnd	9/30/2017 0:00						
tres	d						
@statAttribVal							
name	Doabi	Keraman	Omarz	Dashtak	Khawak	Nazdik-i-Khawak	Gulbahar
ID	11	22	33	44	55	66	77
elevation	2059	2232	2042	1787	2405	2407	1625
x	556224.05	559738.7	558210.6	538531.5	581100.9	581910.24	526291.7
y	3911844.66	3904687	3914910	3900571	3936050	3936407.52	3890750
dataColumn	1	2	3	4	5	6	7
@dataVal							
1/1/2009 0:00	0	0	0	-9999	0	0.1	-9999
1/2/2009 0:00	0	0	0	-9999	0	0.1	-9999
1/3/2009 0:00	0	0	0	-9999	0	0.1	-9999
1/4/2009 0:00	0	0	0	-9999	0.71	0.7	-9999

Exercise 2 (page 66) shows us how to acquire information for the input files and plot them.

The data for relative humidity, wind, and the number of sunshine hours may not be available in some catchments. In case this data (rhum, sunh, wind) is not available, the Penmann-Monteith approach cannot be used for the estimation of evapotranspiration. Instead, the more empirical Hargreaves Samani method, based only on temperature, can be used. A detailed example on how to change the Penmann-Monteith approach to Hargreaves-Samani in the model is shown in Exercise 4 (page 73).

3.3 Running the model

After setting the spatial and climatic input data, it is always important to run the model. It helps confirm that the input data is in accordance with the format of the model. The initial plots from the model run show the following result (Figure 42) in our case.

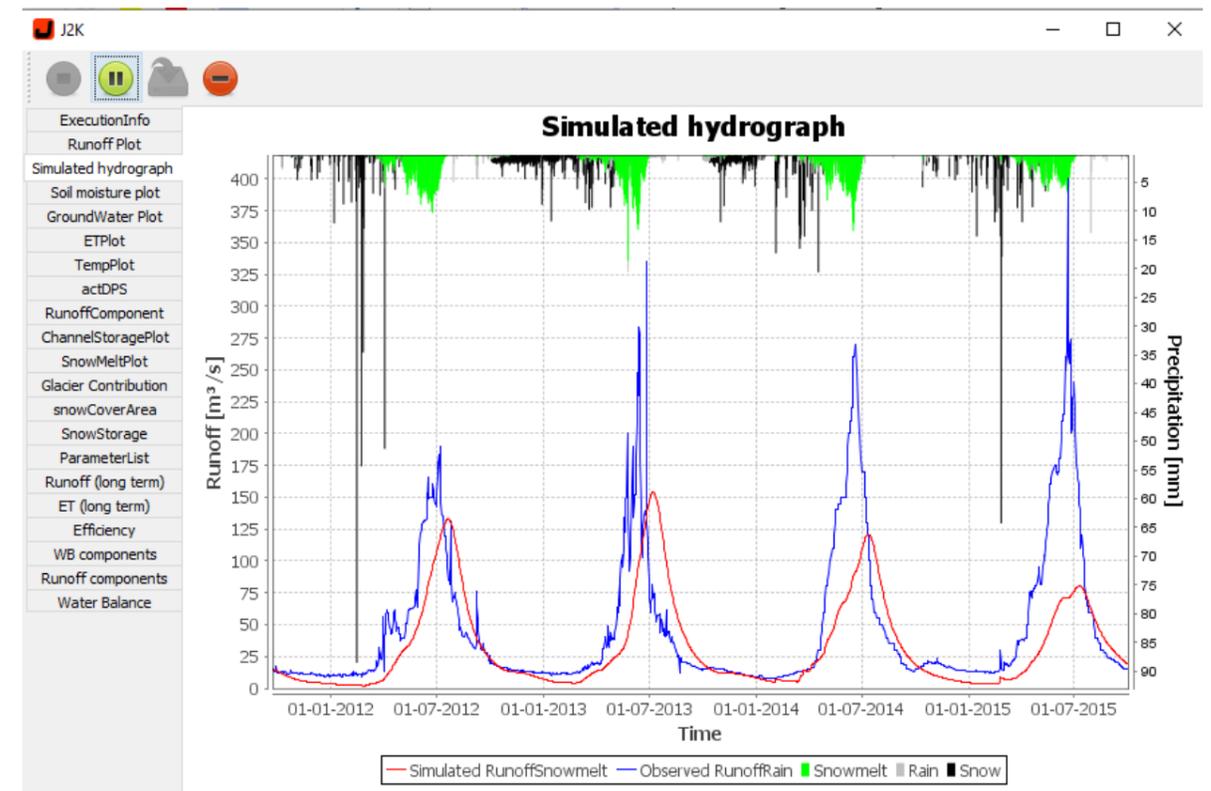
3.4 Model calibration

Calibration is a process by which parameter adjustments are made to obtain a better fit between observed and simulated variables. The desired model accuracy is achieved by changing the model parameter values until a 'satisfactory' agreement between simulated and recorded variables is obtained (Gupta, Beven, & Wagener 2006; Refsgaard & Storm 1996). The objective of the calibration process is to minimize errors due to non-optimal parameter values (Gupta et al. 2006) and to obtain the best possible results.

3.4.1 Manual calibration by trial and error method

In order to successfully use hydrological models, a careful determination of the model parameters is essential. A direct parameter measurement is often not possible, too expensive, or there is no clear physical relation. Consequently, the parameters are adjusted in a trial and error process, such that the simulated factors (for example, run-off) correspond best to the measured values.

FIGURE 42 RUNNING THE MODEL WITH AN INITIAL SETUP



3.4.2 Parameter sampling and auto calibration using the Integrated Optimization Assistant module

The J2000 model provides the platform for auto calibration processes. Parameter sampling and auto calibration in JAMS can be done by using the integrated Optimization Assistant (OPTAS) module. The purposes of applying OPTAS can range from parameter calibration to sensitivity and uncertainty analyses. Accordingly, OPTAS offers both directed and undirected sampling methods. In order to make easy use of this general approach, OPTAS helps users through the process of converting any JAMS model into a new model that does parameter sampling with the original model by wrapping everything into a sampling context.

The following set of steps is performed for the sampling and optimization of the parameters.

Step 1: Configure the efficiency: The calculation of model efficiencies is an important requirement to assess the quality of a model and to guide automated calibration procedures. In order to set up a model efficiency calculation in JAMS, open the model in the JAMS Builder and select the menu entry 'Model>>Configure Efficiencies' (Figure 43).

To set up a new efficiency calculation, or to change an existing one, the following steps are required (Figure 44):

- Select an objective or create a new one and give it a name.
- Select the time of iteration in context.
- Select the attribute representing your simulated property.
- Select the attribute representing your observed property.
- Select the time attribute.
- Press 'OK'.

After clicking on 'OK', choose 'Configure Optimizer' from the model in the JAMS Builder.

FIGURE 43 STEP TOWARDS SELECTION FOR CONFIGURING EFFICIENCIES

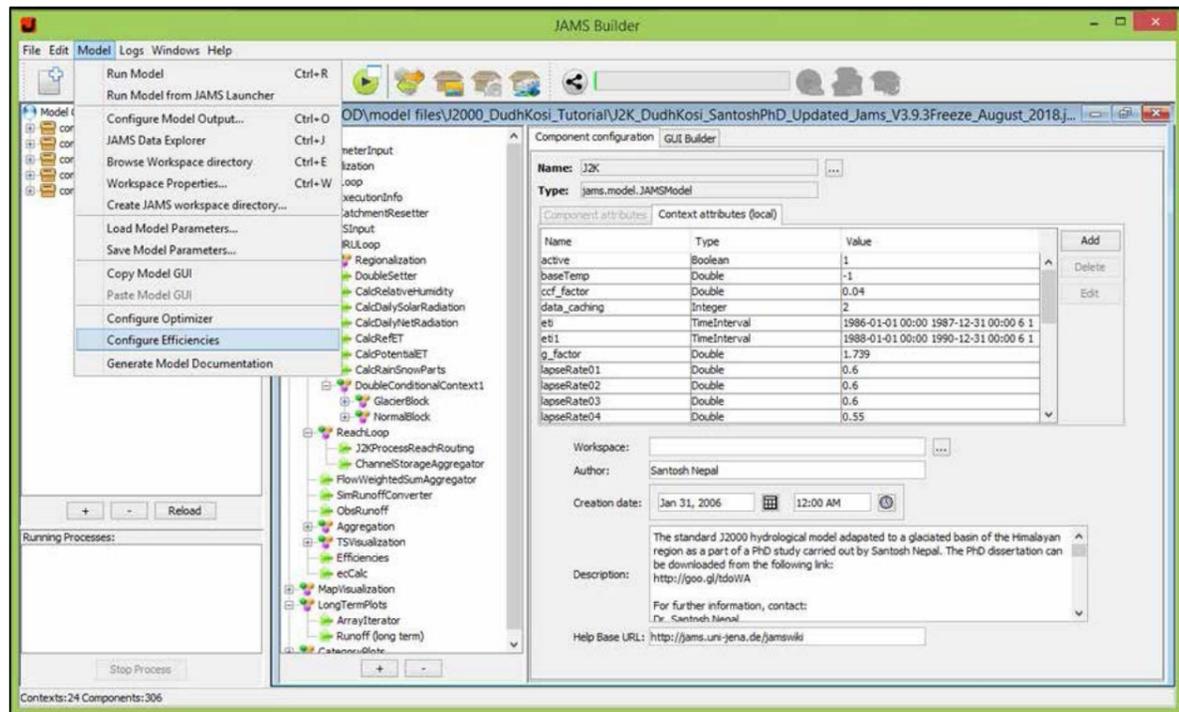
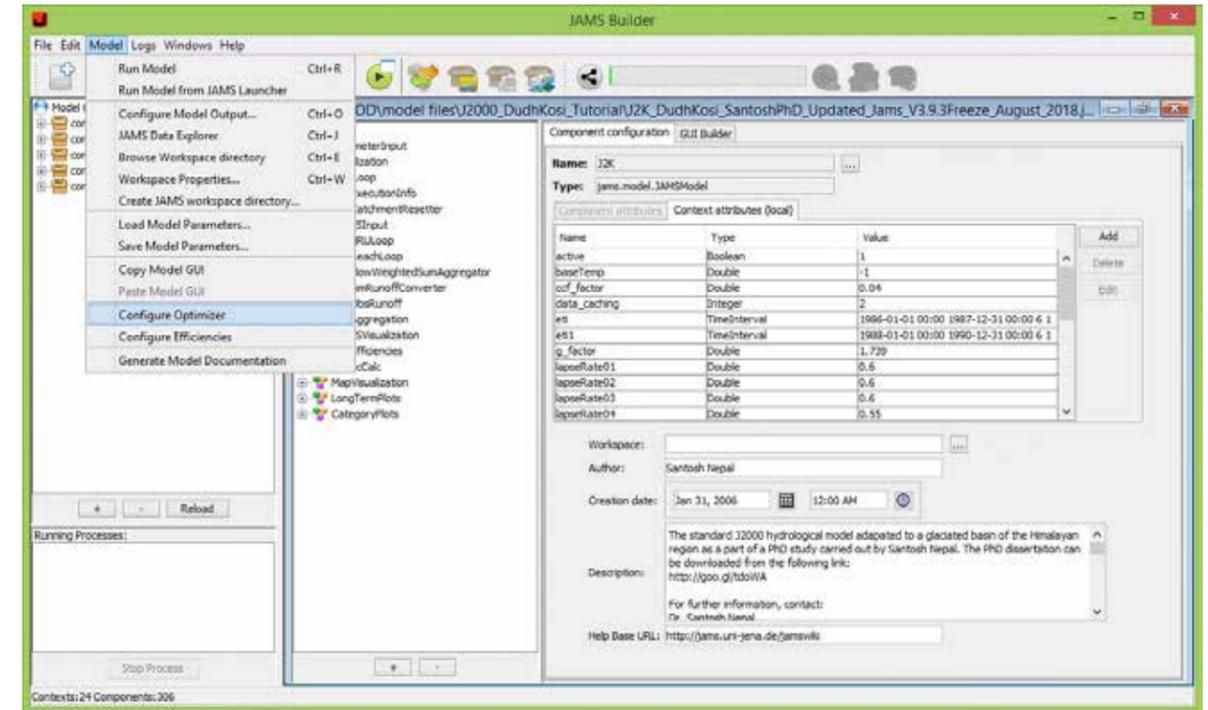
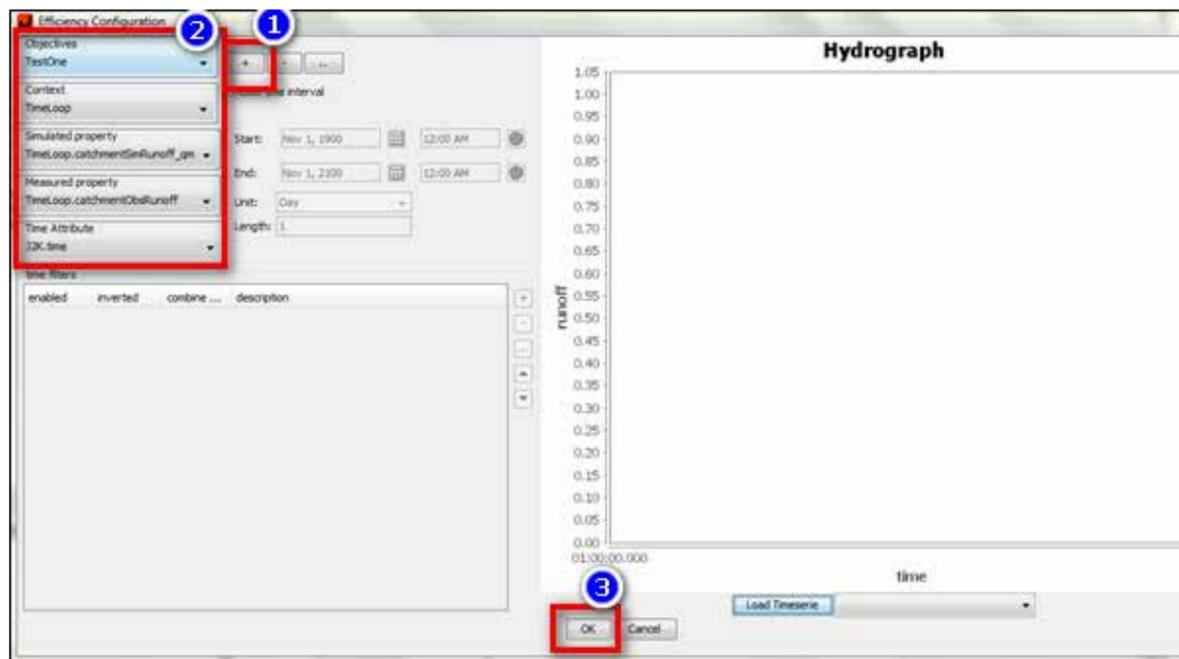


FIGURE 45 STEP FOR SELECTION OF CONFIGURING OPTIMIZER



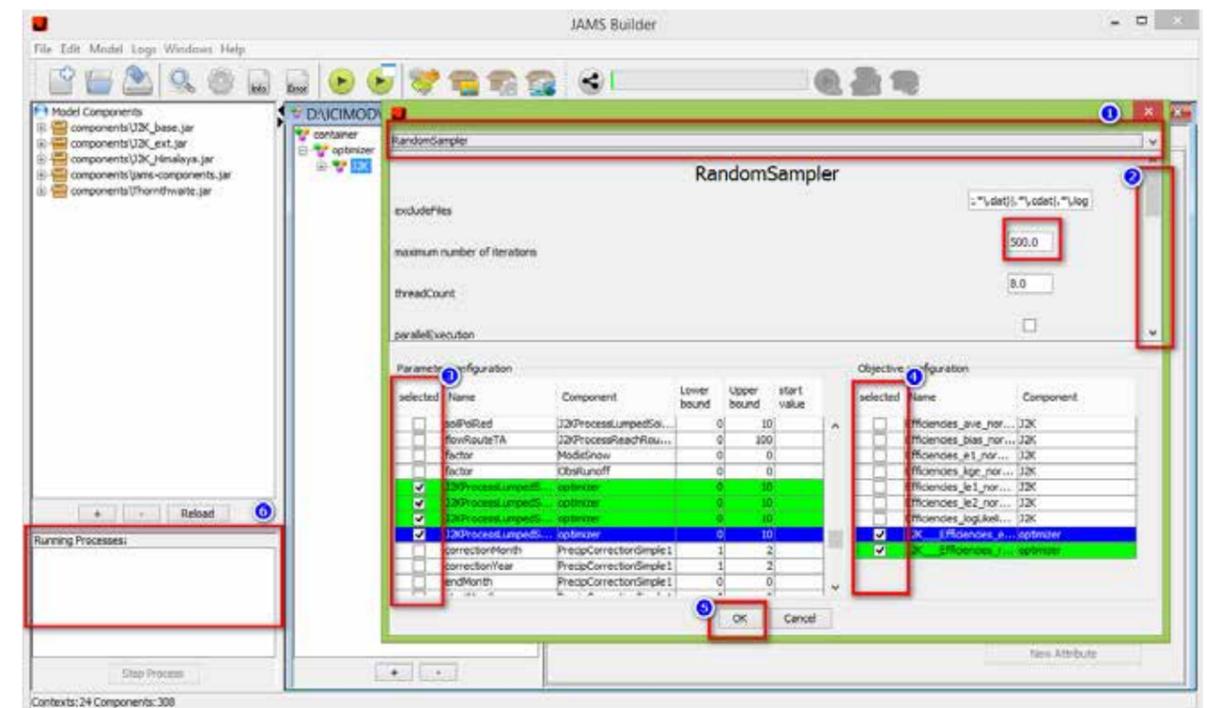
Step 3: In the upper part of the screen is a drop-down menu with the various optimization processes that can be used in the calibration (Figure 46, step 1). In this figure, Random Sampler is selected as an example. Set up the parameters related to the chosen sampling procedure. These processes may include the maximum number of sampling iterations, the number of parallel execution threads, etc.

FIGURE 44 STEPS FOR EFFICIENCY CONFIGURATION



Step 2: Select the model tab and click on the option 'Configure Optimizer'. There should be a new window that enables the configuration of your calibration (Figure 45).

FIGURE 46 CONFIGURATION OF THE OPTIMIZER FOR SENSITIVITY AND UNCERTAINTY ANALYSIS WHEN RANDOM SAMPLER METHOD IS CHOSEN



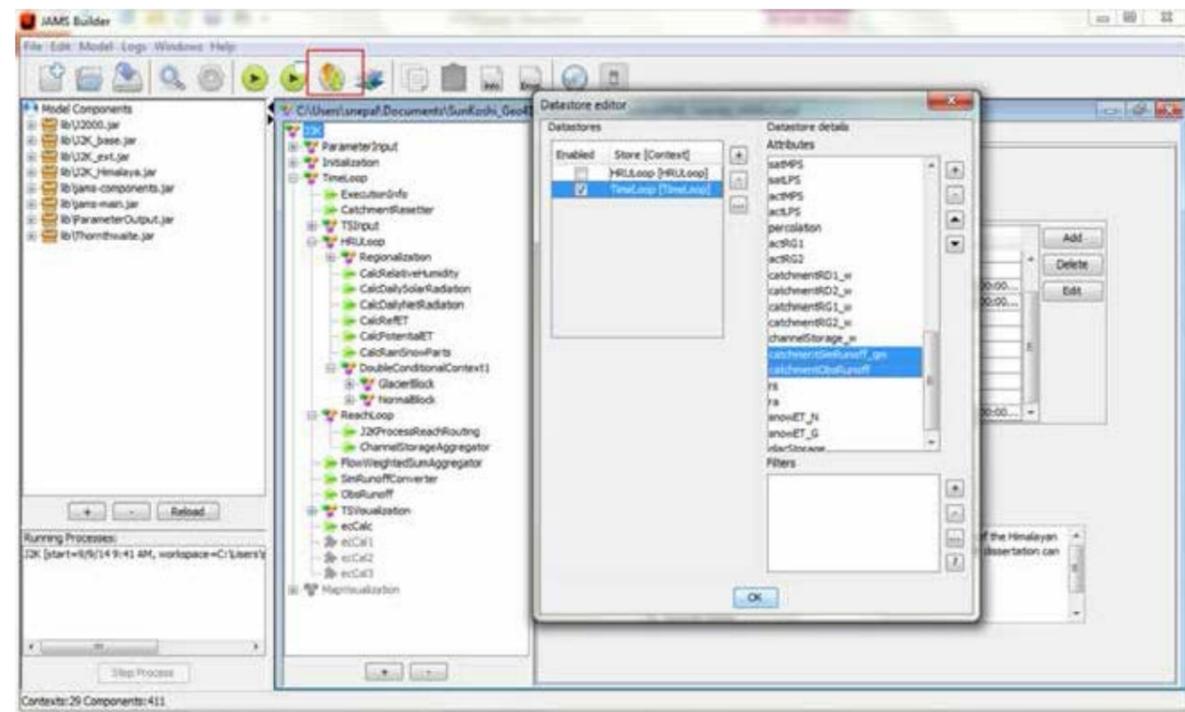
Step 4: In the middle of the dialog area, on the left-hand side, the potential parameters of the model are listed. Select those parameters from the list which you want to calibrate. If you want to select more than one parameter, hold down the CTRL button while selecting the parameters.

Step 5: Now, you can see several input fields for each parameter on the right hand side. You can choose the lower and upper bounds, which define the area in which the parameter can vary. In addition, it is possible to define a start value. This makes sense if a parameter is already known, which enables a starting point for the calibration. Note that if you set one start value, you have to set a start value for all your selected parameters.

Step 6: In the objective configure ([4] of figure 46), select the efficiencies that you are interested in.

Now timeloop information is selected, based on the objective of the analysis. It is advised to disable any outputs that are not required during parameter sampling/optimization. For uncertainty analysis, observed and simulation discharge information is required (Figure 47).

FIGURE 47 STEPS FOR MODEL CONFIGURATION



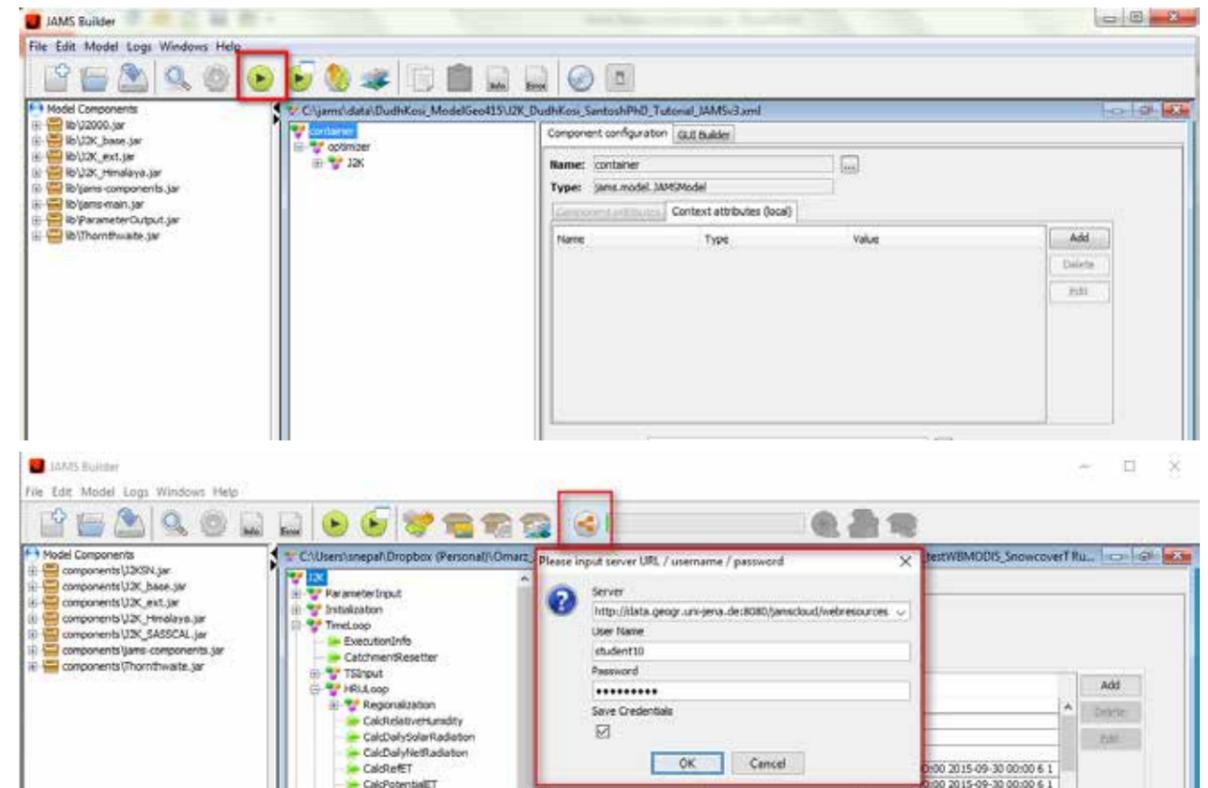
Note: Switch off 'HRULoop' from the output, else the file size would be huge and slow down the optimization process.

Step 7: When you are ready with your settings, you can run the model to start the optimization process and the model will start running in a local machine. Alternatively, the model can be run on the web server (Figure 48).

For a single sampling step to run as quickly as possible, all graphical components are automatically removed from the model. Running the model will, therefore, create no visible output. The only indication that the model has started is a new entry in the window 'Running processes' to the lower left part of the JAMS Builder. As a result, the original model will be transformed into a 'sampling model' by wrapping everything into a sampling context, as described above.

The file output from a model can have a major impact on the runtime of the sampling procedure. After the auto calibration is over (in our example, 2000), you get the output optimizer.dat file in the 'output/current' folder.

FIGURE 48 RUNNING THE MODEL WITH JAMS BUILDER IN A LOCAL MACHINE (TOP) AND THROUGH OPTAS ON A WEB SERVER (BOTTOM)



3.4.3 Sensitivity and uncertainty analysis

Sensitivity analysis is a process of determining how sensitive a model structure and estimated parameters are with regard to its output. It aims to describe the extent to which model output values are affected by changes in model input values. It is potentially useful in all phases of the modelling process: model formulation, calibration, and verification (McCuen 1973). Therefore, for any model, it is necessary to find out which parameters are sensitive and should be taken into account during an optimization process. The process also reveals whether a few or no sensitive parameters can be put to a constant value to make the optimization process simpler (Jansson, Hock, & Schneider 2003).

To carry out the sensitivity and uncertainty analysis, it is first necessary to create a new ensemble. For this, the following steps are recommended.

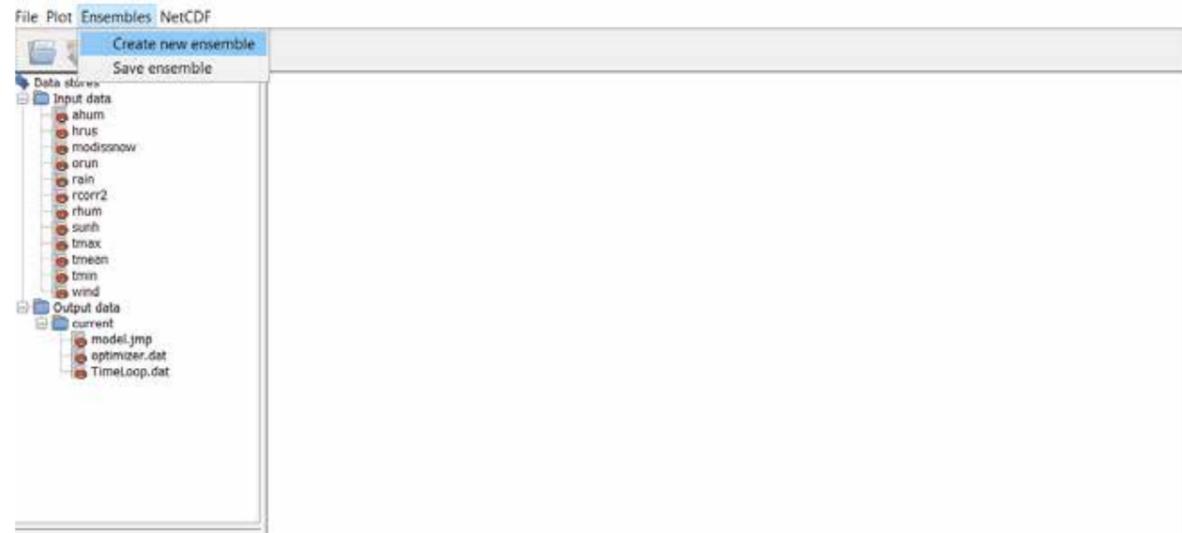
Click on JADE Efficiency Configuration (Figure 49).

FIGURE 49 SELECTION OF JADE IN JAMS BUILDER



After you open JADE, create a new ensemble (Figure 50).

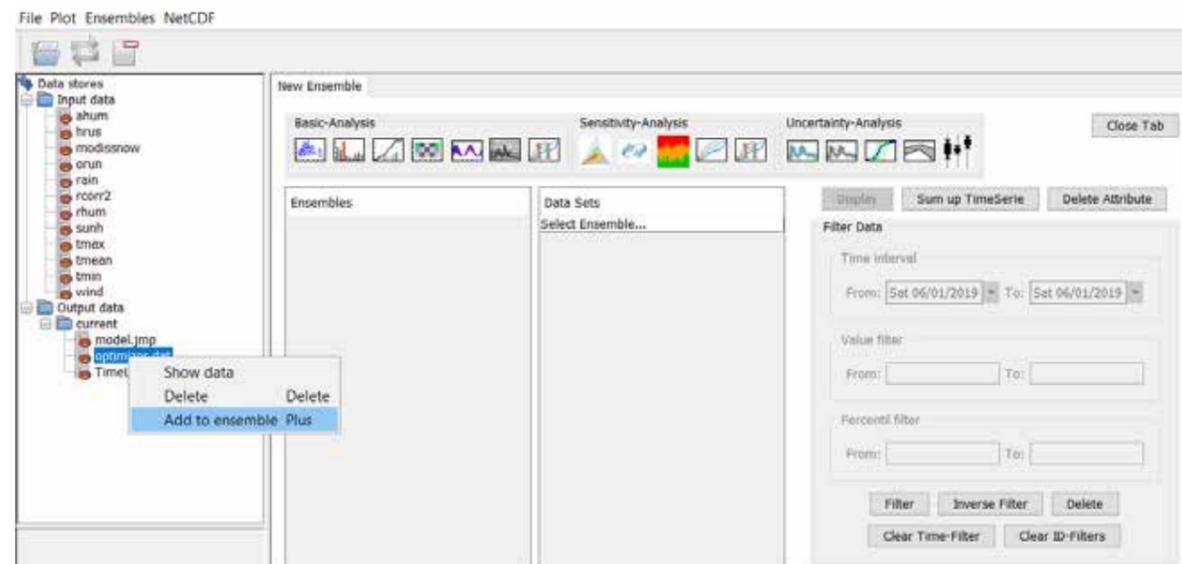
FIGURE 50 CREATING A NEW ENSEMBLE IN JADE



Look for Optimizer and TimeLoop in the current folder.

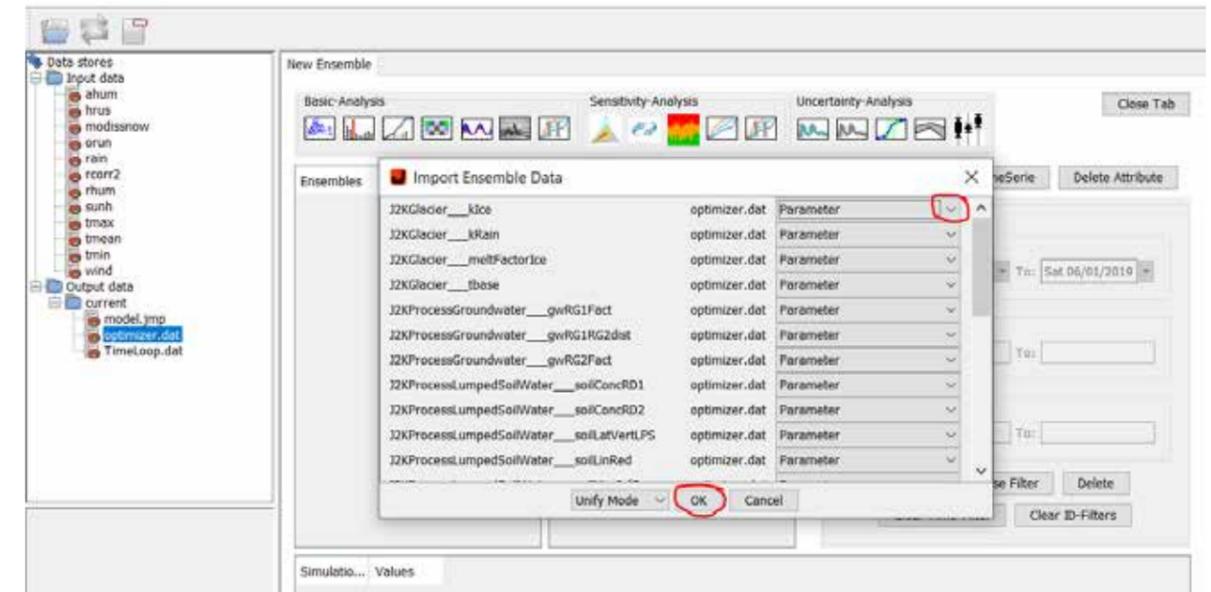
Add Optimizer in the ensemble (Figure 51).

FIGURE 51 ADDING OPTIMIZER TO A NEW ENSEMBLE



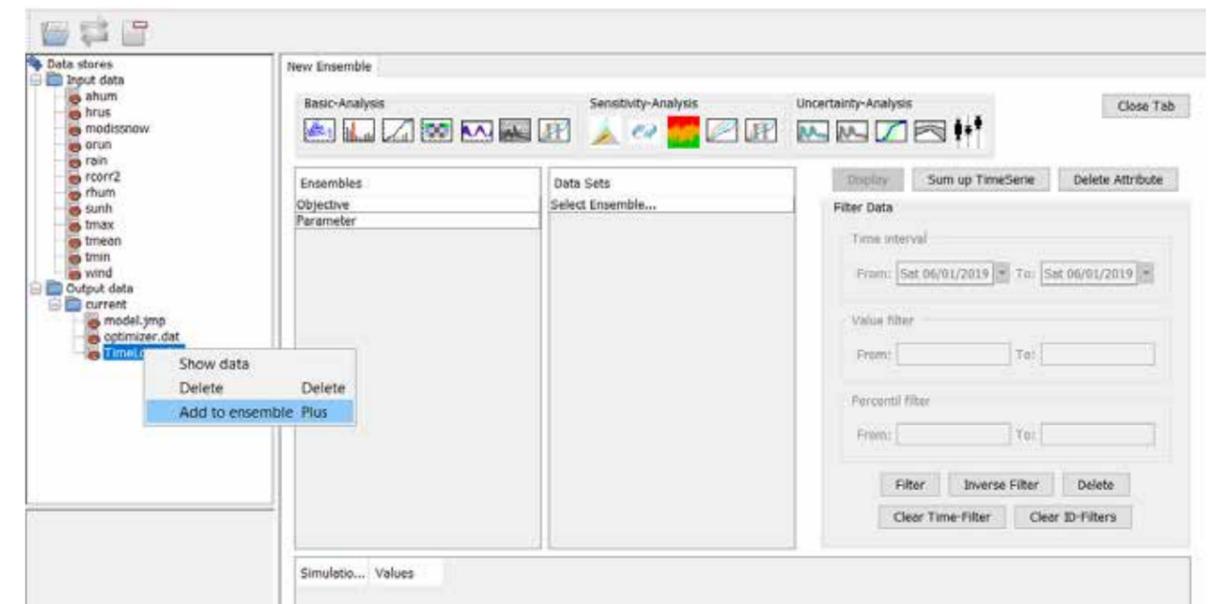
Define the variable required to create the required plot (Figure 52).

FIGURE 52 SELECTION OF PARAMETERS FOR SENSITIVITY AND UNCERTAINTY ANALYSES



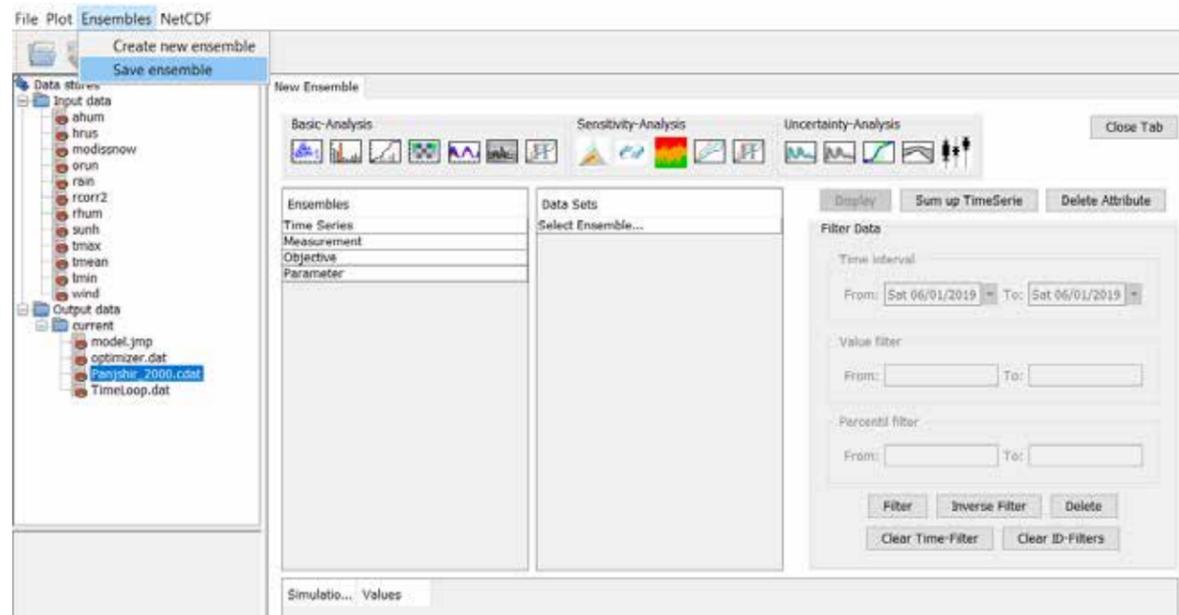
Now add TimeLoop using Add to ensemble Plus (Figure 53).

FIGURE 53 ADDING TIMELOOP IN A NEW ENSEMBLE



Now, save the ensemble as 'name.cdat' and use the different toolset for sensitivity and uncertainty analyses (Figure 54). The time plot, sensitivity analysis, and uncertainty plot can be plotted from here. The parameters or variables are selected and the analysis is done. From the basic plot, the dotted plot, posteriori plot, identifiability plot, and class plot can be plotted. Likewise, regional sensitivity analysis and temporal sensitivity analysis can be done from the sensitivity analysis while uncertainty analysis can be done using Pareto and GLUE methods.

FIGURE 54 SAVING THE ENSEMBLE (WITH .CDAT EXTENSION)



More details on the sensitivity and uncertainty analysis are provided in the next section.

3.4.3.1 SENSITIVITY ANALYSIS

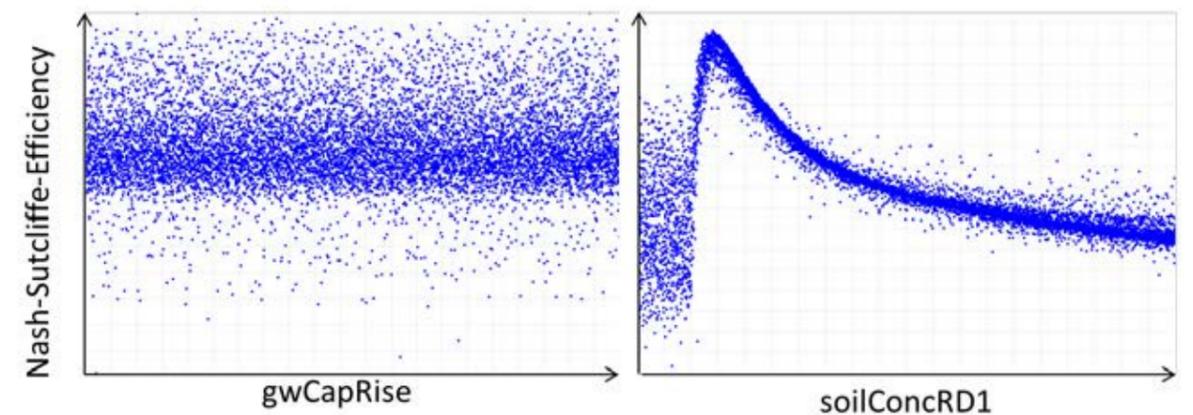
Sensitivity analysis is conducted as a part of the optimization procedure of the J2000 model parameters. It is the study of how uncertainty in a model's output (numerical or otherwise) can be apportioned to different sources of uncertainty in the model's input factors (Saltelli & Sobol 1995). For any model, it is necessary to find out which parameters are more sensitive to model outputs and therefore should be taken into account during a calibration process (Jansson, Hock, & Schneider 2003).

A Monte-Carlo analysis procedure is conducted using the selected parameters to produce a large number of simulations. The number of simulations determines how extensively the parameter space is sampled, and as large a number of simulations as is computationally possible (a function of model run-time and memory) should be performed. Monte-Carlo parameter sampling refers to repetitive model simulation with parameters randomly sampled from probability distributions (for example, uniform or normal). Usually, the model is run in a batch mode, with a randomly-generated matrix of parameter values as inputs, and model output and objective function values stored for each model run in an output matrix.

Figure 55 shows that the distribution is highly influential on values of soilConcRD1 (controls the retention of overland flows) whereas it is not influential on values of gwCapRise (controls capillary rising from groundwater). The objective function Nash-Sutcliffe-Efficiency (E2) is usually used for judging the results of the sensitivity analysis. Regional sensitivity analysis (RSA) has been used to analyse the sensitivity of the model parameters (Hornberger & Spear 1981). This method estimates the impact of a parameter and its interactions with model outputs.

Sensitivity, in this context, is defined as the effect of the parameters on the overall model performance, as indicated by objective functions. The general concept of applying RSA is to split the various model samples into good (behavioural) and bad (non-behavioural) populations and to compare their distribution functions in the objective function space. The parameter sets are split into groups based on their likelihood. If the model's performance is sufficiently sensitive to a particular parameter, there will be a large difference between the cumulative frequency distributions, that is, the parameter has a significant effect on the model output (Wagener et al. 2001).

FIGURE 55 VISUALIZATION OF RESULTS OF THE MONTE-CARLO ANALYSIS WITH SCATTER PLOTS



The example of scatter plots are used in Figure 56 to understand the idea, and compare the distribution of the best (behavioural) simulations and the worst (non-behavioural) simulations. If the distributions are different, the parameter will have an effect on the model's output. This means the parameter is sensitive. Otherwise, it is likely that the parameter is not very sensitive.

FIGURE 56 STATISTICAL DISTRIBUTION FROM A SCATTER PLOT TO UNDERSTAND THE BEST AND WORST SAMPLES

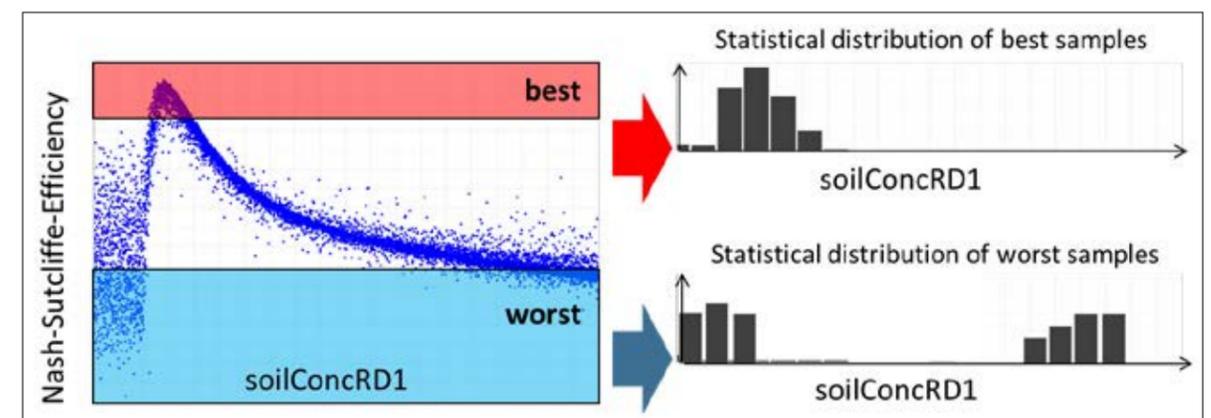


Figure 57 presents examples of RSA of parameters with high and low sensitivity, based on the 2,000 simulations. The red line indicates the cumulative distribution function of the behavioural parameter set, and the blue line indicates the non-behavioural set. The figure to the right (b) shows a larger difference between the parameter sets, indicating the higher sensitivity of the parameter to the model performance and the opposite for the figure to the left (a).

Figure 58 provides a comprehensive depiction of the parameter sensitivity weightage of the 22 parameters based on RSA with Nash-Sutcliffe efficiency (E2) criteria. The more sensitive parameters display higher stakes in the figure. Snow_trs, kice, and krain are the most sensitive parameters. The parameters soilLinRed, soilLatVertLPS, snow_trans, and gwRG2fact are moderately sensitive. The other parameters in this analysis are the least sensitive.

FIGURE 57 REGIONAL SENSITIVITY ANALYSIS OF THE SELECTED PARAMETERS

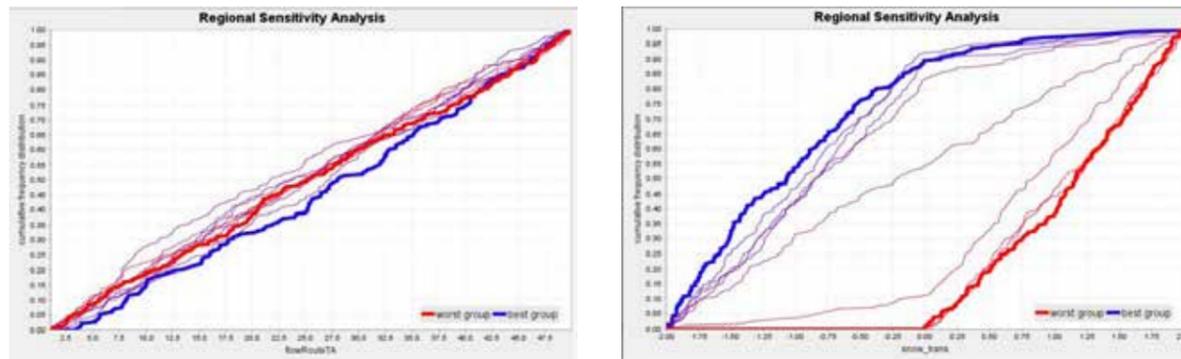
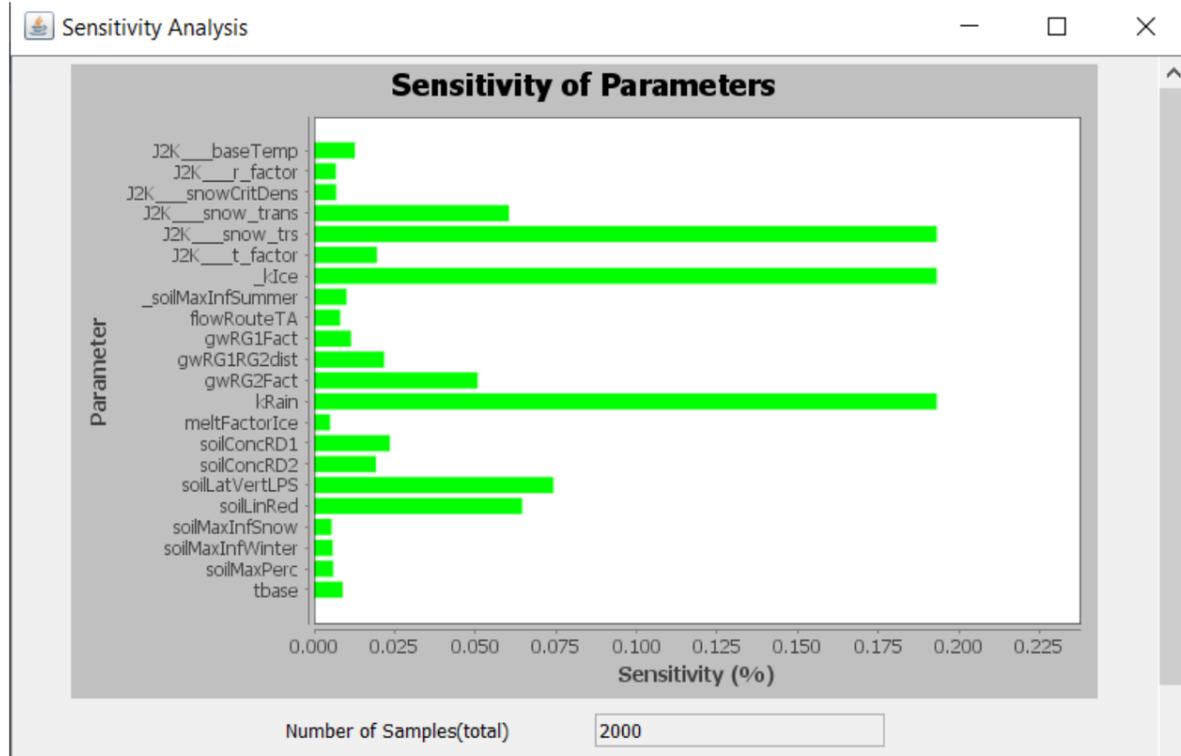


FIGURE 58 SENSITIVITY OF THE SELECTED CALIBRATION PARAMETERS WITH THE NASH-SUTCLIFFE EFFICIENCY CRITERION IN THE PANJSHIR CATCHMENT

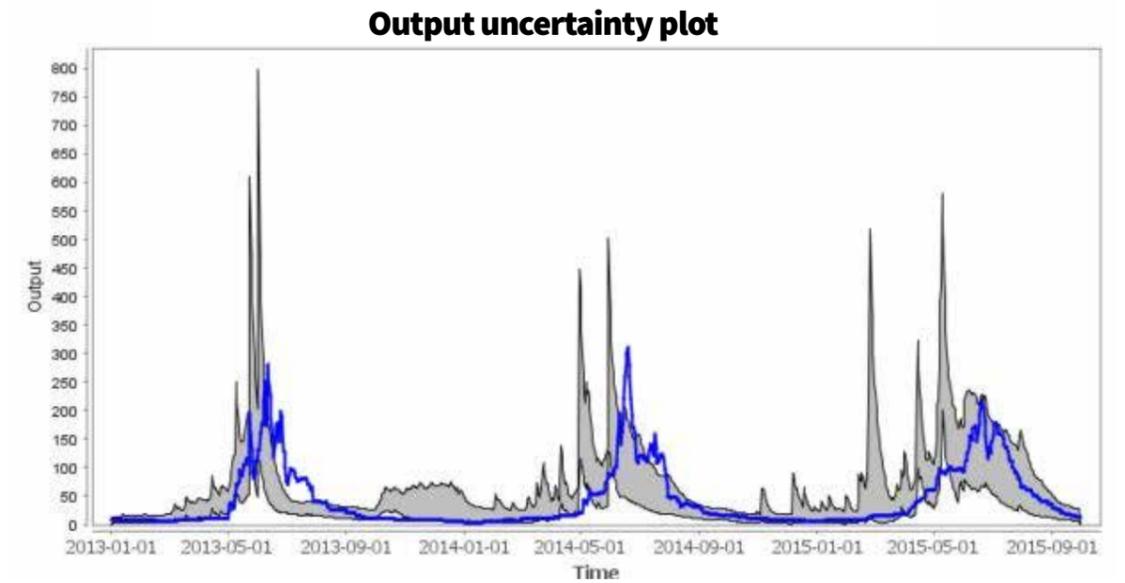


3.4.3.2 UNCERTAINTY ANALYSIS

Uncertainty analysis as a methodological tool provides a general basis for the evaluation of model performance (Weichel, Pappenberger, & Schulz 2007). The uncertainty associated with model predictions has to be properly assessed for effective decision-making processes using modelling results. Here, the General Likelihood Uncertainty Estimation (GLUE) method (Beven & Binley 1992) is applied for the estimation of uncertainty. GLUE is a procedure for uncertainty assessment based on Monte-Carlo simulations. It has been widely applied in hydrology and environmental modelling (Beven & Binley 1992; Montanari 2005).

The GLUE method accounts for all sources of uncertainty, that is, input uncertainty, structural uncertainty, and parameter uncertainty. In Figure 59, the uncertainty band resulting from 2,000 model runs, using the selected 22 calibrated parameters, was plotted. The figure indicates that though the observed hydrograph falls within the acceptable range of uncertainty bands, there needs to be some special attention given to the post-monsoon

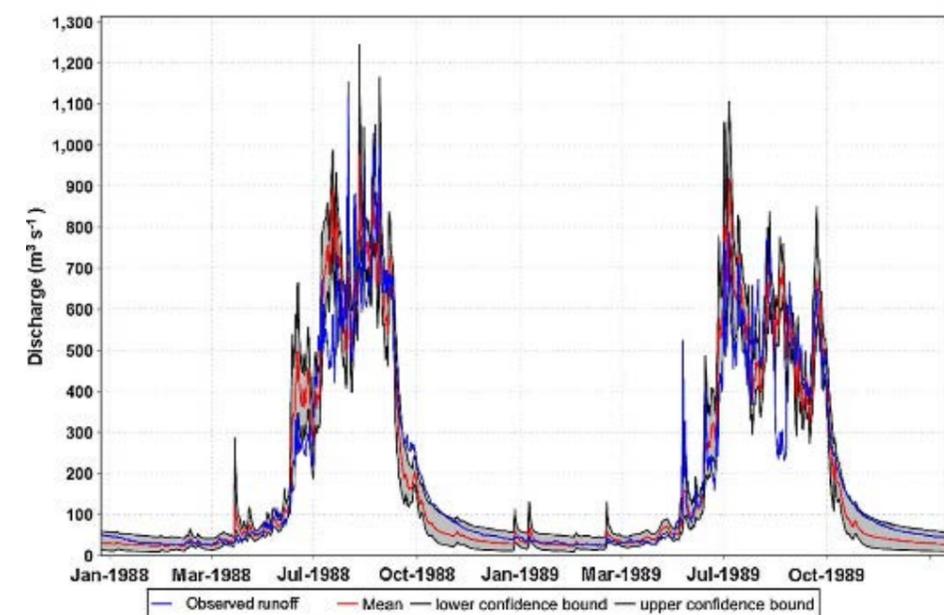
FIGURE 59 RESULTS OF THE UNCERTAINTY ANALYSIS USING THE GENERAL LIKELIHOOD UNCERTAINTY ESTIMATION METHOD



season. The grey band represents ensemble values from 2,000 simulations and the blue band is the observed run-off and the mean of ensemble values.

The uncertainty analysis for the year 1997 using the GLUE method is displayed in the hydrograph in Figure 60 (Nepal, Krause, Flügel, Fink, & Fischer 2014). It shows that there is a good agreement between the observed run-off and the ensemble mean flows based on results of the 1,600 simulations. Similarly, the observed discharge is within the ensemble range of 1,600 simulations barring a few flood peaks. This indicates that the process described by the J2000 modelling system is generally acceptable for the purposes of this model's application. In addition, it has helped identify the range of uncertainty bands, at different stages (for example, low-flow, rising and recession periods, etc) of the hydrograph.

FIGURE 60 RESULTS OF THE UNCERTAINTY ANALYSIS OF DUDH KOSHI FOR 1988–1989



Source: Nepal, Krause, Flügel, Fink, & Fischer (2014)

3.5 Validating the model

By now, the model has been fine-tuned incorporating information from the identified sensitive parameters. Also, the best values obtained from the OPTAS were used to derive greater efficiency. In addition, special attention has been given to capture uncertainty. Once the model has been fine-tuned, the efficiency noted and improvement marked, it is now ready to be validated.

The model's validation serves as evidence for the suitability of a model for a certain intended purpose (Bratley, Fox, & Schrage 1987). Model validation is an important tool for quality assurance. A model can be usefully implemented if it proves to be a reliable representation of real processes (Power 1993).

There are various methods of validation. Some of the suggested methods by Klemes (1986) are as follows: (i) Split-sample test: Used when the available record is sufficiently long and it is split into two halves, one of which should be used for calibration and the other for validation. (ii) Proxy-basin test: It is designed to validate the capability of models to represent the flow dynamics of ungauged catchments. (iii) Differential split-sample test: This method is used in the simulation of a streamflow record in a gauged basin for conditions that prevail after a change in land use, climate, or both; and during (iv) Proxy-basin differential split-sample: The simulation of a streamflow record in an ungauged basin for conditions that prevail after a change in location, climate, or both, is applied.

Following the split-sample test, the model can be classified as acceptable if both validation results are similar and have sufficient properties for the model application. If the amount of data available is not large enough for a 50–50 division, the data should be split in such a way that one segment is large enough to carry out a reasonable calibration. The part remaining is used for validation.

The validation can be done not only with the observed discharge but also with the snow and other measured parameters (Figure 61). In the Panjshir catchment, the model is validated with the snow cover and discharge data. Similarly, the model outcome can be compared to other measured data, results from other models, and published literature values.

The efficiency of these comparisons can be checked visually and by statistical evaluation, as described in subsection 2.2.5 (page 8). If the model results are not satisfactory, one can go back and recalibrate the model parameters. If needed, specific processes will have to be adapted to the model code to better reflect the specific hydrological processes of a catchment.

3.6 Spatio-temporal data aggregation and visualization using the JAMS Data Explorer

The JAMS Data Explorer (JADE) tool can evaluate and visualize input and output data after the model has been run. The JADE can be launched under the menu item 'Model/JAMS Data Explorer'.

The main precondition for displaying and analysing data in space-time is the creation of conditioned model outputs. This can be achieved by creating a workspace, which provides outputs of the model results at each point in time (for example, each day) and space (for instance, each HRU). To achieve this, follow the steps shown in Figure 62. Open the model from the JAMS Builder. Then open the output configuration dialog [Box 1], select/create a spatial datastore, for example, TimeLoop [Box 2], and then configure the output variables to be stored [Box 3].

In order to evaluate the input data that was used for the modelling, select a data set from the input folder by double-clicking on the file (Figure 63). The selected data will be displayed in the box on the right-hand side.

FIGURE 61 MODEL VALIDATION OF THE SNOW COVER AREA FROM MODEL RESULTS WITH MODIS DATA (TOP) AND OBSERVED DISCHARGE DATA (BOTTOM)

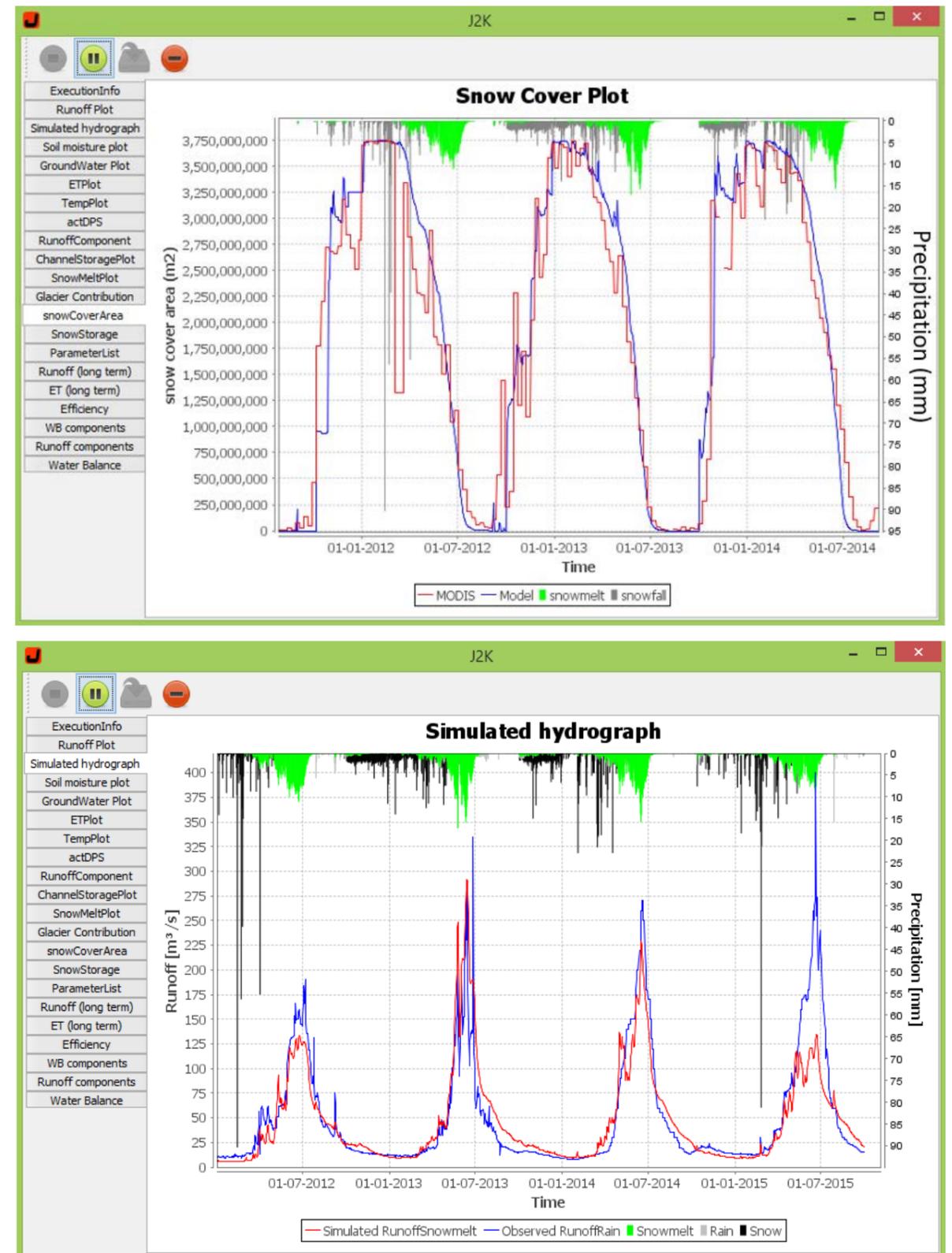
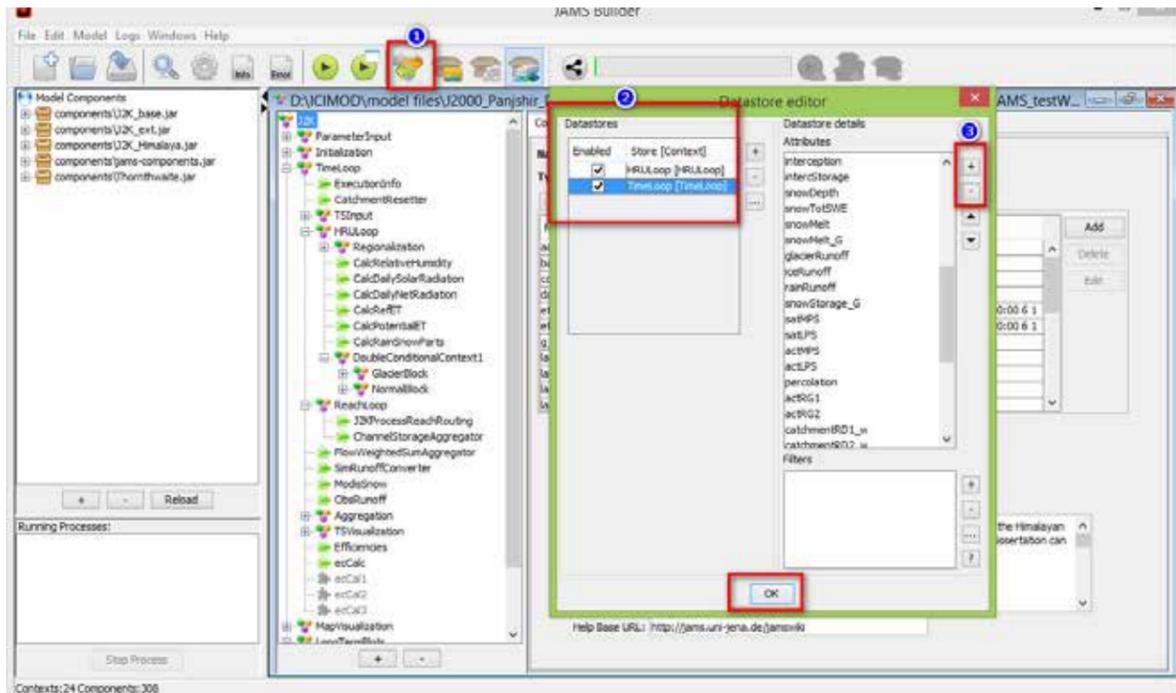


FIGURE 62 SELECTION OF PARAMETERS FOR DATA VISUALIZATION



This example shows data from the 'tmean' data set (mean temperature).

The box at the bottom left contains the following information on the data set:

- Name of the data series.
- Data type.
- Starting point of the time scales.
- End point of the time scales.
- Data density (step size between two data sets).
- Default value, in case no data is available.

The box on the right-hand side contains the following functions:

- Close Tab — closes the data set.
- Time Plot — displays the selected data set (of at least one station) in a diagram. The point in time corresponds to the X-axis.
- Data Plot — displays a comparison of data sets of at least two different stations in a diagram.
- Save Data — by which the selected data set can be saved.
- Statistics — statistical analysis of the selected dataset(s).
- Trend Estimation — provides the trend of the selected data.
- Write to Shapefile — exports the data in the shapefile.

The following example shows the selection of the data set 'Doabi' by clicking on the button 'Doabi'.

In the JADE window (Figure 63), the station data can be selected (by pressing 'Ctrl + A') and dragged to MS Excel directly. By clicking on the button 'Time Plot', the timescale for the measuring station 'Doabi' is displayed in a diagram. The colour and style of the graph can be changed by using the attributes shown in Figure 64.

By clicking on the button 'Statistics', a new window pops up showing the various statistical properties for the measuring station 'Doabi' (Figure 65).

FIGURE 63 USE OF THE JADE TOOL FOR THE INPUT DATA ANALYSIS

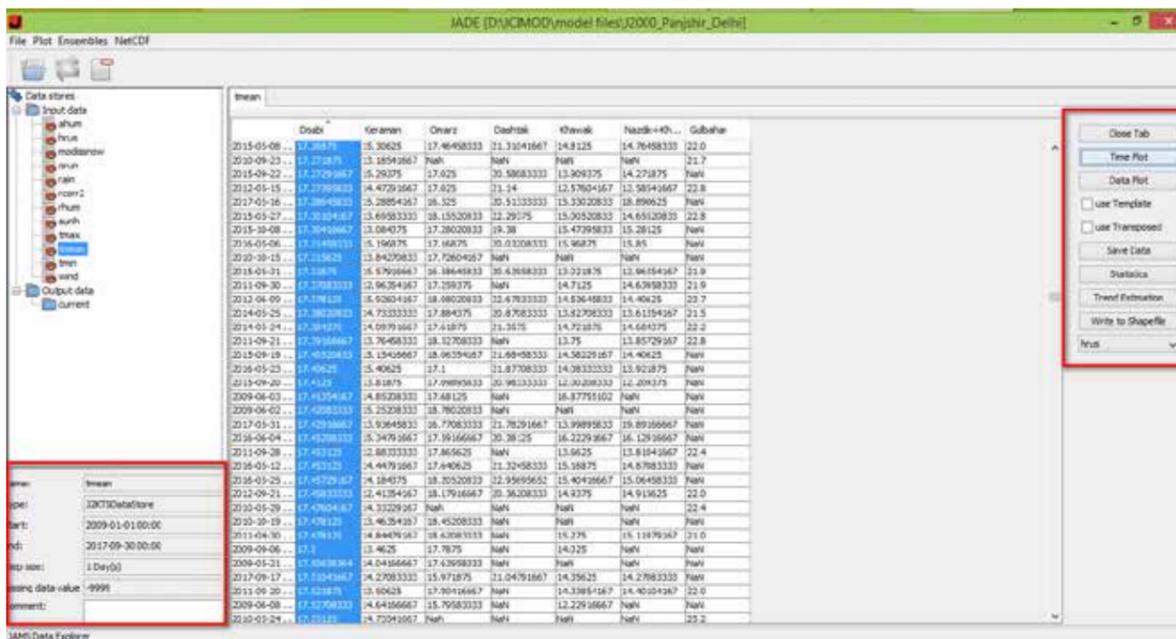
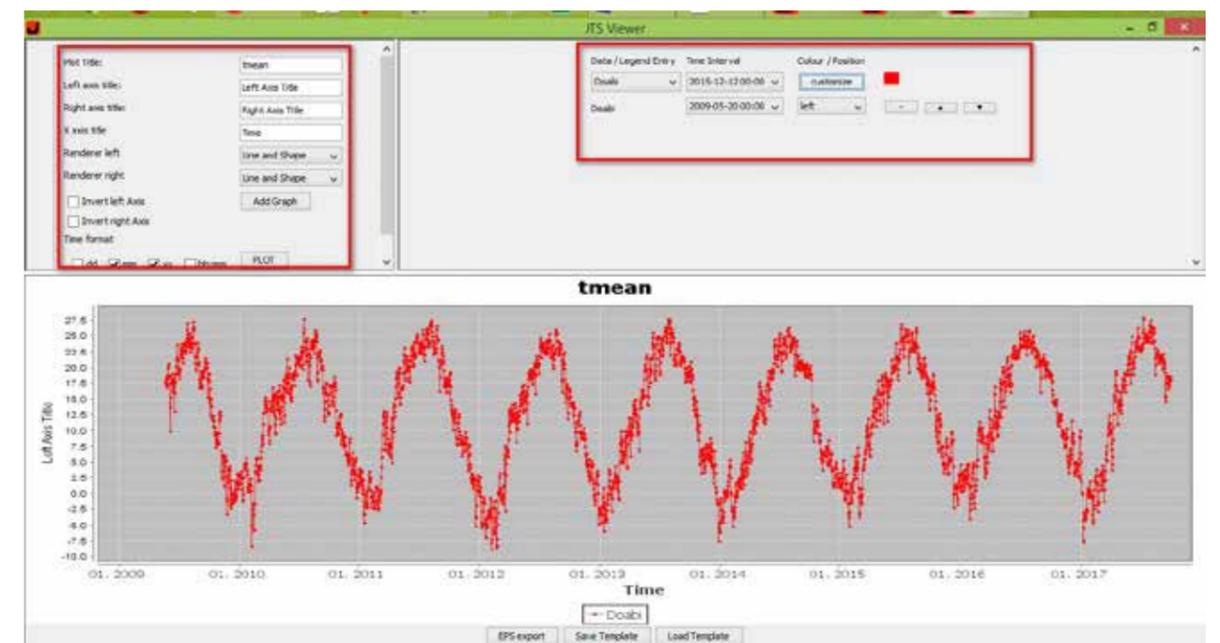


FIGURE 64 DISPLAY OF INPUT DATA USING JADE



Note: The application of the JADE tool for visualization and analysis is also shown in Exercises 8 and 10.

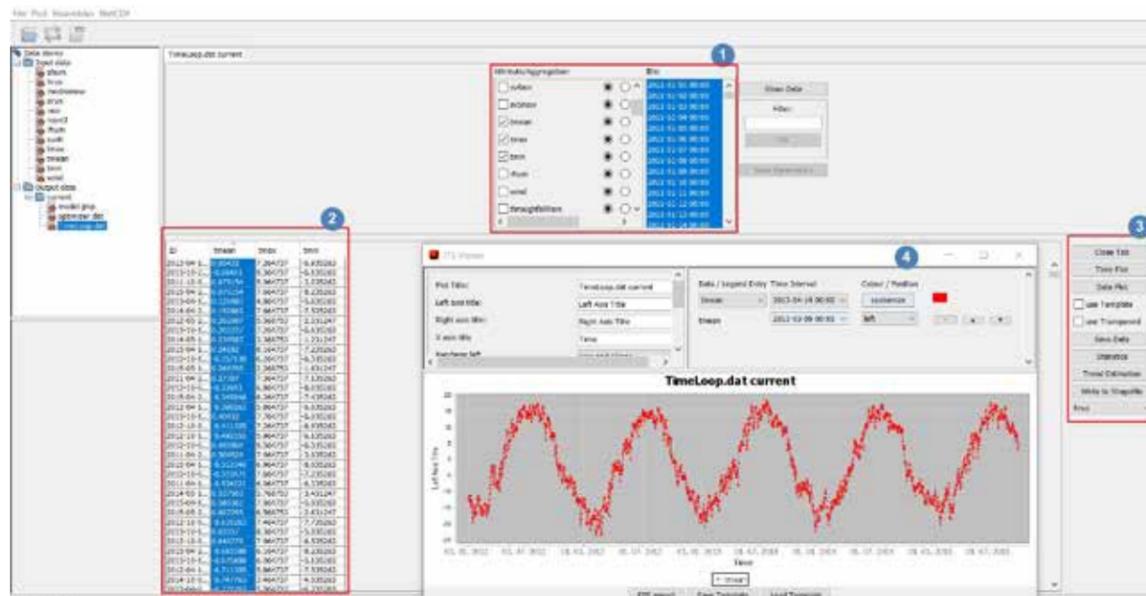
FIGURE 65 STATISTICS OF THE INPUT DATA USING JADE

Parameter	Doabi
Mean	12.507865559754501
Minimum	-8.81145833
Maximum	27.93541667
Lower quartile (Q.25)	4.67291667
Upper quartile (Q.75)	20.421875
Skewness	-0.23069742119903627
Median	13.26354167
Sum	38211.52928504984
Standard deviation	8.874667138414607
Range	36.746875
Curvature	-1.1771617571620474
Variance	78.7597168176561

3.6.1 Model output visualization

The output from the model can be analysed by different methods according to the needs of the user. Initially, one can assess the output water balance, as shown in Exercise 17, or the JADE tool used to analyse and visualize the outputs (Figure 66).

FIGURE 66 VISUALIZATION OF THE VARIABLES FROM JADE



After the model finishes its simulation, open the JADE  from the JAMS Builder toolbar or by pressing 'CTRL+J'.

3.6.1.1 VISUALIZING THE MODEL OUTCOME AT CATCHMENT SCALE

Using the timeloop.dat file (output>>current folder), one can visualize the results of selected variables. In the timeloop.dat file, the values are averaged for the whole basin on a daily basis.

Note: The timeloop.dat file can be directly opened in Excel (or copy pasted) to carry out further analysis in Excel as well.

You can see HRULoop.dat on the left-hand side. Double-click on 'HRULoop.dat'. Now you can see the tabulated data as shown in Figure 67.

Box 1 shows all attributes within the selected file. In our case, it contains the preconfigured attributes, namely area, precip, actET, snowToSWE, actET_mm, outRD1, and outRD2. Aggregation can be carried out according to the variables, either by using the mean or sum.

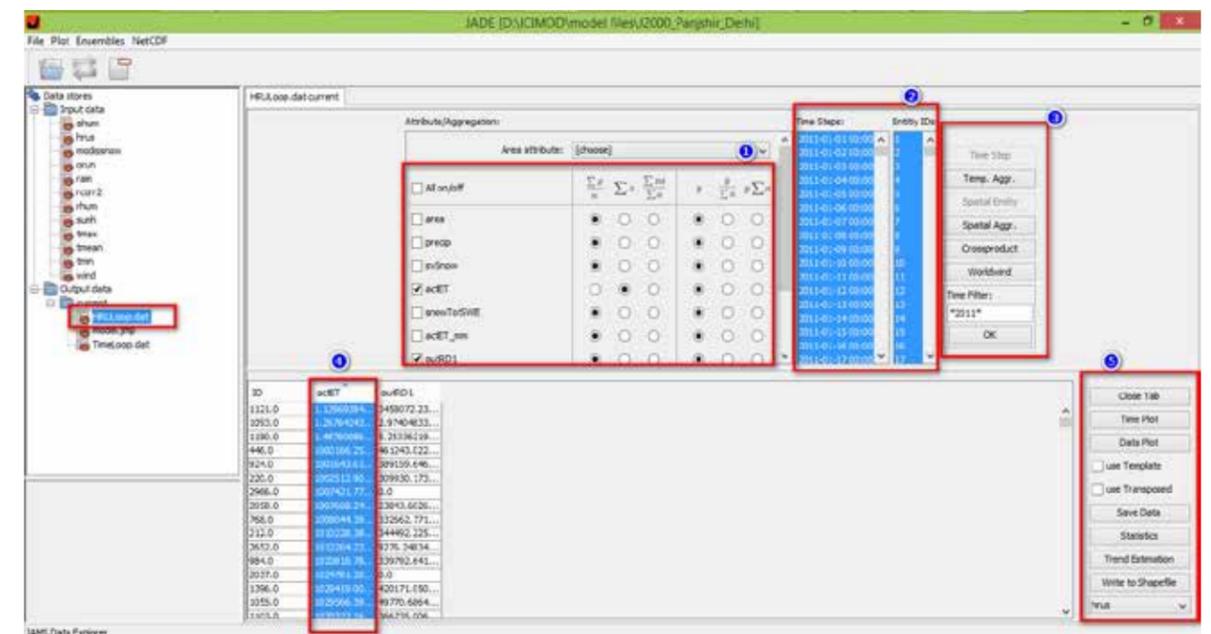
Box 2 shows the time steps for which data is available. J2000 is a daily model and in this case, the simulation was done from 1 January 2011 to 31 October 2014. Box 2 also lists the Entity IDs for all spatial model units. By using the shortcut 'Ctrl+A', all time steps or elements can be selected together.

In Box 3, several functions are available to aggregate the data. Select one or more attributes (for example, actET, outRD1) in Region 1 and a range of time steps and HRUs in Region 2. Then click on 'Time Step' to extract all data for that specific time step without further aggregation. This will generate a table, shown in Box 4. The second column shows the precipitation value for each of these entities. Accordingly, selecting a single ID and pressing the 'Spatial Entity' [Figure 67, Box 3] will result in a table showing a time series of, for example, actET for that specific unit (HRU). It will aggregate the data if you select more than one entity.

Box 5 offers various functions to plot, analyse and export aggregated data.

- Time Step [Figure 67, Box 3] - Lists the selected data of the chosen time step for all HRUs.
- Temp. Aggr. - Aggregates all data for selected HRUs for all time steps.
- Spatial Entity - Lists the selected data of the chosen HRUs for all time steps.
- Spatial Aggr. - Aggregates all data for selected time steps for all HRUs.
- Crossproduct - Lists all data for selected time steps for the selected HRUs.

FIGURE 67 DATA AGGREGATION IN JADE

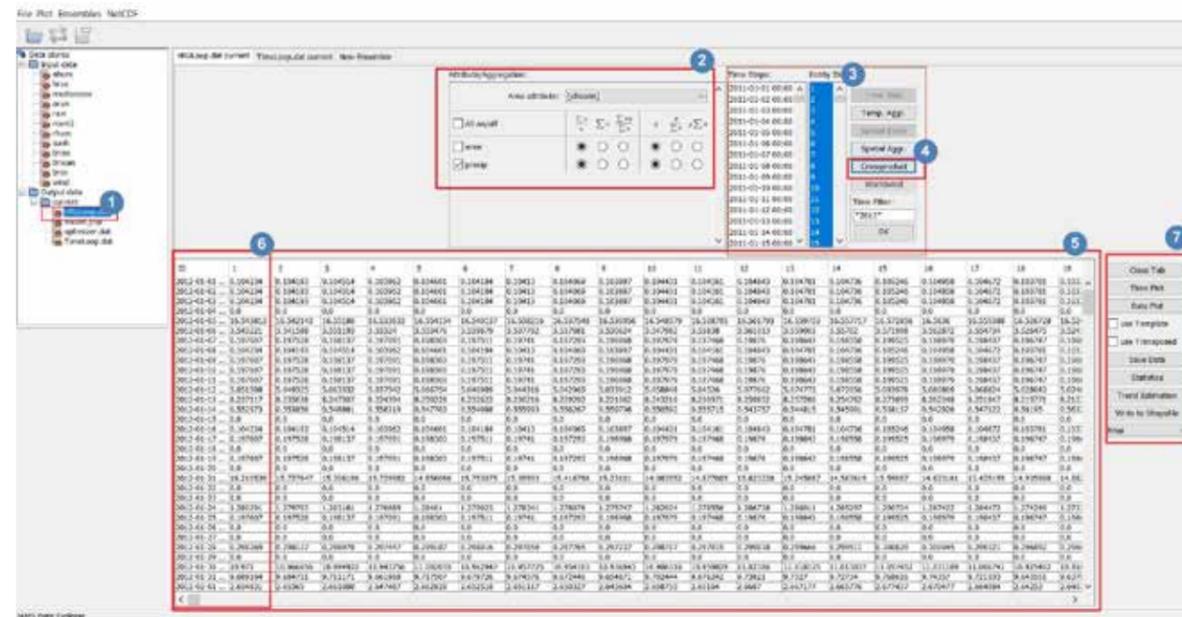


- Worldwind – Displays the selected variable overlaid on the digital globe in a new window. The map automatically zooms into your model's extent.
- Time Filter – Offers the possibility of listing aggregated data for particular months or years.

Note: The HRULoop.dat file is large in size as it contains the selected variables for each HRU. These files can be imported in Excel, but due to their large size, the importing is sometimes not smooth. It is therefore advisable to work using the JADE tool. Further, the cross-product data [Figure 68, step 4] can be generated, that is, all the data for selected time steps for selected HRUs [Figure 68, step 6]. This cross-product data can be saved in 'sdat' format [Figure 68, step 7], which is smaller in size than HRULoop.dat files.

The data can be aggregated by selecting a number of time steps, followed by using one of the aggregation functions. The selection of the time steps can be done manually, or automatically using wildcards.

FIGURE 68 VISUALIZATION OF THE OUTPUT FROM THE MODEL USING CROSSPRODUCT



- Manually:
 1. To select individual data: press the CTRL key and select/unselect individual time steps.
 2. To select a range of data: click on a first time step, press SHIFT, and click on a second time step to select the range.
 3. To select all data: click on the list and press CTRL+A.
- Automatically:
 1. Type a search term into the 'Time Filter' text box, using wildcards to match one or more time steps. For example,
 - 2012* to match all values in 2012.
 - *-10-* to match all October values.
 - *-*-01* to match all first days in all months.
 2. press ENTER/OK to mark all the matching time steps.

After the selection of time steps, you have to choose how data should be aggregated in time. This is controlled by two groups with three columns of radio buttons each (Figure 70). The first group (1) controls the type of aggregation:

$\frac{\sum x}{n}$: This will calculate the average of the values for the selected time steps.

$\sum x$: This will calculate the sum of the values for the selected time steps.

$\frac{\sum x\alpha}{\sum \alpha}$: This will calculate the weighted average of the values for the selected time steps. For this purpose, the area attribute must also be selected.

The time steps are usually equal, so there should be no need to use the weighted average option. However, depending on the unit of the aggregated attribute, a unit conversion may be required. This is handled by the options in the second group:

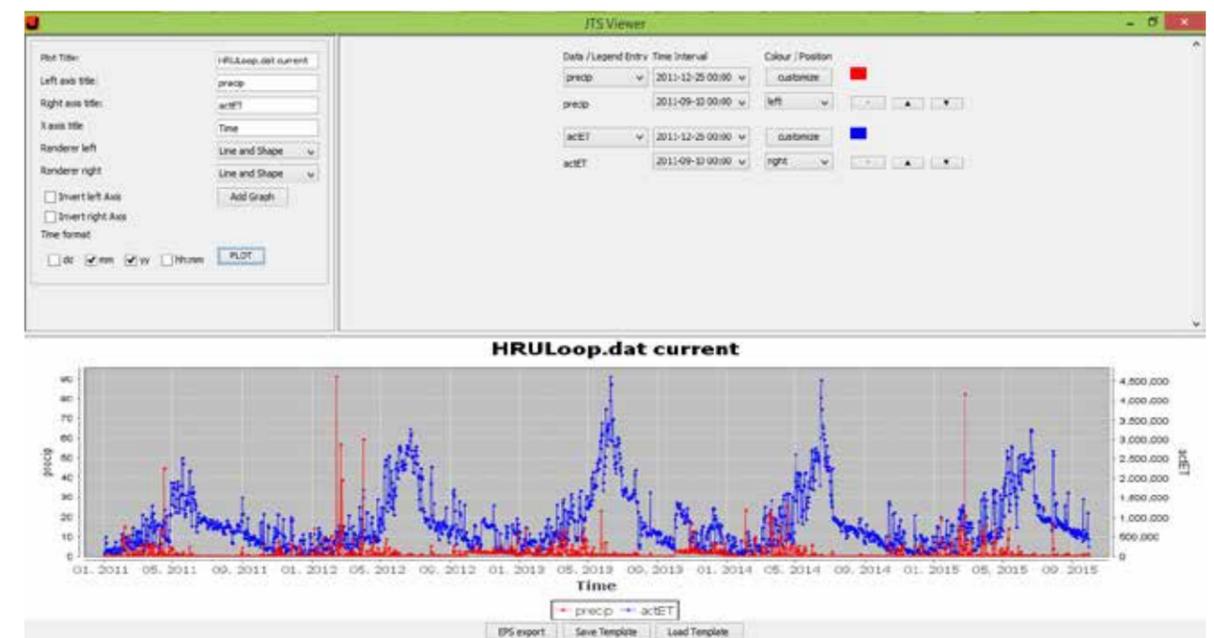
y leaves the aggregated value untouched.

$\frac{y}{\sum a}$ divides the aggregated value by the average/overall area. For this purpose, the area attribute [Figure 68, box 2] must also be selected.

$y\sum a$ multiplies the aggregated value with the average/overall area. Again, the area attribute must be selected.

After the selection of time steps, attributes, and aggregation/conversion options, press the 'Temp. Aggr.' button to start the data extraction process. The time plot can be displayed from the aggregated data, as shown in Figure 69. In addition to aggregating spatiotemporal data in space/time and displaying or exporting the results, JAMS offers the unique option of visualizing data in space and time, by making use of the NASA Worldwind engine.

FIGURE 69 VISUALIZATION OF THE TIME PLOT USING JADE



Once you have followed the steps described in Figure 70, in Worldwind, you should see a digital globe, which would have already zoomed in to the extent of the geometries of your spatial model units.

In order to display the model results using Worldwind (Figure 71), you first need to create a classification of your data and a related colour ramp by clicking on 'Classify' and then selecting the attribute to classify (for instance, actET). Set the data classification method (for example, quantile classification) to start the classification. After the processing is finished, select the colour range for the visualization of the result and click on 'Apply' to start the visualization. You can press the 'start/stop' buttons to start/stop the visualization. To access information about

FIGURE 70 STEPS FOR GENERATING WORLDWIND IN JAMS

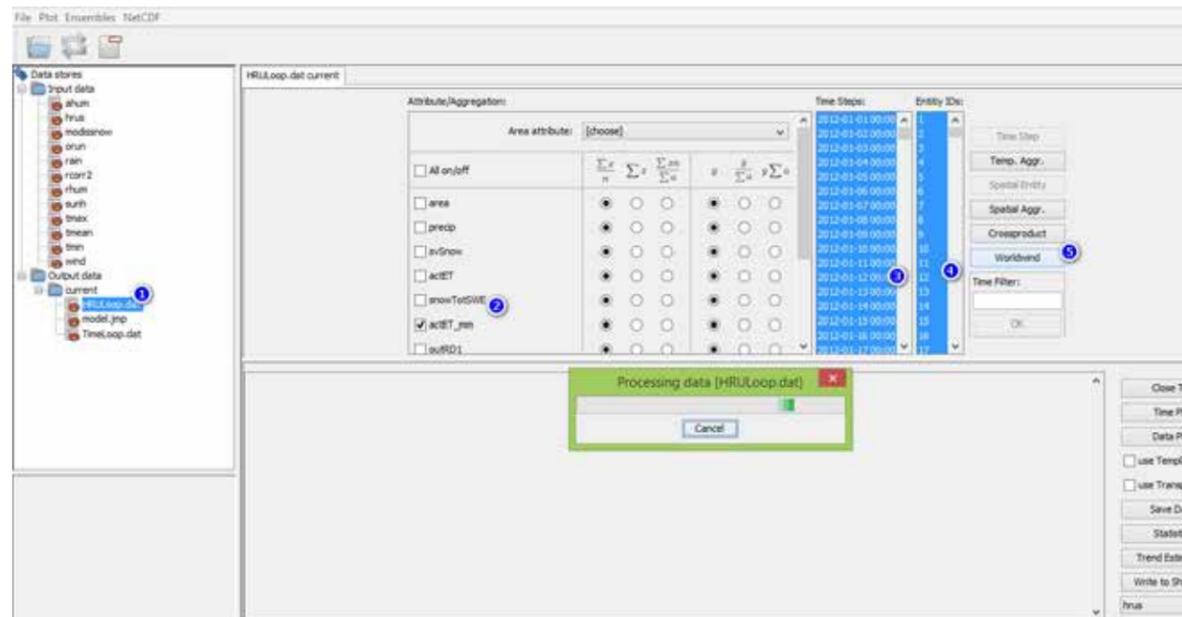


FIGURE 72 GATHERING INFORMATION ABOUT THE HRU USING WORLDWIND

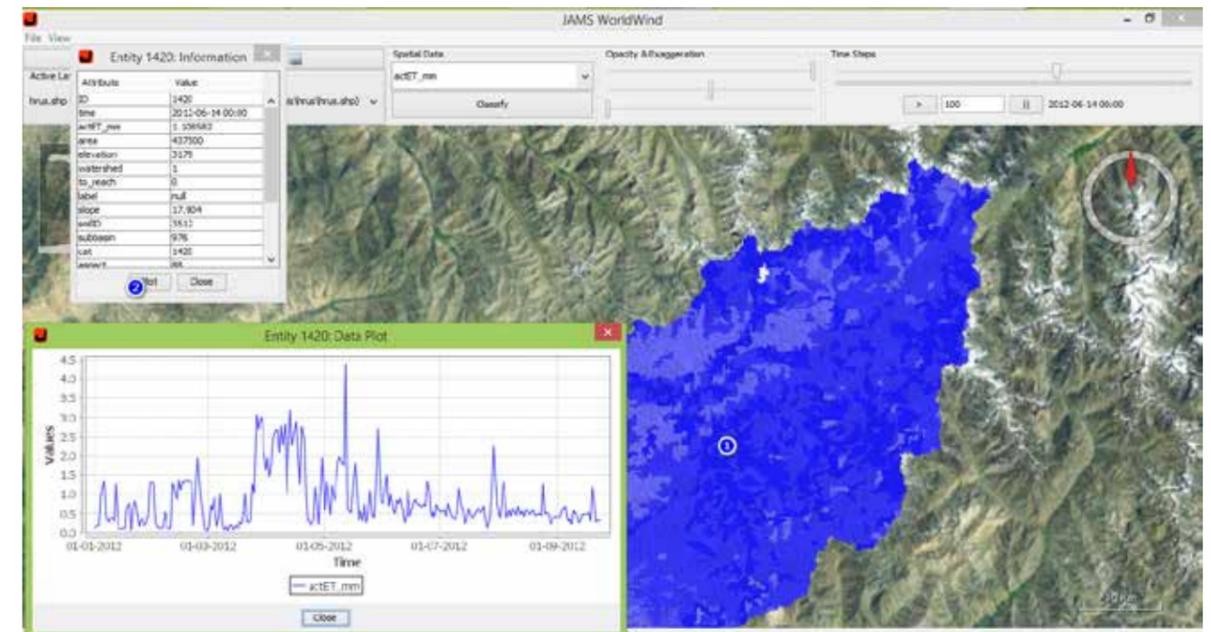
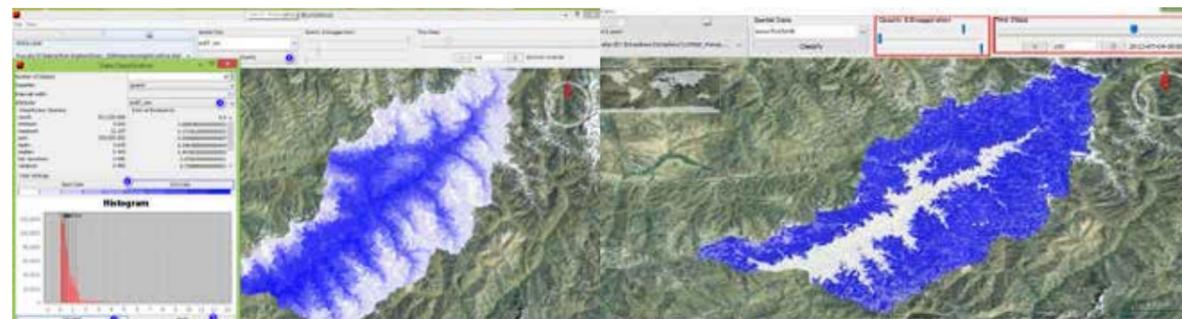


FIGURE 71 WORLDWIND FOR DATA VISUALIZATION SHOWING TWO DIFFERENT TIMES OF THE YEAR



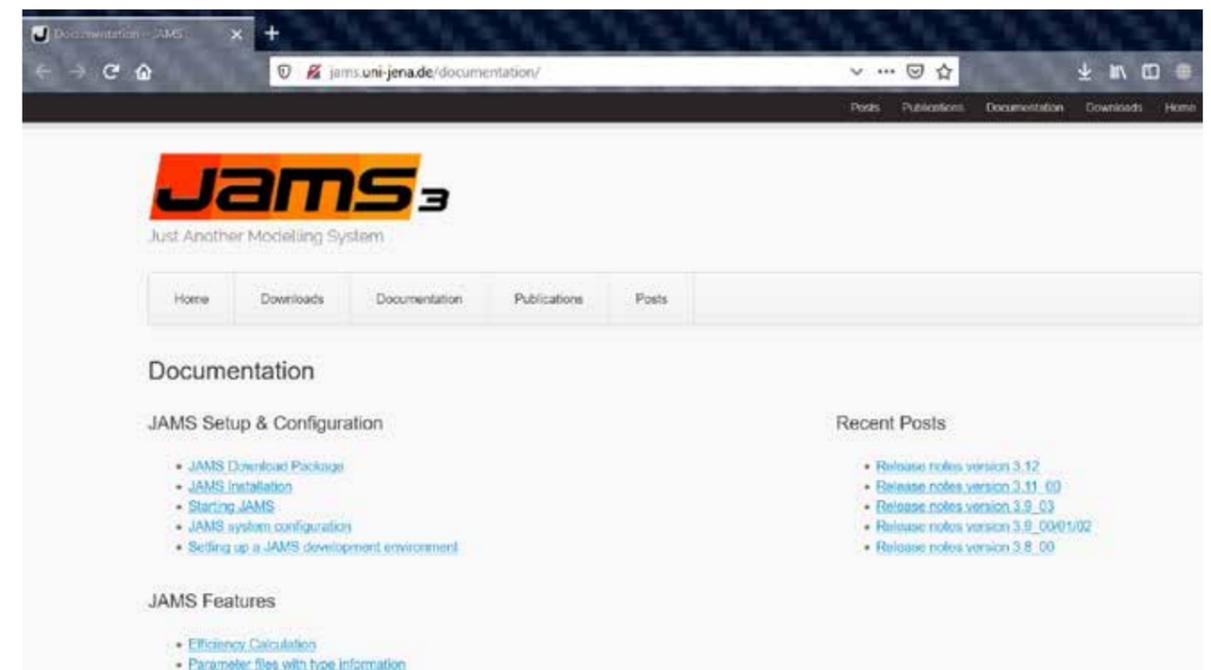
individual model entities, just move the pointer over the model unit. The extraction of all the data and the loading of the viewer may take some time. You can also get more detailed information about a particular HRU by clicking on any point of the displayed 'HRU' on the Worldwind (Figure 72).

Note: If your data is not displayed in Worldwind, then make sure the attributes corresponding to the IDs of your spatial model units are interlinked. Also, refer to the existing attributes of the hrus shapefile located at input/local/gis/hrus, and ensure that the HRUID column is there. If it is missing, you can manually add the column in arcGIS or QGIS.

Further details are available at < <http://jams.uni-jena.de/documentation/jams-features/aggregate-your-spatial-temporal-data-with-jams-data-explorer-jade/> >

More details of the model and its documentation (Figure 73) are available at: < <http://jams.uni-jena.de/documentation/> >

FIGURE 73 JAMS AND ITS DOCUMENTATION WEBSITE





Exercises

The exercises that follow are relevant for an assessment of the different water balance components of the Hindu Kush Himalayan region. The examples, and the exercises, are based in the Panjshir catchment.

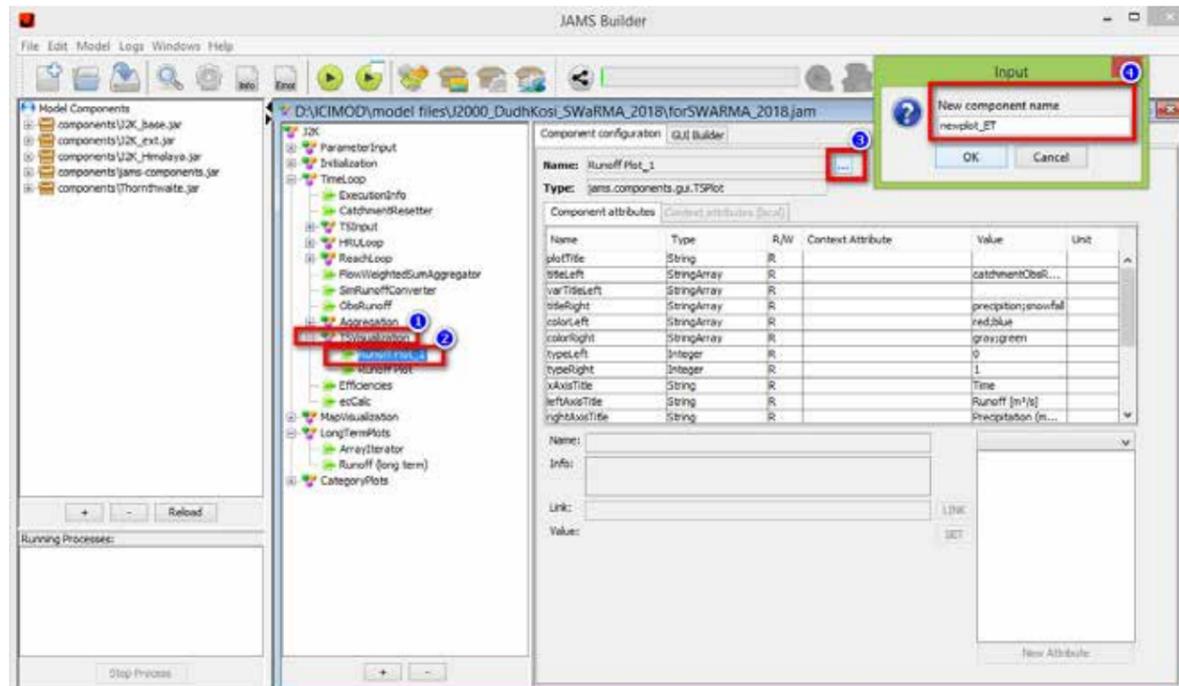
Exercise 1: Creating new plots for visualization in the J2000 model

Objective: To create new plots in the J2000 model

Procedure:

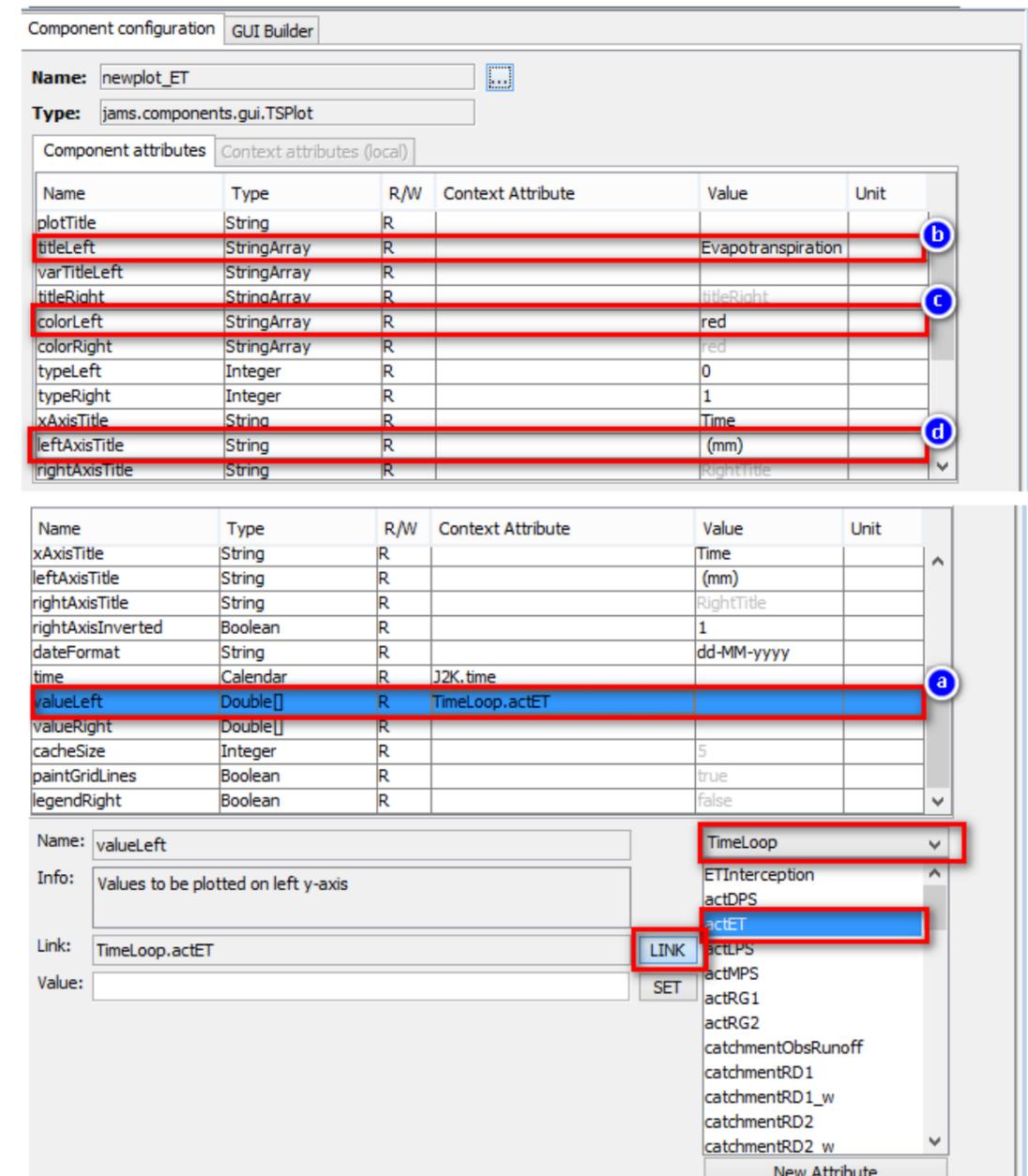
1. Open the file in JAMS Builder.
2. The 'TSVisualization' component of the JAMS Builder (Figure 74) brings up a graphic display of the different output variables. The 'TSVisualization' component can be expanded or collapsed (click the '+' and '-' signs respectively, on the left side, for this). The existing plots will be shown [Box 1].
3. The new plot can be created by using the existing plot. Drag one of the existing plots (for example, Runoff plot) and hold the CTRL key (a '+' sign will appear) and then let go of both the keys. The new plot will appear with a new name (Runoff overall_1) [Box 2].
4. Change the name of the component. Click the '[...]' box to the right of 'Name' [Box 3]. This will bring up a new window and you can change the name of the new plot (for example, 'newplot_ET') [Box 4].

FIGURE 74 PROCESS OF CREATING A NEW PLOT IN JAMS BUI



5. Mainly, four things have to be changed for the new plot (Figure 75):
 - a. valueLeft: Change the attribute you want to show, select the value from TimeLoop. (Example: Choose 'actET' from 'TimeLoop' and click on 'Link').
 - b. titleLeft: Provide the name of the legend used in the plot. (Example: Evapotranspiration is written and click on 'Set').
 - c. colorLeft: Provide the colour of the line names under the window 'Value'. (Example: Red is written).
 - d. leftAxisTitle: Provide the unit for the attribute you have selected from TimeLoop (Example: [mm]).
6. Run the model to see the new plot.

FIGURE 75 COMPONENT CONFIGURATION FOR THE NEW PLOT



Additional Exercise 1a: Plotting three variables of evapotranspiration (actET, potET, refET) in a single graph

Hint: Separate the names by a semicolon. Use the control key to select more than one attribute from TimeLoop (Figure 77). Result: Figure 76

FIGURE 76 VISUALIZATION OF EVAPOTRANSPIRATION PLOTS FROM ADDITIONAL EXERCISE 1A

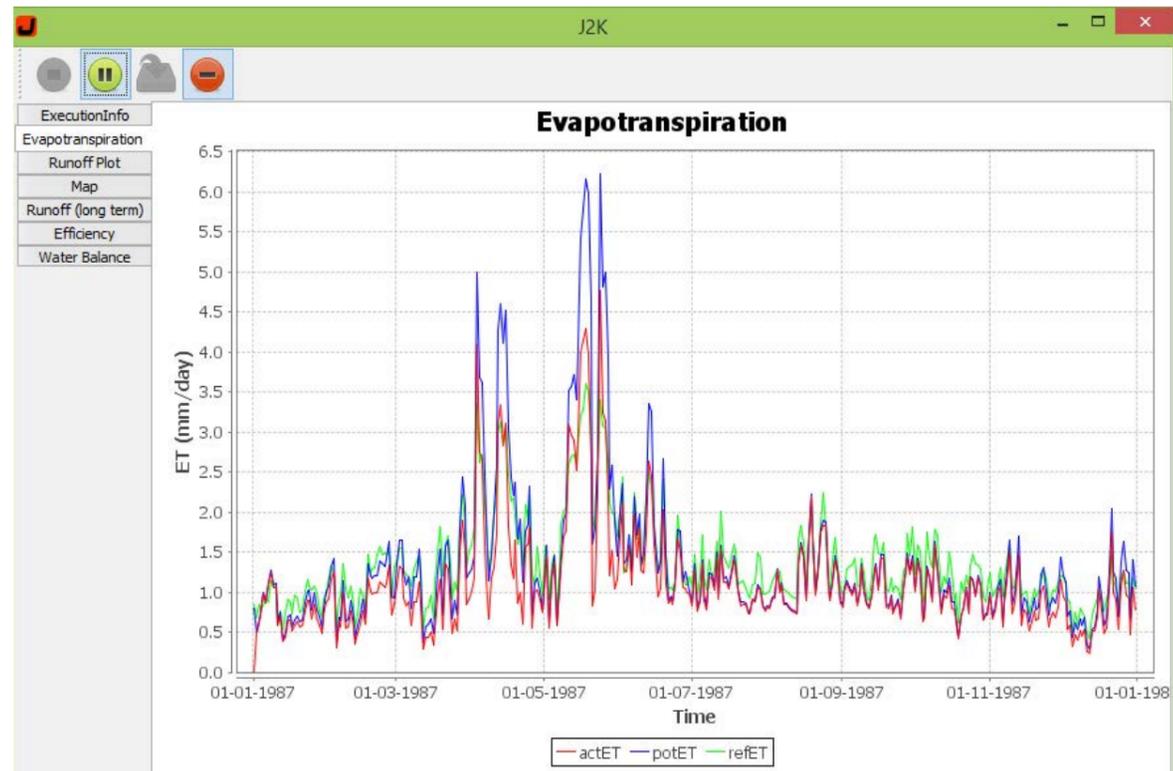


FIGURE 77 COMPONENT CONFIGURATION FOR THE VISUALIZATION OF EVAPOTRANSPIRATION PLOTS FROM ADDITIONAL EXERCISE 1A

Component configuration GUI Builder

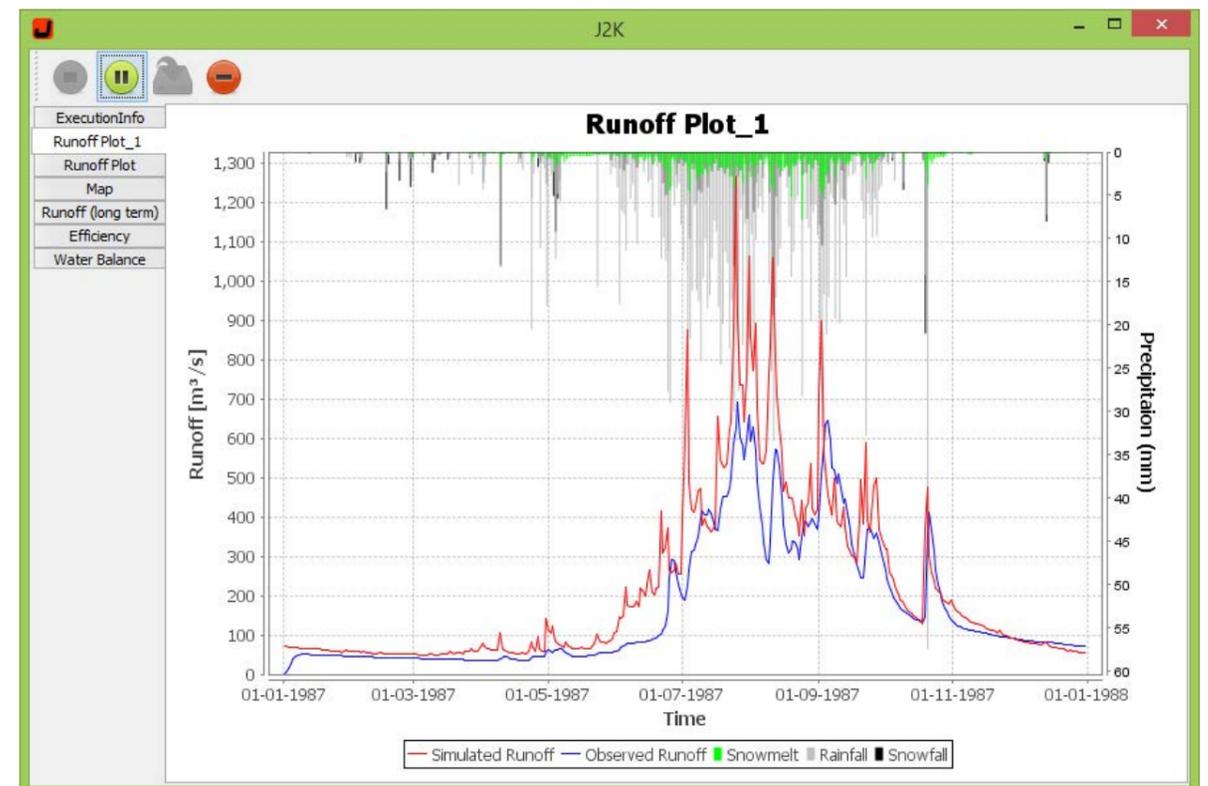
Name: Evapotranspiration

Type: jams.components.gui.TSPlot

Component attributes Context attributes (local)

Name	Type	R/W	Context Attribute	Value	Unit
plotTitle	String	R			
titleLeft	StringArray	R		actET;potET; refET	
varTitleLeft	StringArray	R			
titleRight	StringArray	R		titleRight	
colorLeft	StringArray	R		red;blue;green	
colorRight	StringArray	R		red	
leftAxisTitle	String	R		ET (mm/day)	
rightAxisTitle	String	R		RightTitle	
rightAxisInverted	Boolean	R		1	
dateFormat	String	R		dd-MM-yyyy	
time	Calendar	R	J2K.time		
valueLeft	Double[]	R	TimeLoop.actET;potET;refET		
valueRight	Double[]	R			
cacheSize	Integer	R		5	
paintGridLines	Boolean	R		true	
legendRight	Boolean	R		false	

FIGURE 78 VISUALIZATION OF THE RUN-OFF AND PRECIPITATION PLOT FROM ADDITIONAL EXERCISE 1B



Additional Exercise 1b: Plotting the graph with information in both axes

1. Plot simulated and observed discharge in the left axis and snowmelt, rainfall, and snowfall in the right axis by creating a new plot.
2. Provide a title and colour to the variables and run the model to see the new graph.

Result: Figure 78

Hints:

At valueLeft: Select 'catchmentObsRunoff;catchmentSimRunoff_qm' from the 'TimeLoop' and click on 'link'.

At colorLeft: Write 'red;blue' and click on 'set'.

At titleLeft: Write 'Simulated Runoff;Observed Runoff' and click on 'set'.

At leftAxisTitle: Write 'Runoff [m³/s]' and set it.

Similarly,

At valueRight: Link TimeLoop.snowMelt;svRain;svSnow.

At colorRight: Set green;lightgray;black.

At titleRight: Set Snowmelt;Rainfall;Snowfall.

At rightAxisTitle: Set precipitation (mm).

And finally, set value as 'true' in rightAxisInverted.

Exercise 2: Plotting the input variables of the model

Objective: To acquire information on the input files and plot them

Procedure:

This exercise will help understand the input files. The first exercise teaches us the method for understanding the climatic/hydro-meteorological input file. The additional exercise helps us explore the parameter input files some more.

Precipitation vs discharge is plotted in the first exercise:

1. Go to the folder containing the model input data.
2. Open the precipitation data (rain.dat) and paste it into Excel (you can use a notepad editor such as Notepad++).
3. Select the year 1987, and calculate the average daily precipitation. To take the average value, use the formula available in Excel (=AVERAGE(number1, number2, number3,number4...)) as shown in Figure 79.

FIGURE 79 PROCESS FOR TAKING AN AVERAGE OF THE DATA OF MANY STAT

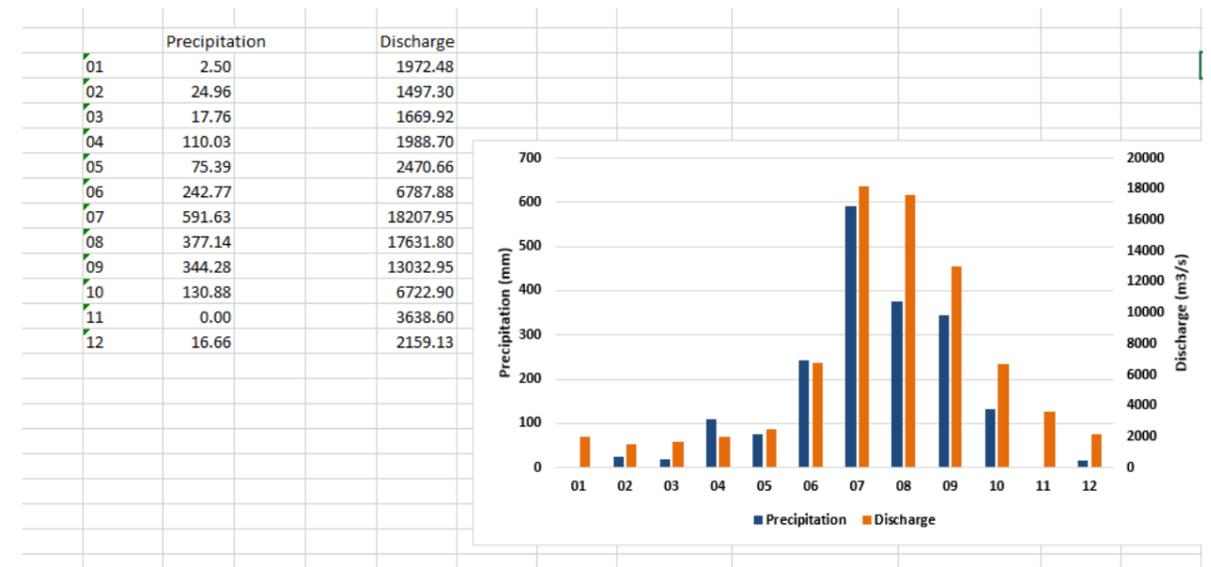
1/2/1987 0:00	0	0	0	0	0	0	0
2/2/1987 0:00	1.809896	2.191074	1.666763	0	0	0.402112	0
3/2/1987 0:00	0.403937	0.01518	0.340366	1.346045	0.431041	0	0
4/2/1987 0:00	1.645489	1.752083	1.795931	0.667871	2.7236	1.146112	4.33E-04
5/2/1987 0:00	1.181623	0.685823	1.30078	1.20704	5.162224	1.822377	8.57E-04
6/2/1987 0:00	0	0	0	0	0	0	0
7/2/1987 0:00	0	0	0	0	0	0	0
8/2/1987 0:00	0	0	0	0	0	0	0
9/2/1987 0:00	0	0	0	0	0	0	0
10/2/1987 0:00	0	0	0	0	0	0	0
11/2/1987 0:00	0	0	0	0	0	0	0
12/2/1987 0:00	0	0	0	0	0	0	0

4. Copy the average precipitation in a separate sheet along with the date.
5. Similarly, open the discharge data (orun.dat) in Notepad++ and copy it into Excel.
6. Keep the precipitation and discharge data in different columns (Figure 80).
7. Convert the daily data to monthly data (Figure 81) (see the next exercise for details).

FIGURE 80 ARRANGEMENT OF PRECIPITATION AND DISCHARGE DATA

	A	B	C	D	E
1	Date	Precipitaion	Discharge		
2	1/1/1987	0	72.45		
3	1/2/1987	0	71.185		
4	1/3/1987	0	69.92		
5	1/4/1987	0	68.655		
6	1/5/1987	0	68.655		
7	1/6/1987	0	68.655		
8	1/7/1987	0	67.39		
9	1/8/1987	0	66.125		
10	1/9/1987	0	66.125		
11	1/10/1987	0	64.86		
12	1/11/1987	0	66.125		
13	1/12/1987	0.289612365	64.86		
14	1/13/1987	0	64.86		
15	1/14/1987	0	64.86		
16	1/15/1987	0	63.595		
17	1/16/1987	0	63.595		
18	1/17/1987	0	63.595		
19	1/18/1987	0	62.33		
20	1/19/1987	0	62.33		
21	1/20/1987	0	62.33		

FIGURE 81 BAR GRAPH FOR PRECIPITATION AND DISCHARGE

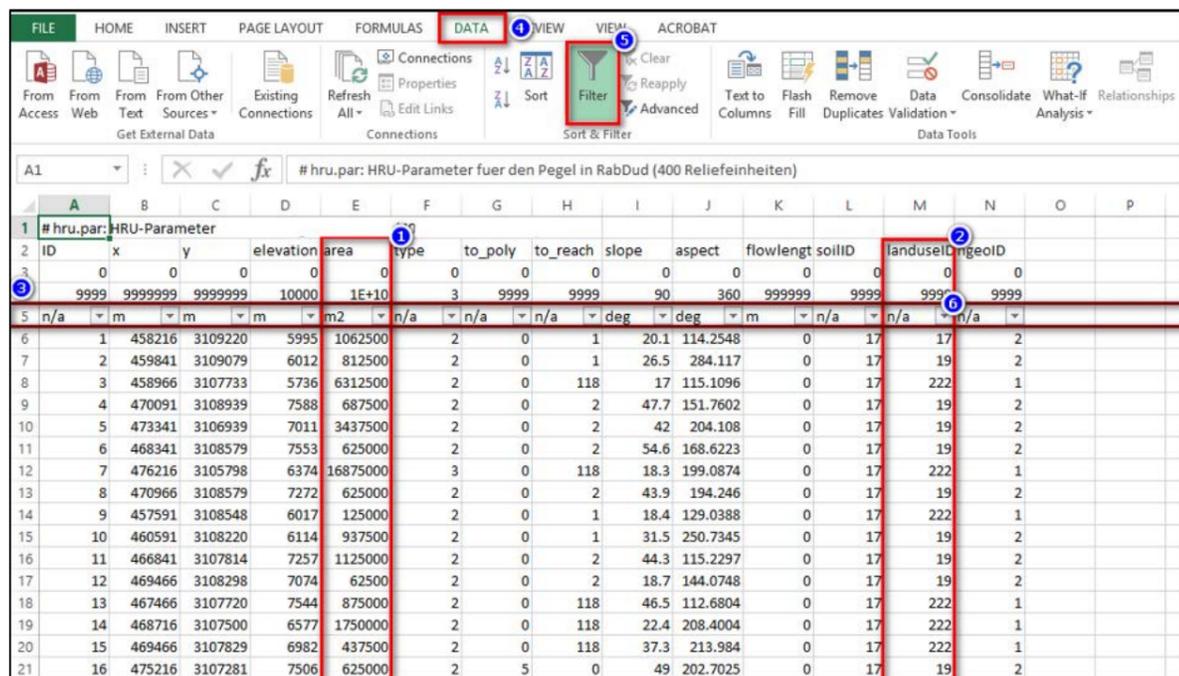


Additional Exercise 2a: Calculating the percentage of different land use types

- Go to the parameter folder.
- Open the file parameter/hrus.par in Excel.
- Identify the area and land use located in the file (Figure 82, steps 1 and 2)
- Arrange a similar type of land use type (landuseID).
 - Select the row just above the row at which the data starts (step 3).
 - Go to the DATA tab (step 4).
 - Click on 'Filter' (step 5).
 - Arrange a similar landuseID on the basis of increasing or decreasing IDs by clicking on the filter tool in the land use row (step 6).
- Observe the area of similar land use type.
- Calculate the sum of the area of similar land use types.
- Now you can convert the sum of each type of land use to a percentage value (sum of each land use ID/sum of total area*100) to know the percentage of each land use type.

To know the details and name of each land-use ID, you can open the 'landuse.par' file located in the same folder.

FIGURE 82 USING THE FILTER BUTTON IN EXCEL TO SORT THE DATA



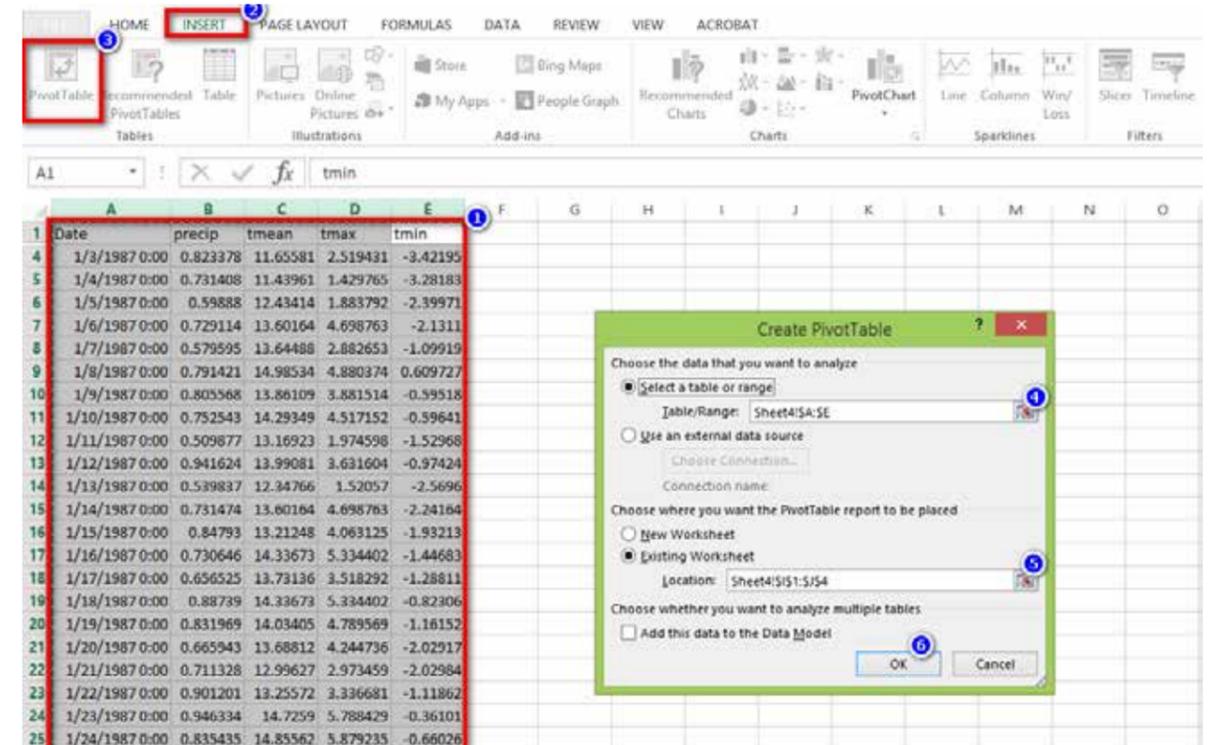
Exercise 3: Converting daily data to monthly data

Objective: To learn about the PivotTable

Procedure:

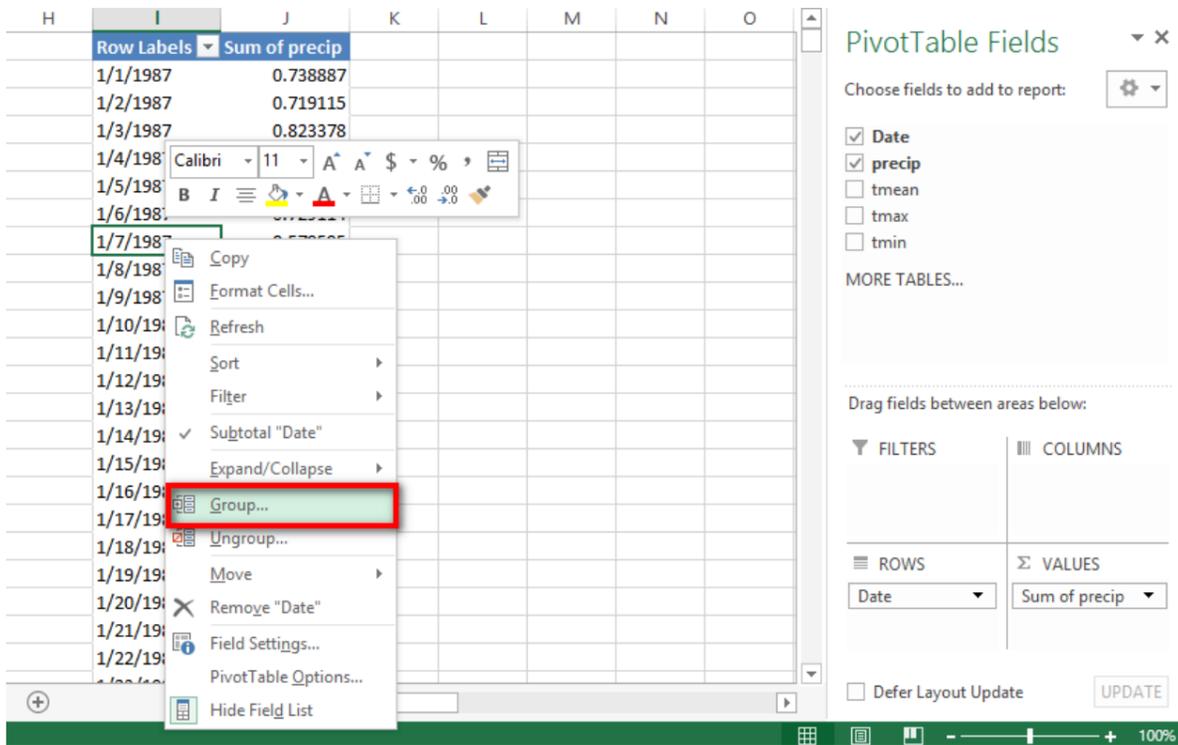
- Open the data in Excel.
- Select the data (Figure 83, [Box 1]).

FIGURE 83 INSERTING THE PIVOTTABLE



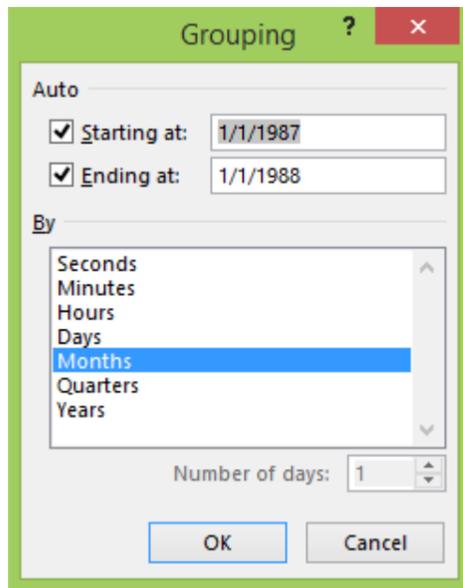
- Go to the INSERT tab [Box 2].
- Click on the PivotTable [Box 3].
- In the new pop-up window, make sure you have selected the required data [Box 4] and provided the worksheet for the display of the PivotTable [Box 5].
- Click OK at the end [Box 6].
- In 'PivotTable', select the date and the variable (for example, precip).
- Right-click on one of the dates and click on Group (Figure 84).

FIGURE 84 USING THE GROUP FUNCTION TO CONVERT THE DAILY DATA TO MONTHLY DATA IN THE PIVOTTABLE



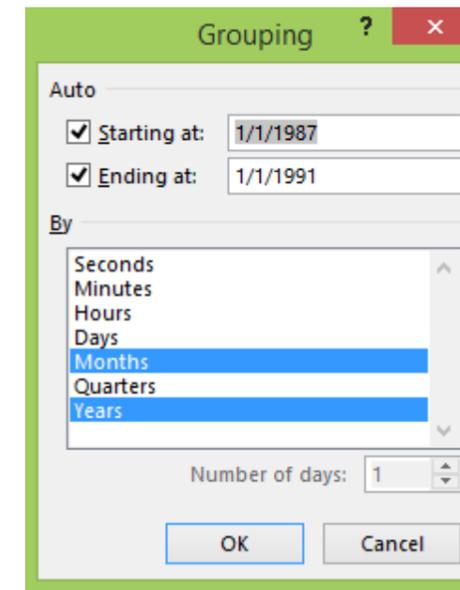
9. Select the kind of grouping (in Figure 85, grouped on the basis of months).

FIGURE 85 GROUPING THE VARIABLES ACCORDING TO MONTHS



10. If you have more than a year of data and want to group the data by both years and months, select both the variables (Figure 86).

FIGURE 86 GROUPING THE VARIABLES ACCORDING TO BOTH MONTHS AND YEARS



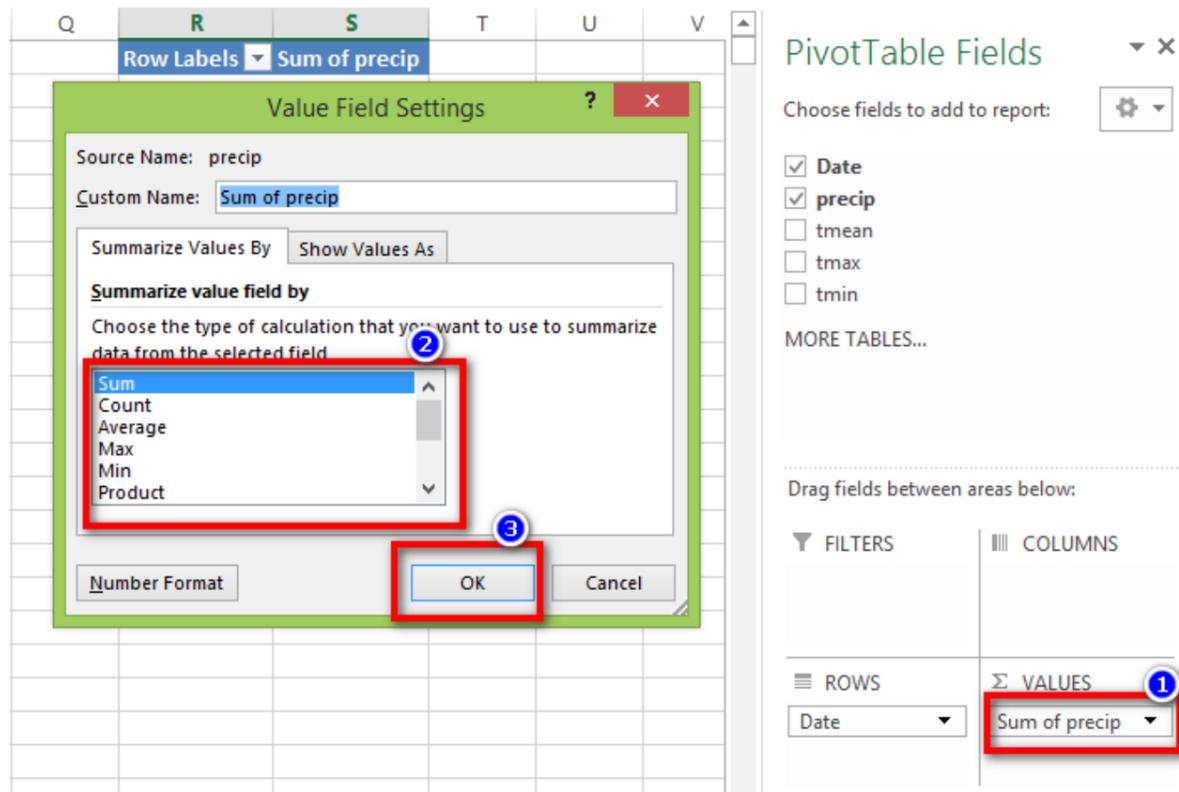
11. The data will be grouped monthly as follows (Figure 87):

FIGURE 87 GROUPING THE DAILY DATA BY MONTH

Row Labels	Sum of precip
1987	
Jan	25.565802
Feb	52.113278
Mar	50.076651
Apr	139.495818
May	113.959252
Jun	263.673448
Jul	569.023987
Aug	384.919391
Sep	344.553027
Oct	144.340371
Nov	23.148793
Dec	36.827022

12. You can also choose the type of calculation to summarize the data (Figure 88). Click on VALUES to see the value field setting, and you can choose either sum, count, average, etc.

FIGURE 88 WAYS TO SUMMARIZE THE DATA USING THE PIVOTTABLE



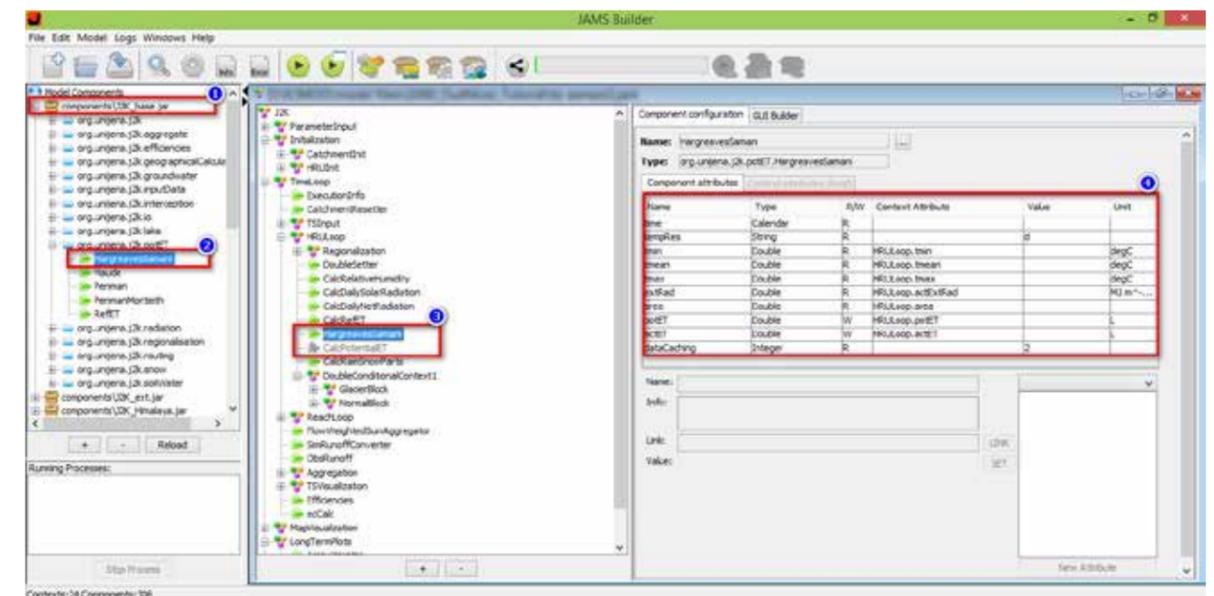
Exercise 4: Observing the difference in actual evapotranspiration on changing the module from Penman–Monteith to Hargreaves–Samani

Objective: To understand the difference between the two evapotranspiration formulae

Procedure:

1. Run the model with the Penman–Monteith evapotranspiration equation (which is, by default, in the model), and save the output in an Excel sheet.
2. Now open the model in JAMS Builder.
3. In the model component, open 'components/J2K_base.jar' by clicking on [+] (Figure 89, Box 1).

FIGURE 89 SELECTION OF THE HARGREAVES–SAMANI MODULE

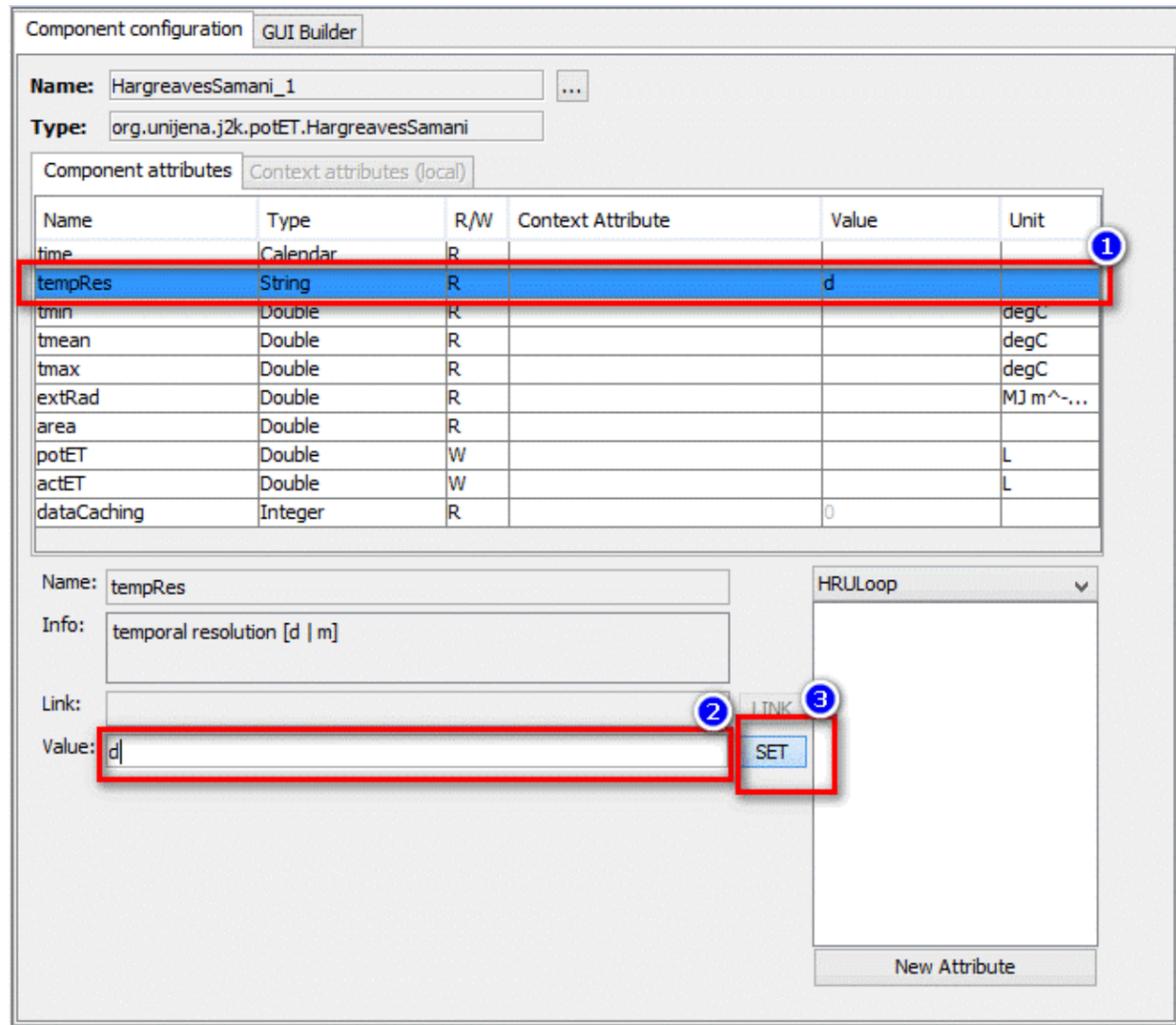


4. Open org.unijena.j2k.potET by clicking on [+] (Box 2).
5. Drag Hargreaves–Samani to the J2K model component and near the location where CalcPotentialET is located (in J2k>TimeLoop>HRULoop) (Box 3).
6. Right click on CalcPotentialET and disable it (Box 3).
7. Now go to the component attribute of Hargreaves–Samani and fill the 'Context Attribute' with reference to the CalcPotentialET (Box 4).

8. To fill the component attribute:

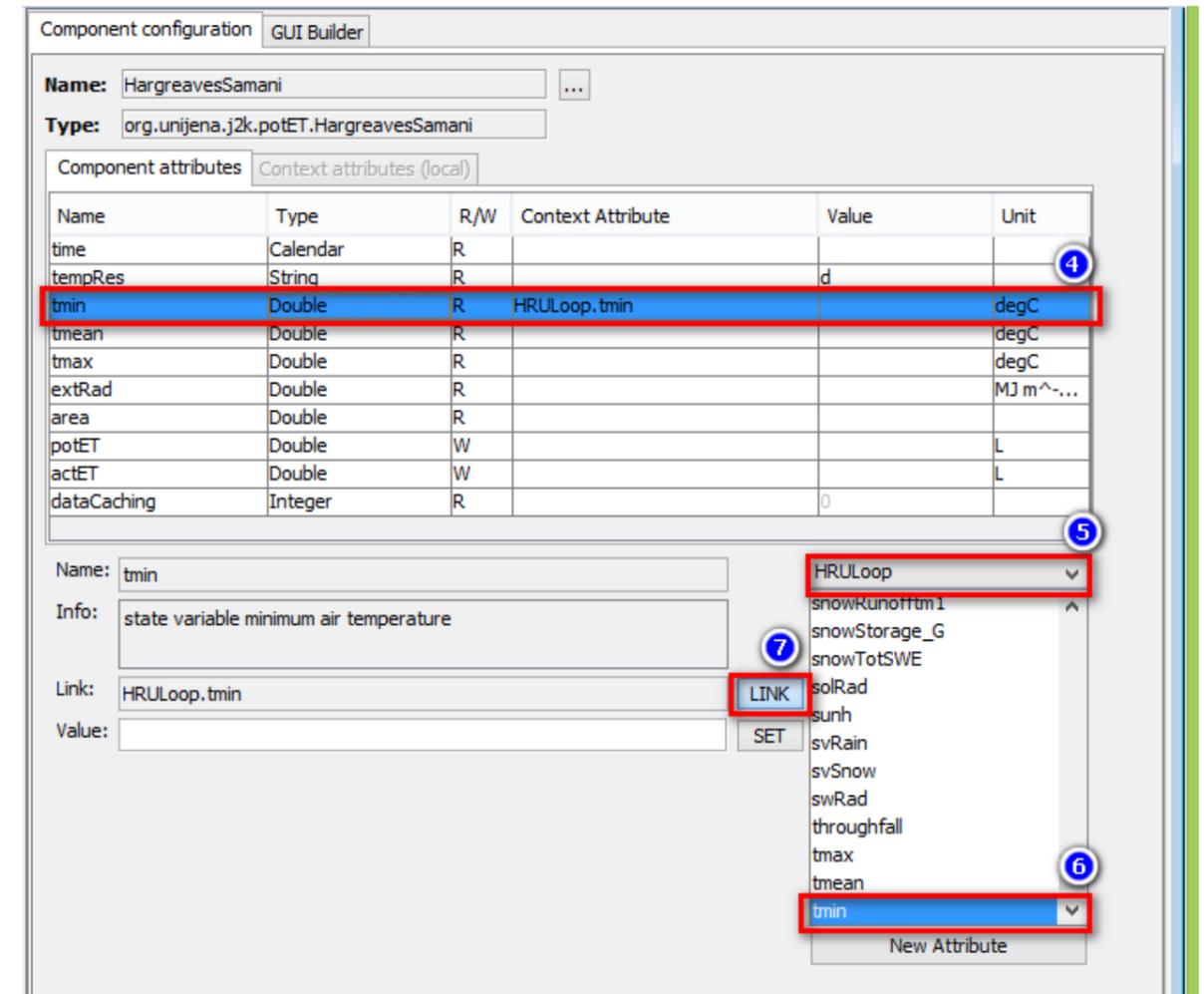
- Select the component attribute (for example, tempRes) (Figure 90, Box 1).
- Go to the value and type the value (for example, 'd') (Box 2).
- Click SET (Box 3) and observe how the data fits into the component attribute.

FIGURE 90 INSERTING THE VALUE IN THE COMPONENT CONFIGURATION



- Similarly, select the next component attribute (for example, tmin) (Figure 91, Box 4).
- Select HRUloop (Box 5).
- Select the required attribute (for example, tmin) (Box 6).
- Click on LINK (Box 7).
- Observe how it is linked in the Context Attribute.
- Continue a similar process for the other names provided in the Component attributes.
- If you are confused, take reference from CalcPotentialET.

FIGURE 91 INSERTING THE CONTEXT ATTRIBUTE IN THE COMPONENT CONFIGURATION



Before running the model don't forget to unselect the 'rs' and 'ra'. Here is the step:

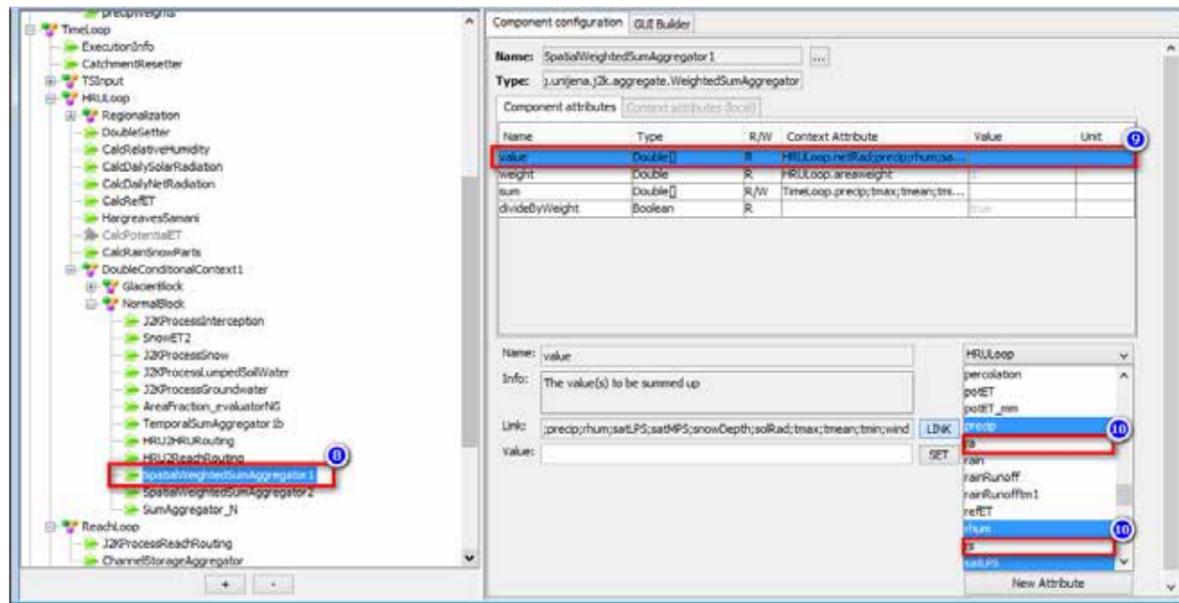
- Go to SpatialWeightedSumAggregator1 (Hint: HRUloop>DoubleConditionalContext1>NormalBlock>SpatialWeightedSumAggregator1) (Figure 92, step 8).
- In Component attributes, select the value (step 9).
- In HRUloop, unselect the 'rs' and 'ra' attribute by clicking 'Ctrl + rs' and 'Ctrl + ra'.

9. Now run the model.

10. Observe the plots.

(Is there any change in the run-off plot and soil moisture?)

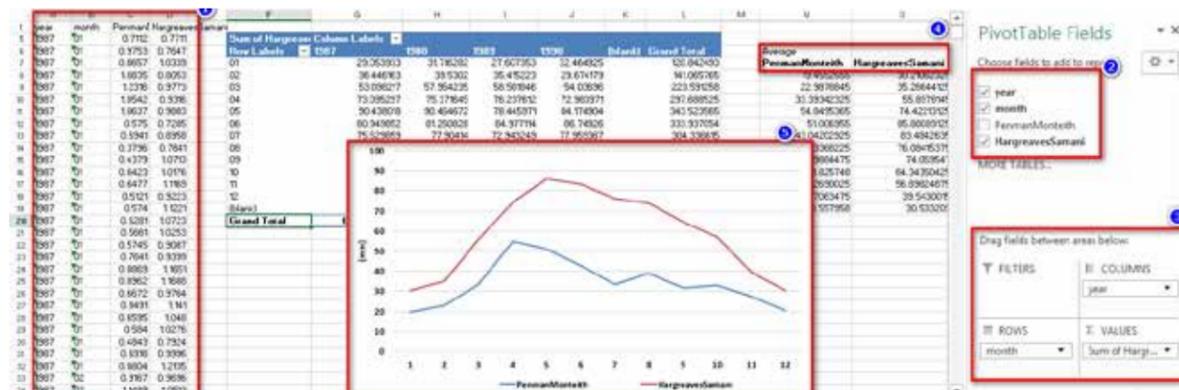
FIGURE 92 SELECTION AND REMOVAL OF DIFFERENT ATTRIBUTES IN SPATIAL WEIGHTED SUM AGGREGATOR



Now you have successfully run the model using both the Penman–Monteith and Hargreaves–Samani equations for evapotranspiration.

11. Collect actual evapotranspiration numbers of both equations (Figure 93, Box 1).
12. Use the PivotTable to get the monthly average (Boxes 2 and 3) (also refer to Exercise 3, page 69).
13. Plot the line graph from the data (steps 4 and 5).
14. You can clearly observe the difference in the value on using these two equations for evapotranspiration.

FIGURE 93 METHOD OF CREATING GRAPHS USING THE PIVOTTABLE IN EXCEL



Exercise 5: Adapting the evapotranspiration values from the Hargreaves–Samani method by developing calibration parameters

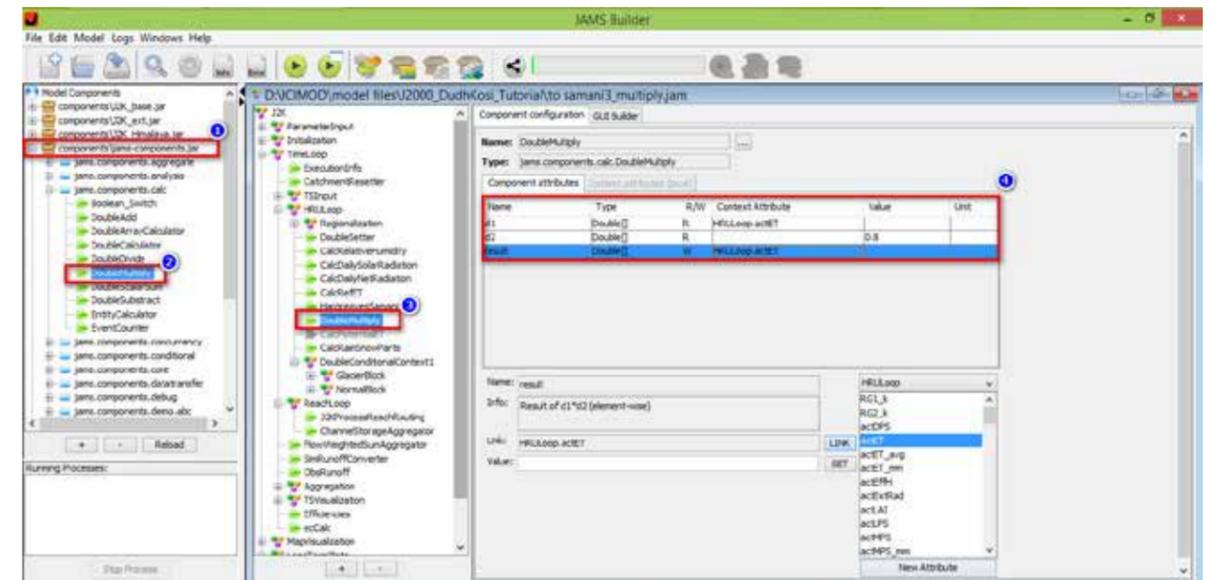
Objective: To learn about making an adjustment in the different outcomes

Procedure:

We can use the different operational functions such as multiplication, addition or division to adjust any value obtained from any module. In this exercise, the multiplicative function is used to adjust the ET value calculated via the Hargreaves–Samani method with respect to the ET value via Penman–Monteith.

1. Run the model with the Penman–Monteith evapotranspiration equation. Save the result.
2. Run the model with the Hargreaves–Samani evapotranspiration equation. (follow Exercise 4). Save the result.
3. Now, open the model in JAMS Builder.
4. Expand 'jams.components.calc' by clicking on '+' in the 'components\jams-components.jar' section in Model Components (Figure 94, [Box 1]).

FIGURE 94 USE OF THE MULTIPLICATIVE FUNCTION IN JAMS



5. Select 'Double multiply' [Step 2].
6. Drag it near 'Hargreaves–Samani' [Box 3].
7. In Component configuration, for 'd1', select one of the attributes from the HRULoop (example: actET) and click on 'LINK'.
8. Insert the value of 'd2' as 0.8 (or any suitable value) [Box 4].
9. Now, keep the result attribute the same as previously selected (example: same actET).

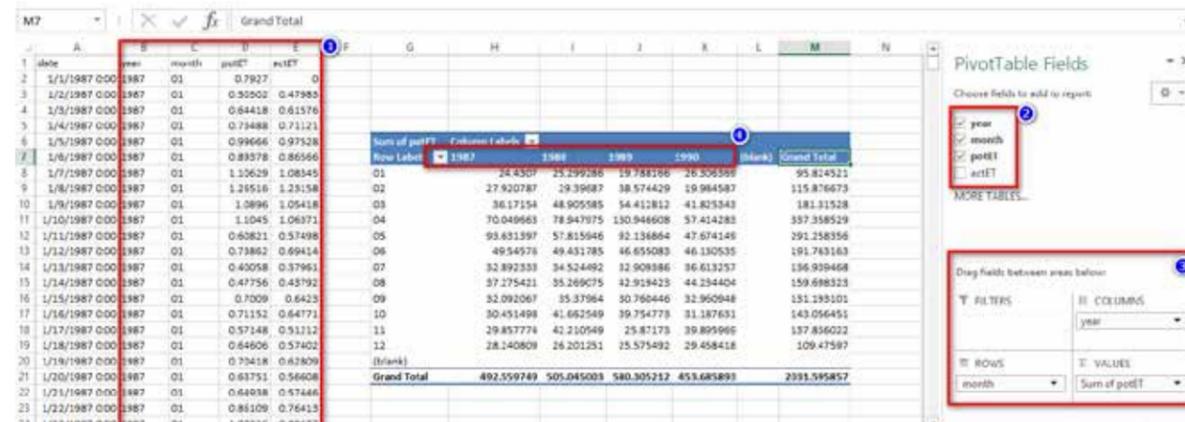
Hint: Now, the result is the same (example: actET) but is multiplied by 0.8.

- Save it and run the model.
- Save the result.
- Plot the line graph of the output (our example: actET) from the results of Penman–Monteith (the result from step 1), Hargreaves–Samani (from step 2), and the result from the multiplicative function (from step 11).

Did the multiplicative function minimize the gap between the ET values of Penman–Monteith and Hargreaves–Samani?

As an additional exercise, run the model with a different value of d2 and compare the outputs. Which value of d2 is able to minimize the difference of the ET values between Hargreaves–Samani and Penman–Monteith?

FIGURE 95 CREATING AVERAGES OF DATA IN A PIVOTTABLE



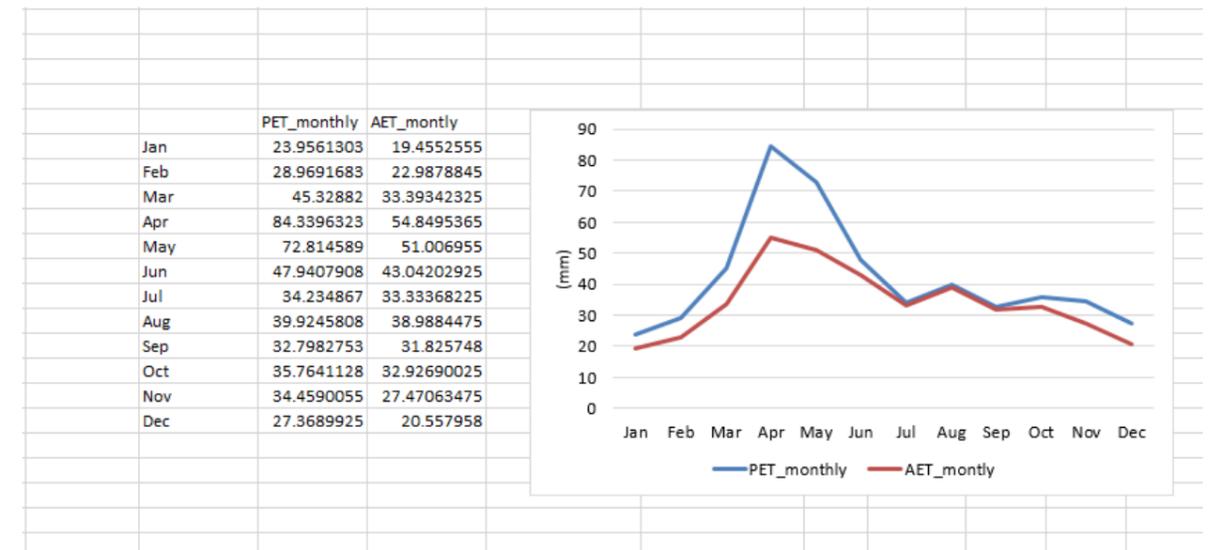
Exercise 6: Displaying the long-term averages of potential and actual evapotranspiration

Objective: Calculation and plotting of the long-term averages of different variables

Procedure:

- Open the timeloop.dat file (output/current/timeloop.dat) in Excel.
- Select the parameters potential evapotranspiration (potET) and actual evapotranspiration (actET).
- Create monthly data by using the PivotTable (Figure 95). (Select data as shown in Box 1, insert a PivotTable, select the month, year, and ET value as in Box 2, use the summation function to get the sum of evapotranspiration for each month as in Box 3).
- Calculate the average potET of each month from 1987 to 1990 as shown in Box 4. Hint: use =AVERAGE(number1,number2,number3...) to calculate the average of the given years in Excel. Similarly, calculate the average actET.
- Now we have the monthly averages of actual and potential evapotranspiration from 1987 to 1990.
- Plot this data by inserting the line graph in Excel. Figure 96 is our graph, how is yours?

FIGURE 96 AVERAGE MONTHLY ACTUAL AND POTENTIAL EVAPOTRANSPIRATION, 1987–1990



Exercise 7: Observing how changes in temperature affect evapotranspiration

Objective: To observe the influence of temperature on evapotranspiration

Procedure:

In this exercise, the change in evapotranspiration is observed by increasing the temperature by 2 and 4.

1. Open the model in JAMS Launcher and run the model.
2. Copy and save the evapotranspiration value from the output file.
3. Now go to the Scenarios option [Box 1] (Figure 97).

4. Change the temperature scenario to 2. (It will increase the current temperature of the basin by 2.) [Box 2].
5. Save the model [Box 3].
6. Run the model [Box 4].
7. Copy and save the evapotranspiration value from the 'output/timeloop.dat' file.
8. Now, change the temperature scenario to 4.
9. Save and run the model.
10. Copy and save the evapotranspiration value from the 'output/timeloop.dat' file.
11. Use the PivotTable to get the monthly average evapotranspiration value for these three temperature scenarios (Figure 98, Box 1).
12. Copy the average monthly ET for all scenarios and paste as values [Box 2].
13. Plot the line graph to see the difference [Box 3].

FIGURE 97 TEMPERATURE CHANGE SCENARIO IN JAMS LAUNCHER

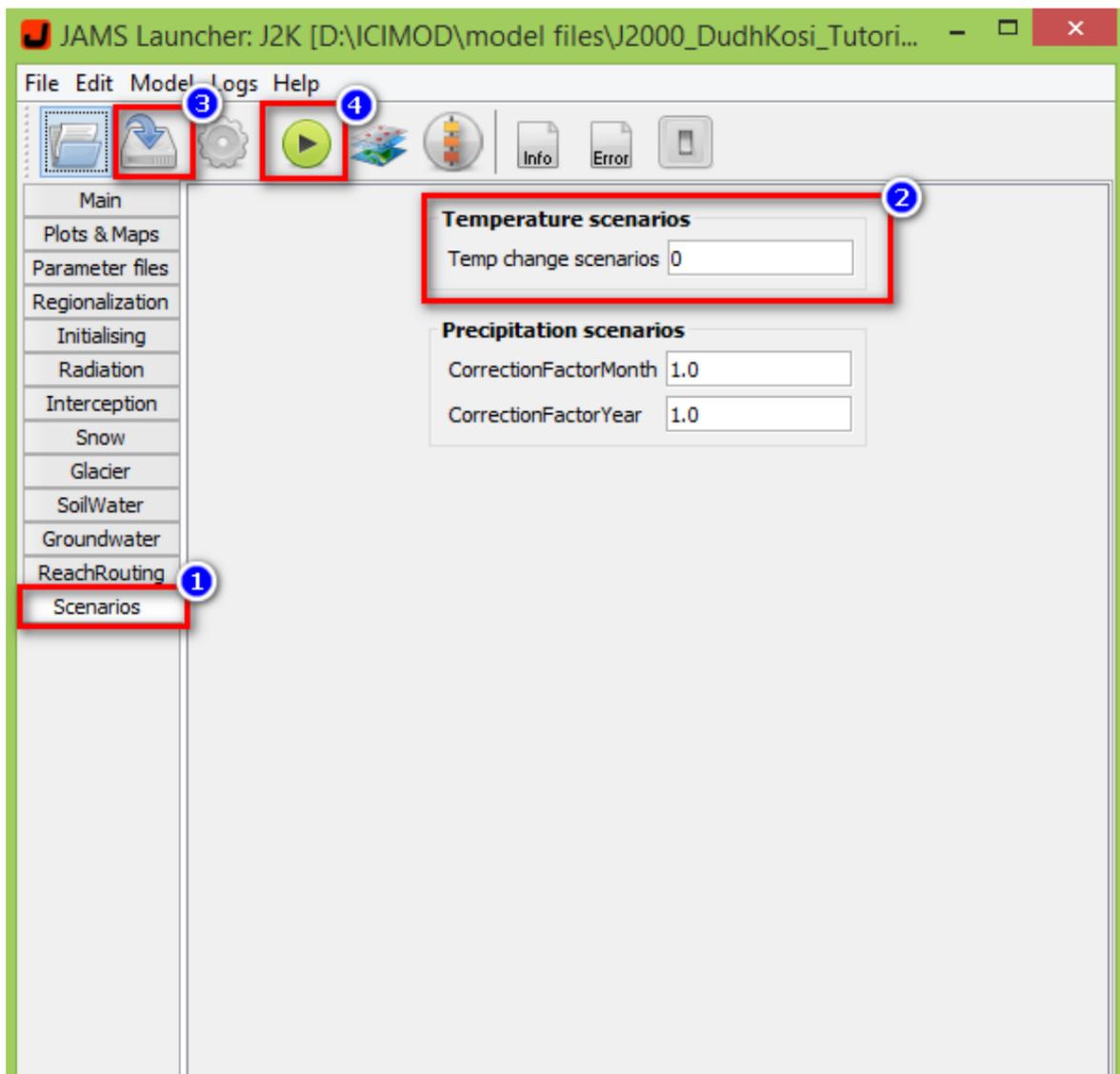
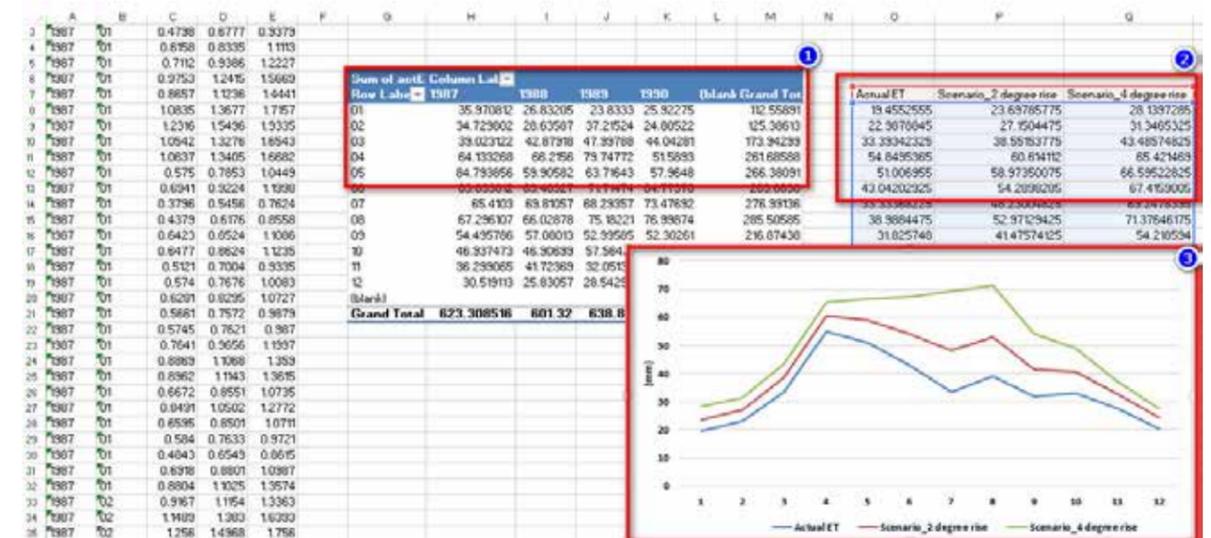


FIGURE 98 USE OF THE PIVOTTABLE TO CALCULATE THE MONTHLY VALUE OF EVAPOTRANSPIRATION



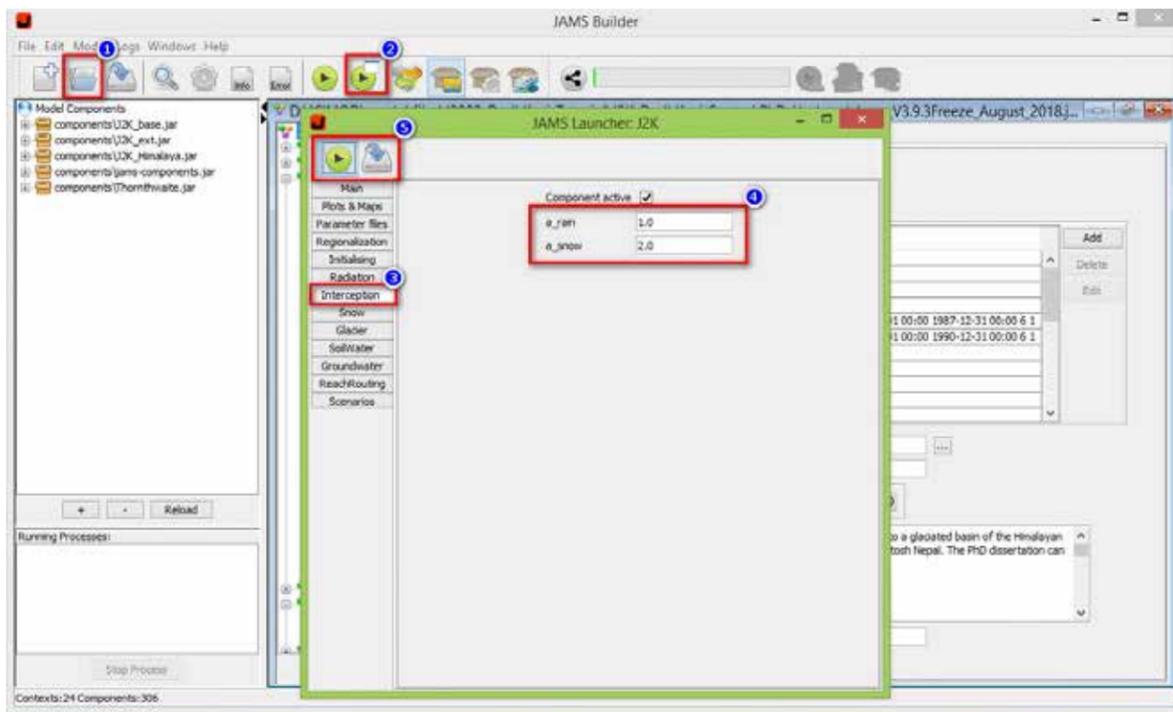
Exercise 8: Observing how a change in interception value changes evapotranspiration

Objective: To visualize the role of interception in evapotranspiration

Procedure:

1. Open the model in JAMS Builder (Figure 99, Box 1).

FIGURE 99 USE OF THE INTERCEPTION MODULE

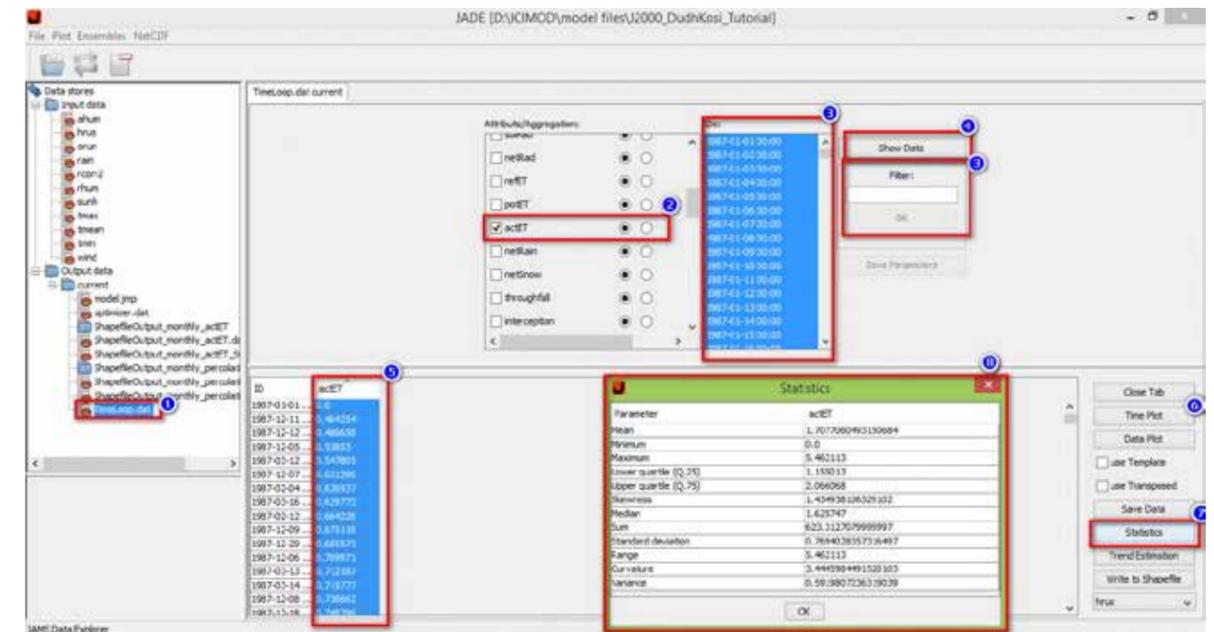


2. Launch the model using the JAMS Launcher.
3. Go to the interception module.
4. Keep the value of 'a_rain' as 1.0 and 'a_snow' as 2.0.
5. Run the model.
6. Click on JADE once the process is complete.

7. Click on 'timeloop.dat' (Figure 100, Box 1).
8. Select 'actET' (Box 2)
9. Select the time frame manually or by using the filter option (Box 3).

Hint: To select the year 2009, you can use '2009*' in the filter option.

FIGURE 100 CALCULATING STATISTICS OF A CERTAIN PARAMETER



10. Click on 'show data' (Box 4).
11. Select 'actET' (Box 5).
12. Click on 'Time Plot' to observe the variation of ET in time (Box 6) Result in Figure 101.
13. Click on statistics (Figure 100, Box 7).
14. Observe the statistics (Box 8) and note it.
15. Now, change the value of 'a_rain' to 5.0 and 'a_snow' to 5.5 from the JAMS Launcher.
16. Repeat steps 7–14 and note the values.
17. Change the value of 'a_rain' to 9.0 and 'a_snow' to 9.5 from the JAMS Launcher (Figure 102).
18. Repeat the steps 7–14 and note the numbers.
19. Compare the minimum, maximum, mean, and sum from these three scenarios.

How much are the changes?

FIGURE 101 DISPLAY OF ACTUAL EVAPOTRANSPIRATION USING THE JTS DATA VIEWER

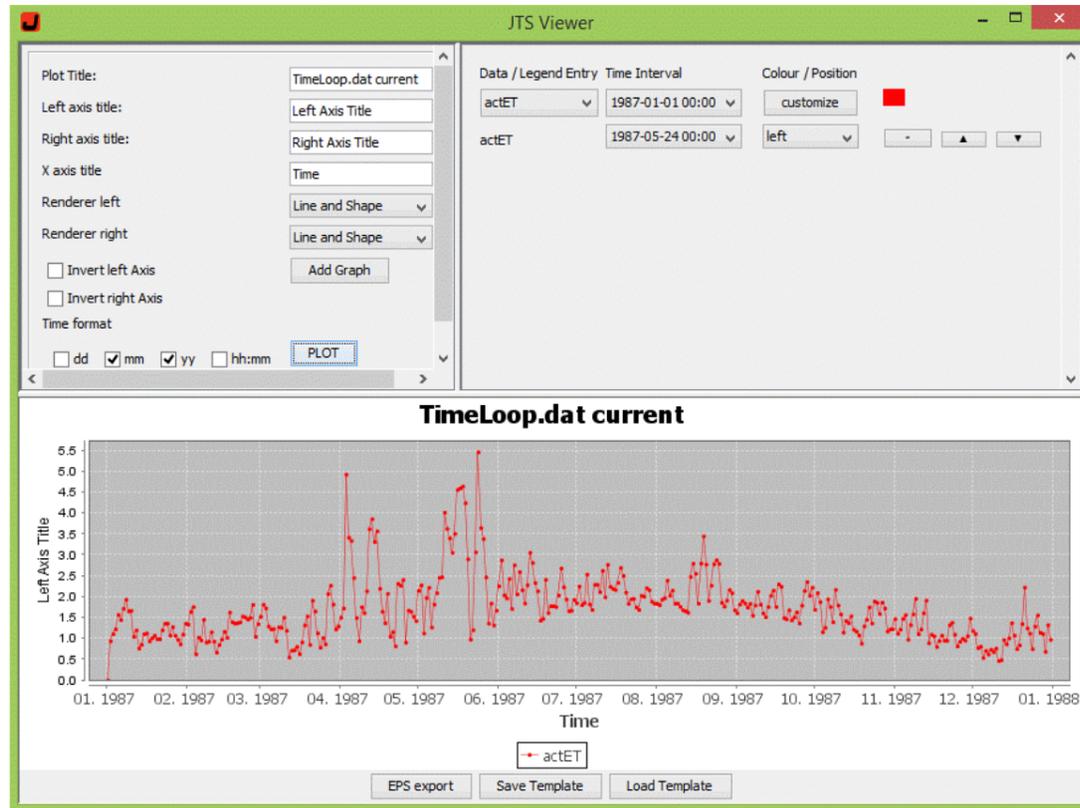


FIGURE 102 INTERCEPTION MODULE AND CHANGE IN PARAMETER VALUE



Exercise 9: Quantification of snow and glacier outcomes

Objective: To visualize the different components of snow and glaciers in output data

Procedure:

1. Open the output file in Excel.
2. Identify the different forms of snowmelt presented in the output.

Hint: 'SnowToSWE' (Snow in soil water equivalent), 'SnowStorage_G' (Snow storage in the glacier), 'Snowmelt' (Snowmelt from the non-glaciated area), and 'Snowmelt_G' (Snowmelt from the glaciated area).

3. Select a year for the analysis (let's take data from 1988).
4. Calculate the monthly discharge (in mm) of the year using the Pivot Table.

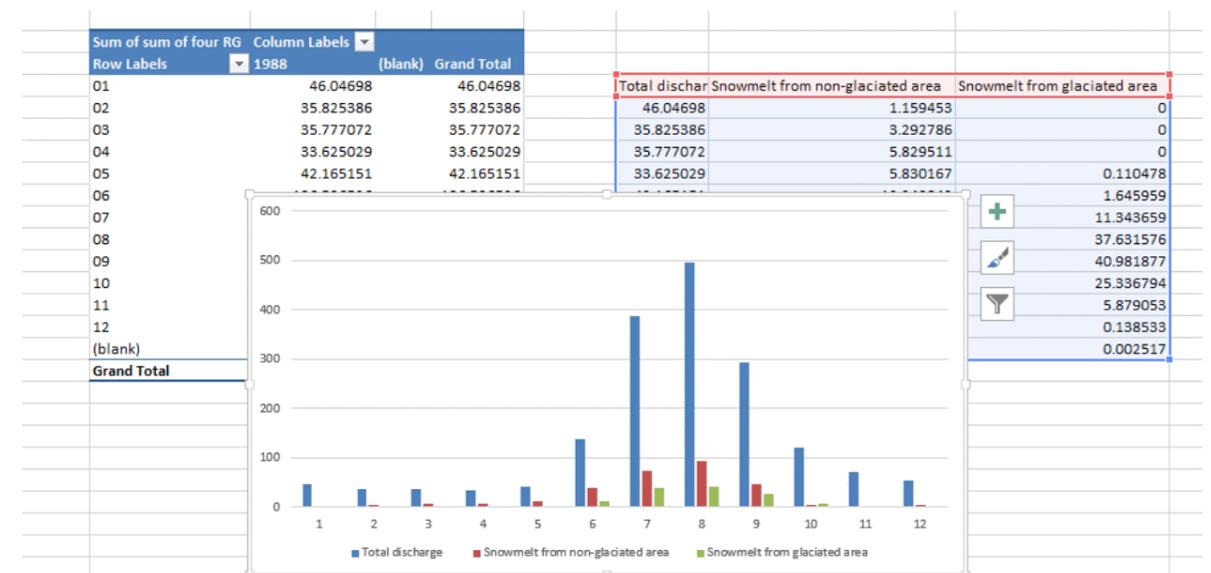
Hint: Calculate the sum of 'catchmentRD1_w', 'catchmentRD2_w', and 'catchmentRG1_w, catchmentRG2_w' and save the value in a new column named 'catchment_runoff'.

5. Calculate the monthly snowmelt values from the non-glaciated and glaciated areas.

Hint: Use the PivotTable.

6. Plot the total catchment run-off and snowmelt from the glaciated and non-glaciated areas (Figure 103).

FIGURE 103 CALCULATION OF SNOWMELT'S CONTRIBUTION TO DISCHARGE USING THE PIVOTTABLE

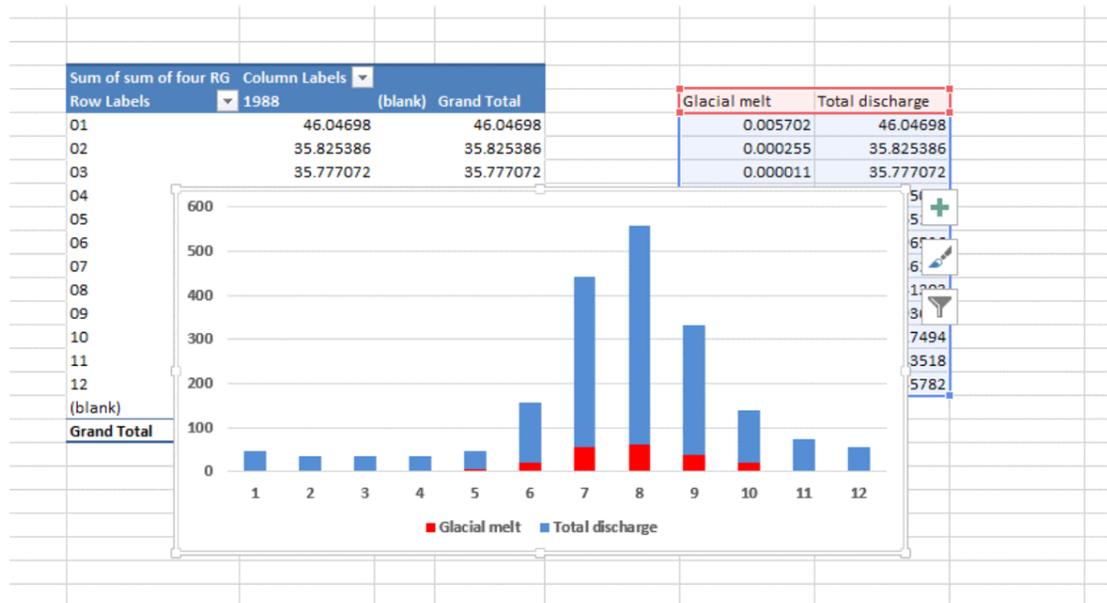


Additional exercise 9a:

Now let's observe the contribution of glacial melt to discharge.

1. Identify the different forms of glacial melt from the model.
2. Calculate the monthly glacial melt contribution to total discharge from the basin (take an example of 1988).
 - Calculate the monthly discharge (catchment run-off)
 - Calculate the total monthly glacial melt (Hint: Glaciermelt: 'snowmelt_G' + 'icerunoff' + 'rainrunoff') (see Figure 104).

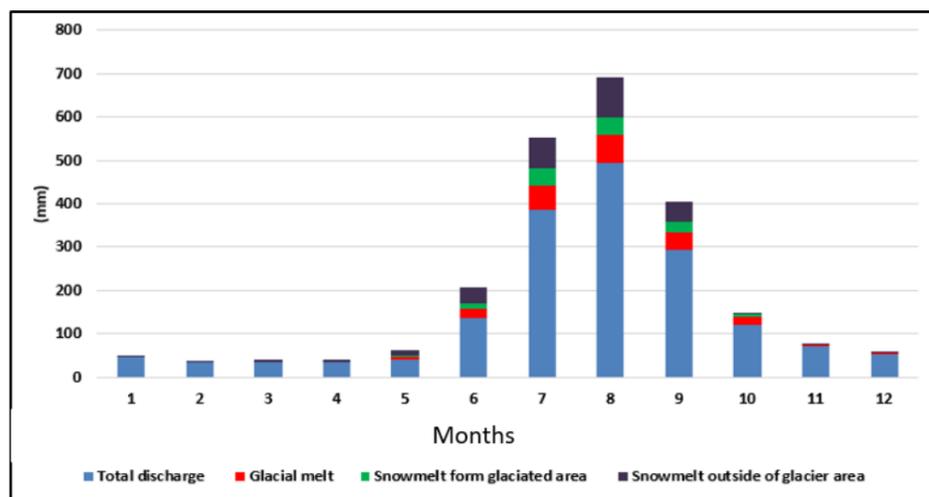
FIGURE 104 CALCULATION OF GLACIAL MELT'S CONTRIBUTION TO DISCHARGE USING THE PIVOTTABLE



Additional exercise 9b:

Show the contributions of snowmelt and glacial melt to the discharge in a single graph (Answer hint: Figure 105).

FIGURE 105 SNOW AND GLACIAL MELT CONTRIBUTIONS TO DISCHARGE FROM RAINFALL AND GROUNDWATER



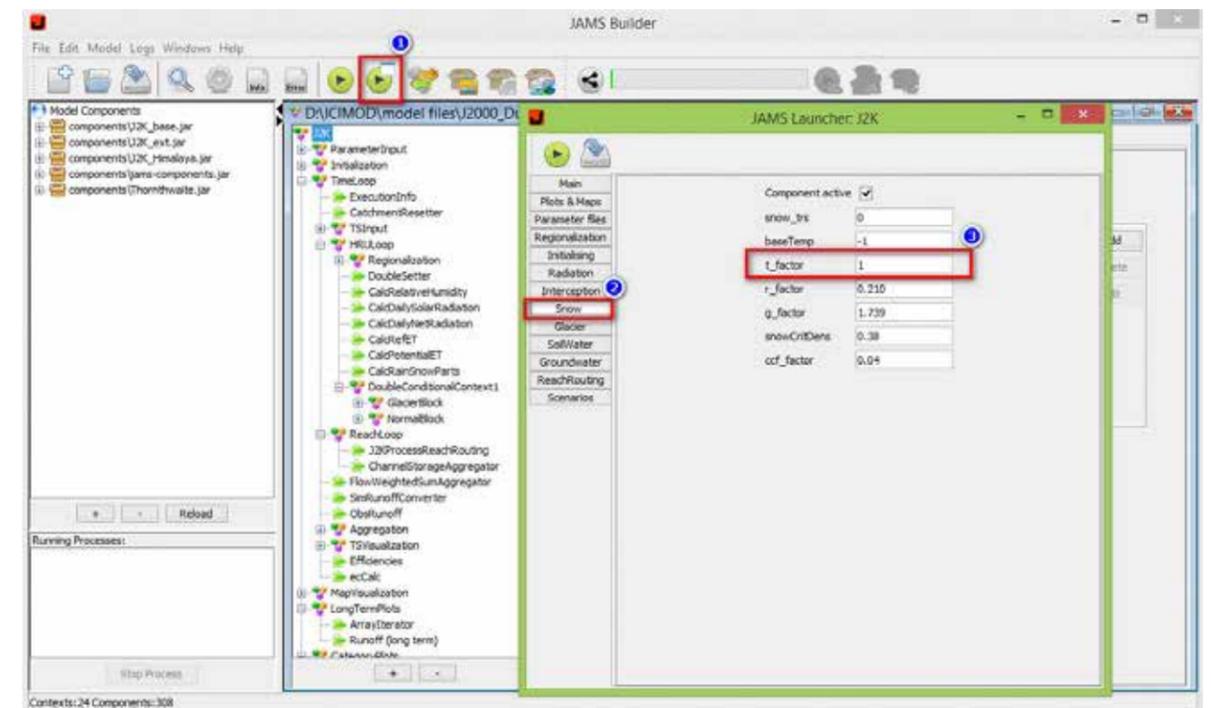
Exercise 10: Changing the temperature factor and critical density to observe the effects on snowmelt and simulated discharge

Objective: Change the different parameters of snow to find out which parameter is sensitive

Procedure:

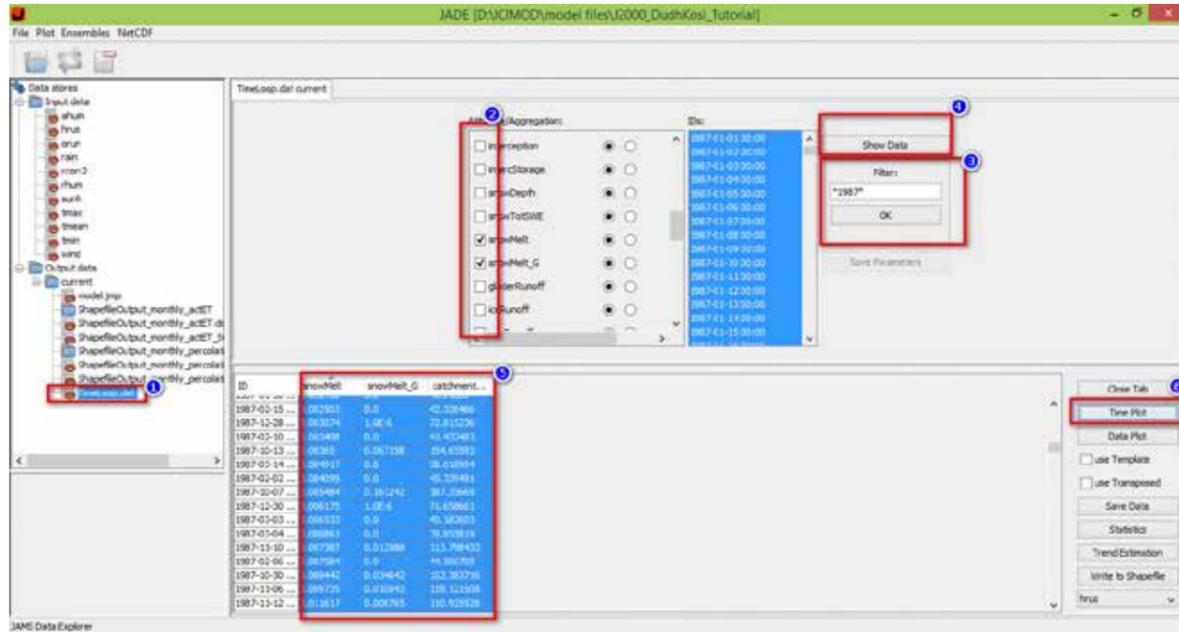
1. Open the model in JAMS Builder.
2. Click on 'open the model in JAMS Launcher' (Figure 106, Box 1).

FIGURE 106 TEMPERATURE FACTOR IN THE SNOW MOD



3. Click on the snow module (Box 2).
4. Change the value of temperature factor ('t_factor') to 1 (Box 3).
5. Save and run the module.
6. After the process is completed, click on JADE from the JAMS Builder.
7. Click on 'TimeLoop.dat' (Figure 107, Box 1).
8. Select on the required attributes ('snowmelt', 'snowmelt_G', and 'catchmentSimRunoff_qm') (Box 2).
9. Use the filter to select the required year. (Hint: *1987*) (Box 3).
10. Click on 'Show Data' (Figure 107, Box 4).
11. Select the data (Box 5).

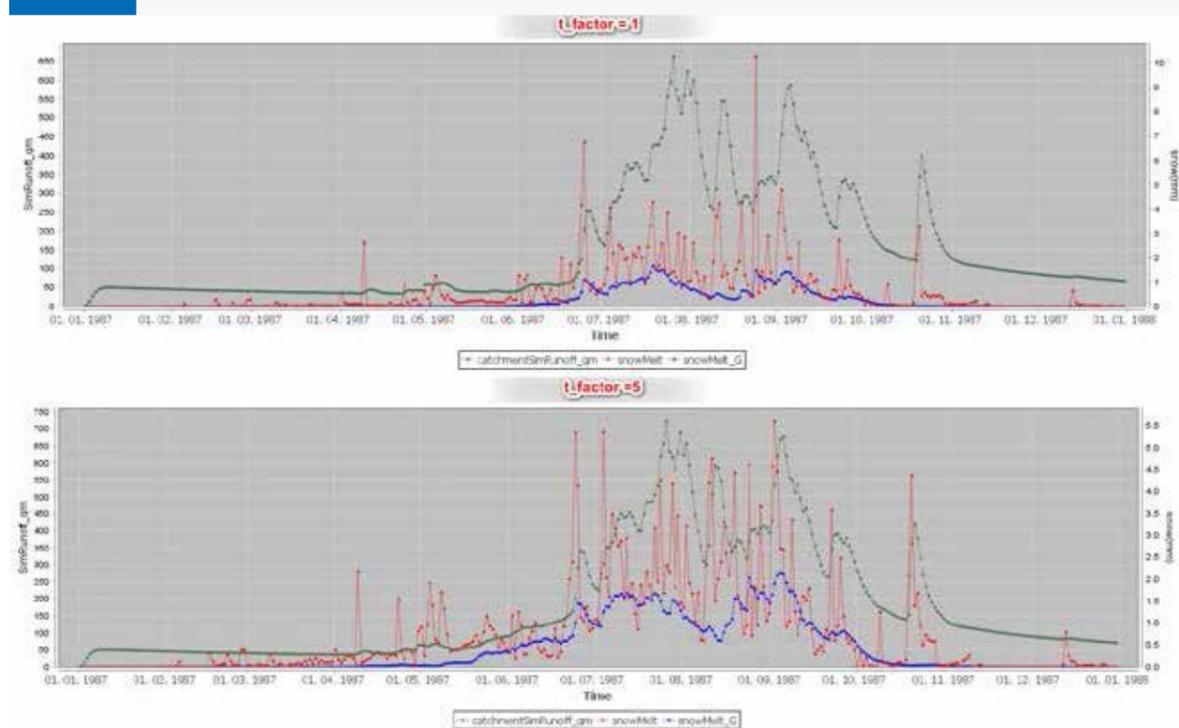
FIGURE 107 STEPS FOR PREPARING THE TIME PLOT



12. Click on time plot (Box 6).
13. Observe the output graph and save it.
14. Now change the value of 't_factor' to 5.
15. Repeat steps 5-13.

What changes did you observe in the graphs (Figure 108)?

FIGURE 108 OUTPUT GRAPHS OBTAINED FROM THE CHANGE IN THE TEMPERATURE FACTOR



Additional exercise 10a:

Repeat the same exercise for different values (0.1 and 0.9) of snow critical density (Figure 109). Compare the output graphs (Figure 110).

Did you notice which parameter is more sensitive?

FIGURE 109 CHANGE IN THE VALUE OF SNOW CRITICAL DENSITY(SNOWCRITDENS)

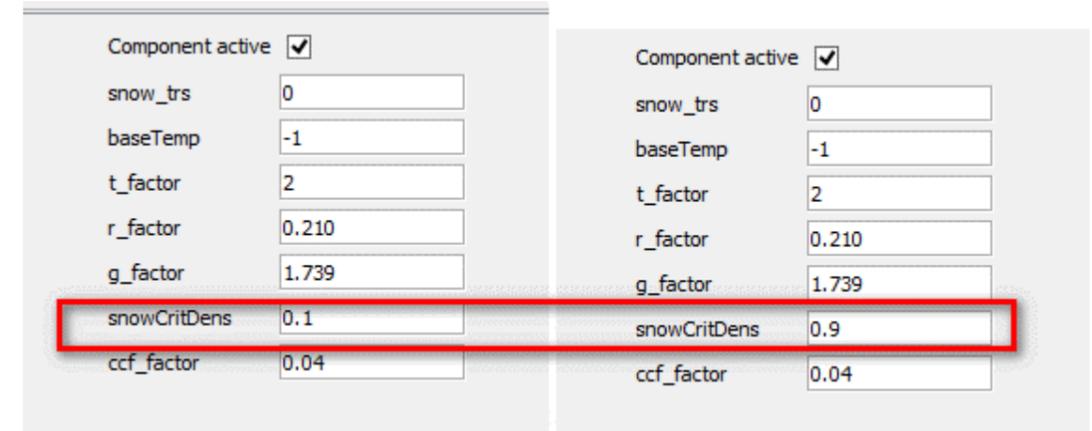
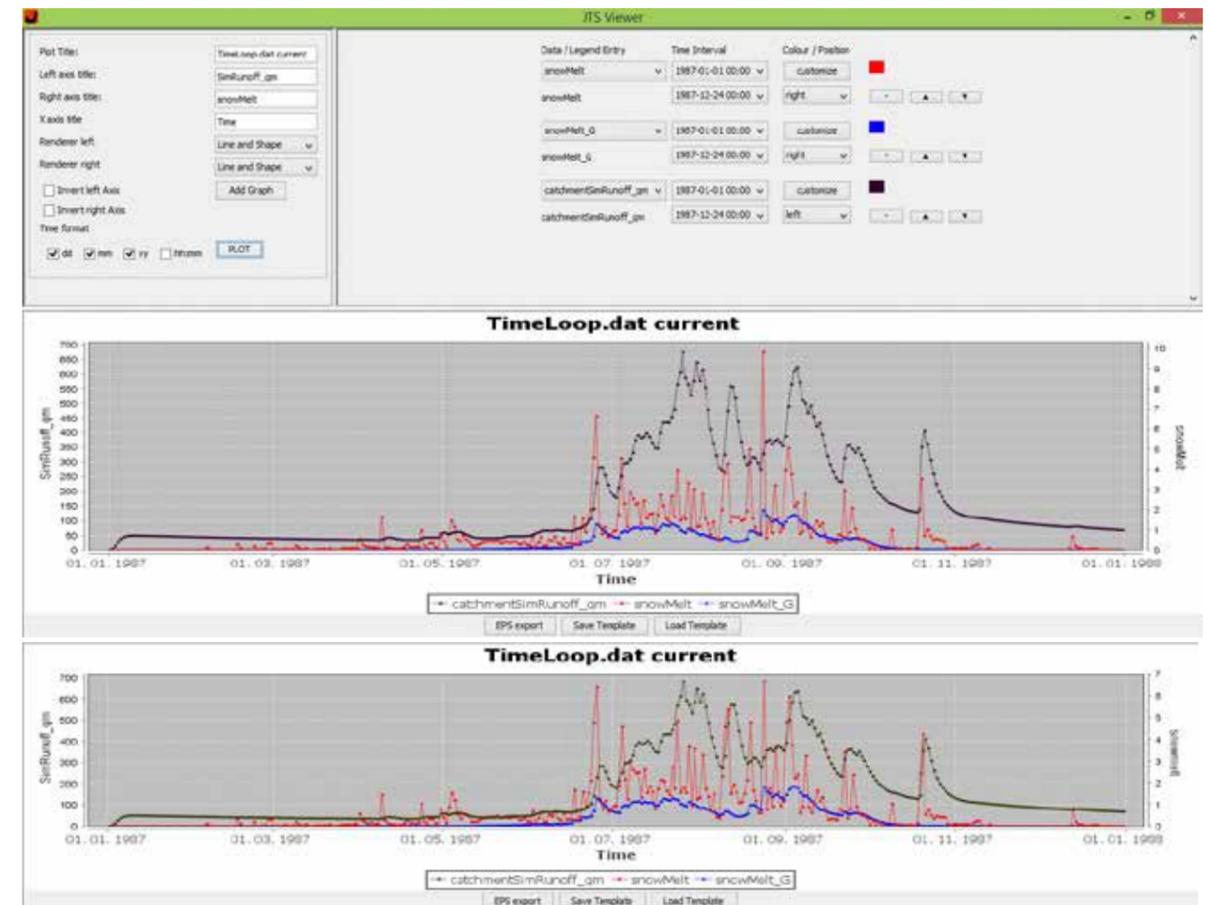


FIGURE 110 SNOWMELT PLOTS FOR TWO DIFFERENT VALUES OF SNOWCRITDENS IN THE JTS DATA VIEWER



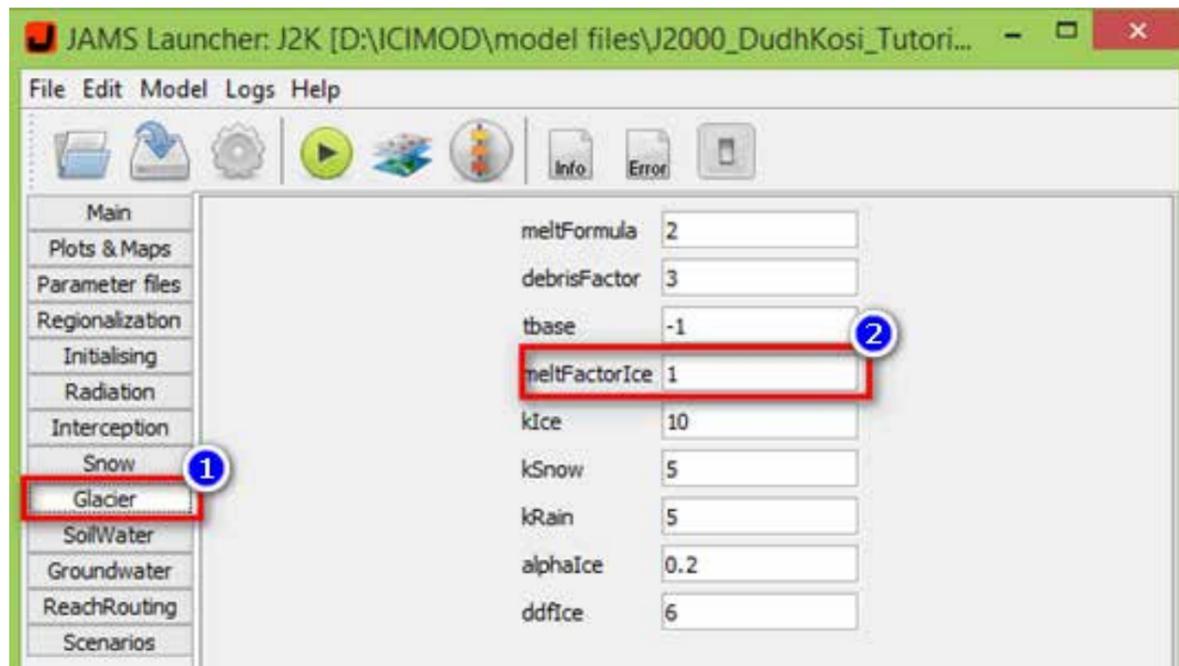
Exercise 11: Changing 'alpha ice' and 'meltFactorIce' to see how it affects glacier run-off

Objective: To change the different parameters of the glacier and find the sensitive parameter and how it affects glacial run-off

Procedure:

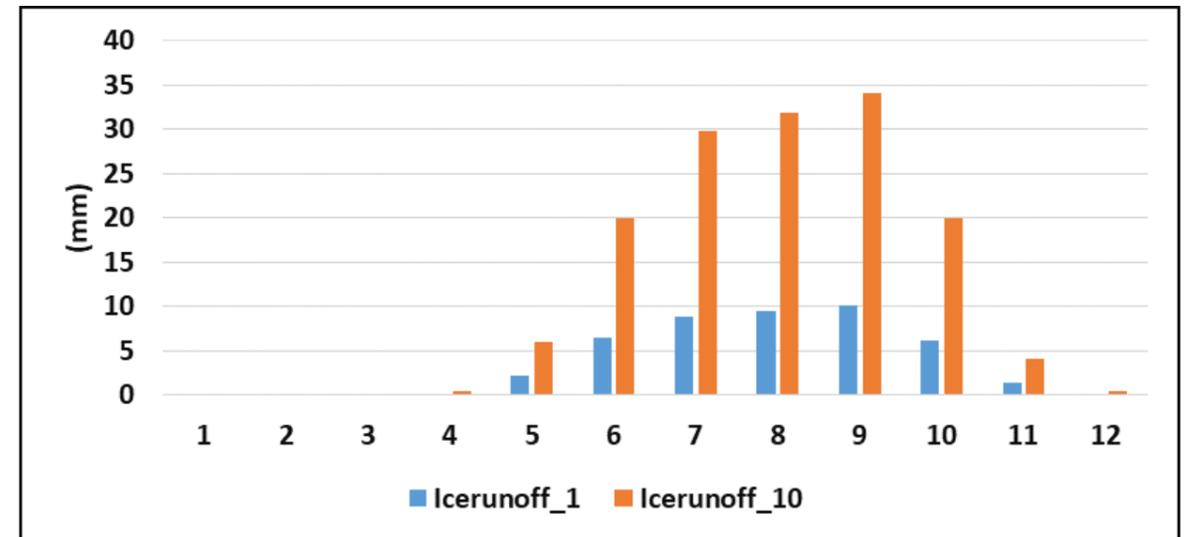
1. Open the model in JAMS Launcher.
2. Click on the 'Glacier' module (Figure 111, Box 1).

FIGURE 111 CHANGING THE VALUE OF MELTFACTORICE IN THE GLACIER MOD



3. Change the value of 'meltFactorIce' to 1 (Box 2).
4. Save and run the model.
5. Save the output in an Excel sheet.
6. Now, change the value of 'meltFactorIce' to 10.
7. Save and run the model.
8. Save the output in an Excel sheet.
9. Compare the difference in ice run-off for these two values of 'MeltfactorIce' (Figure 112).

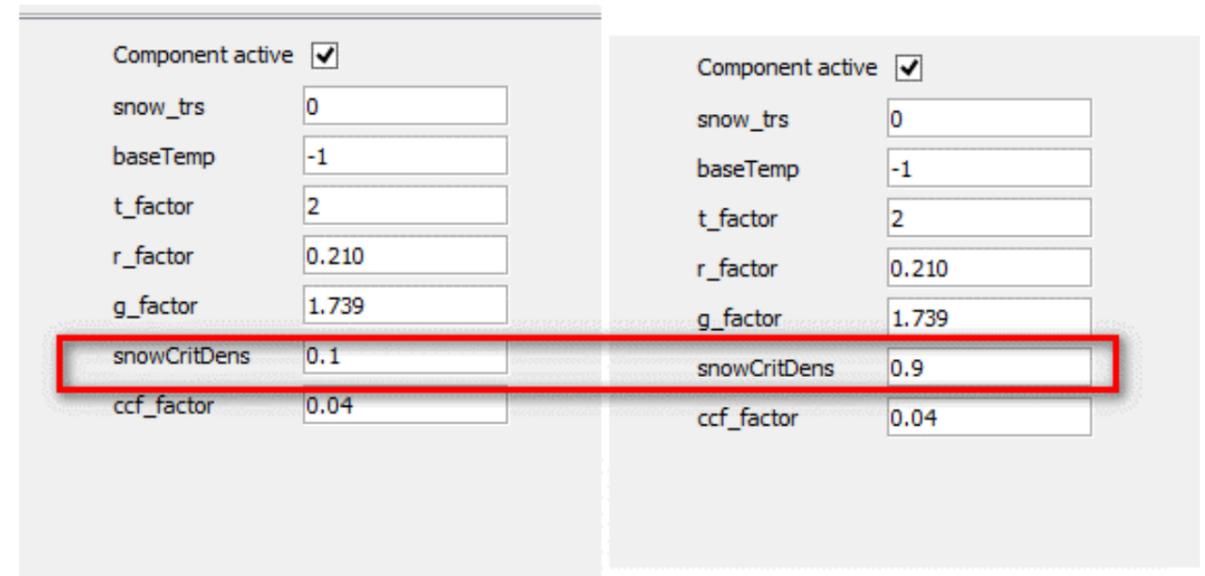
FIGURE 112 ICE RUN-OFF FOR TWO DIFFERENT VALUES OF MELTFACTORICE



Additional exercise 11a:

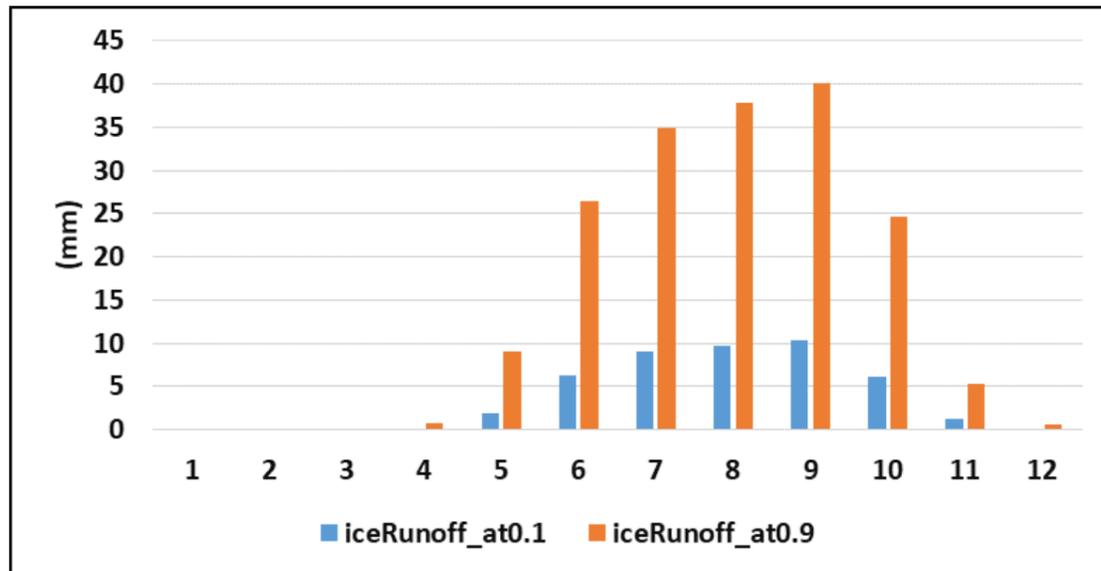
1. Now let us try a similar exercise to examine the impact of snow critical density on ice run-off.
2. Change the value of 'snowCritDens' to 0.1 (Figure 113).
3. Save and run the model.
4. Save the output of the model.
5. Now change the value of 'snowCritDens' to 0.9.
6. Save and run the model.
7. Save the output of the model.
8. Compare the difference in ice run-off for these two values of 'snowCritDens'.

FIGURE 113 CHANGE IN THE VALUE OF SNOW CRITICAL DENSITY



Did your graph look the same as Figure 114? Which parameter is more sensitive?

FIGURE 114 ICE RUN-OFF FOR TWO DIFFERENT VALUES OF SNOW CRITICAL DENSITY



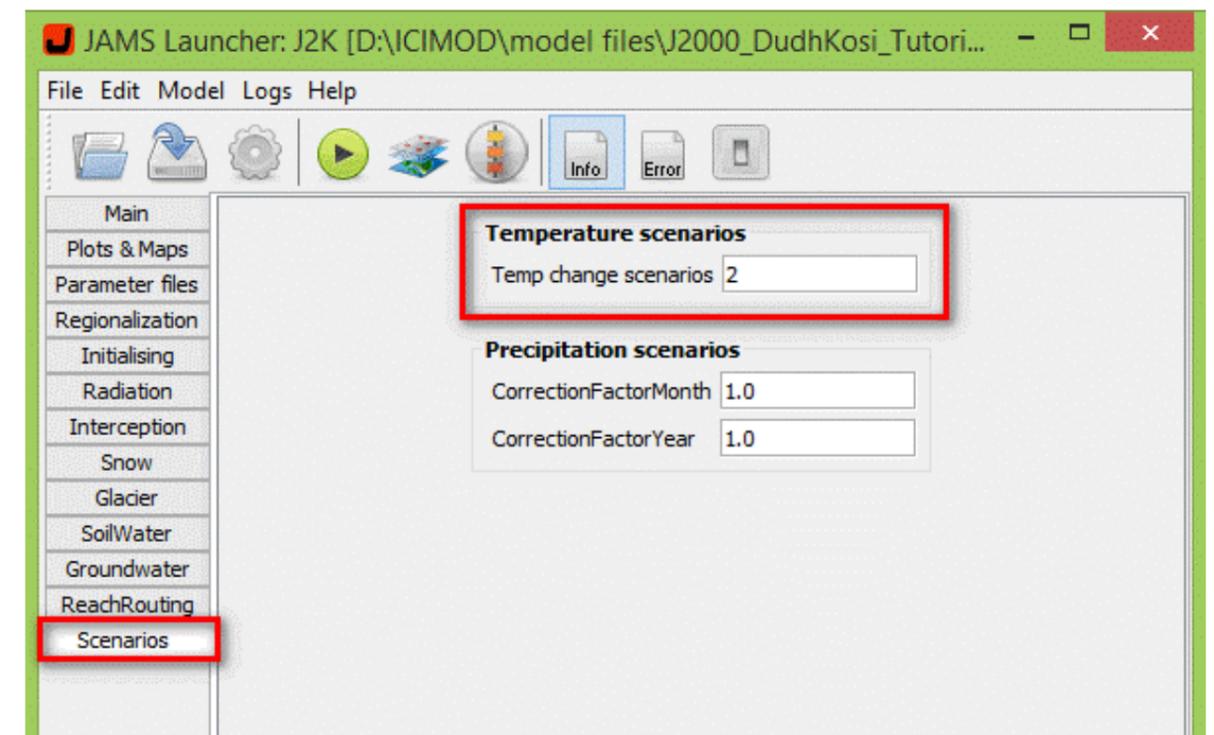
Exercise 12: How a change in temperature impacts snowmelt and monthly discharge

Objective: To observe the impact of global climate change on the extent of snowmelt

Procedure:

1. Open the model from JAMS Launcher.
2. Run the model.
3. Save the output of the model.
4. Now go to the 'Scenarios' module of the model through JAMS Launcher (Figure 115).

FIGURE 115 USE OF THE TEMPERATURE CHANGE SCENARIO



5. Change the 'Temp change scenarios' input to 2.
6. Save and run the model.
7. Save the output of the model.
8. Now change the 'temp change scenarios' input to 4.
9. Save the output of the model.
10. Now plot the major outputs for these different temperature scenarios (Figures 116–119).

Hint: Discharge, Snowmelt (snowmelt from the non-glaciaded area), Snowmelt_G (snowmelt from the glaciaded area), SnowStorage_G (Snow storage in the glacier), and SnowToSWE (Snow total soil water equivalent).

FIGURE 116 SNOWMELT OUTSIDE THE GLACIATED AREA FOR A 2- AND 4-DEGREE RISE IN TEMPERATURE

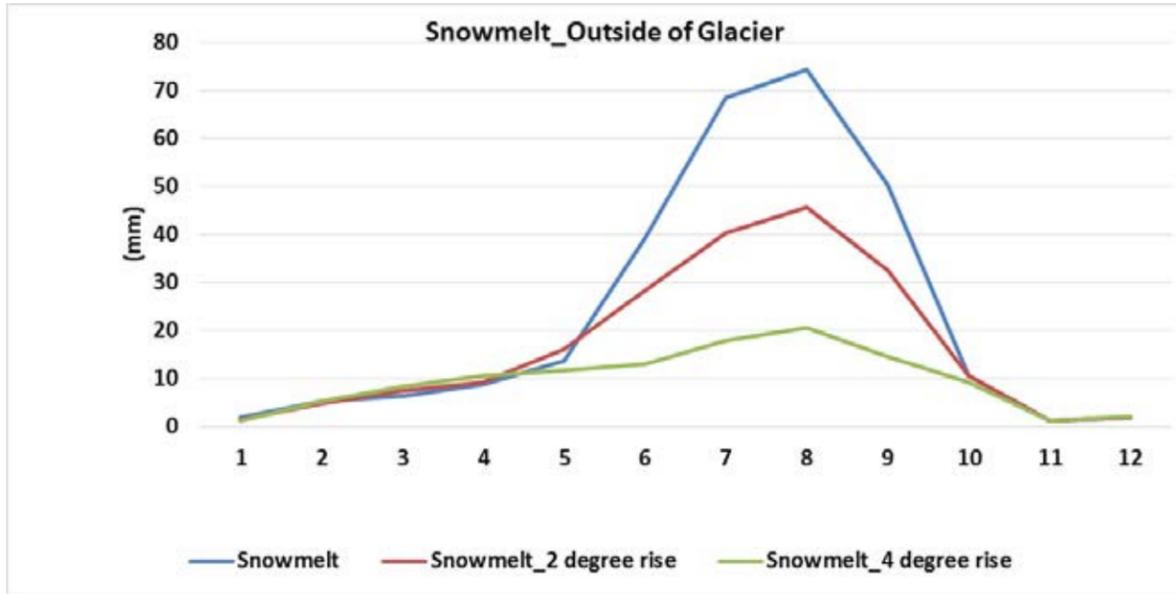


FIGURE 118 TOTAL SNOWMELT (FROM THE GLACIATED AND NON-GLACIATED AREAS) FOR A 2- AND 4-DEGREE RISE IN TEMPERATURE

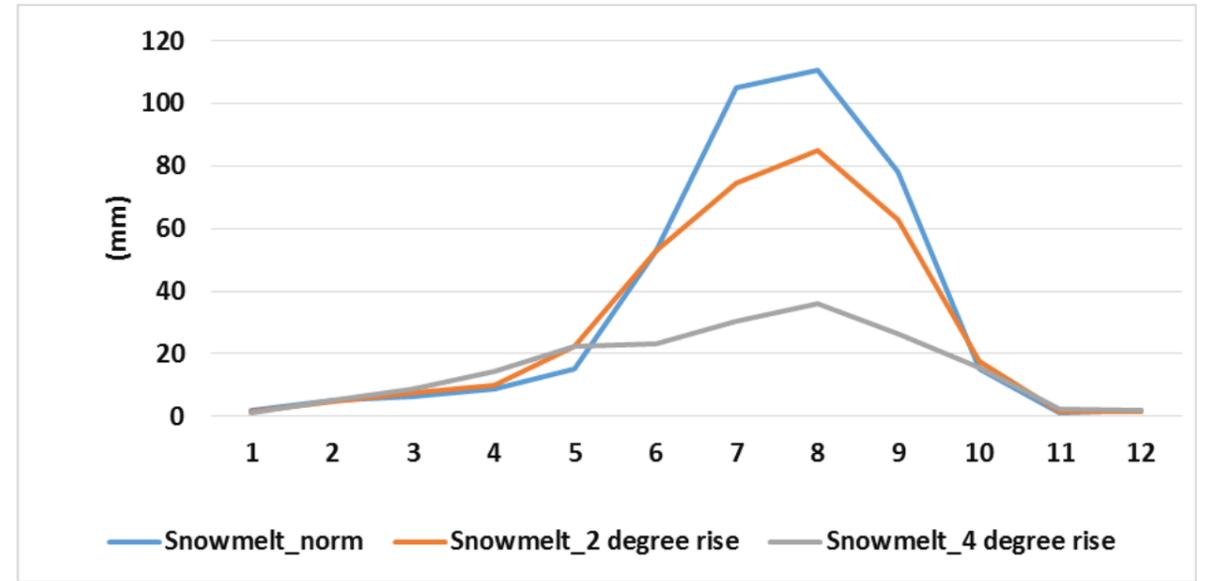


FIGURE 117 SNOWMELT FROM THE GLACIATED AREA FOR A 2- AND 4-DEGREE RISE IN TEMPERATURE

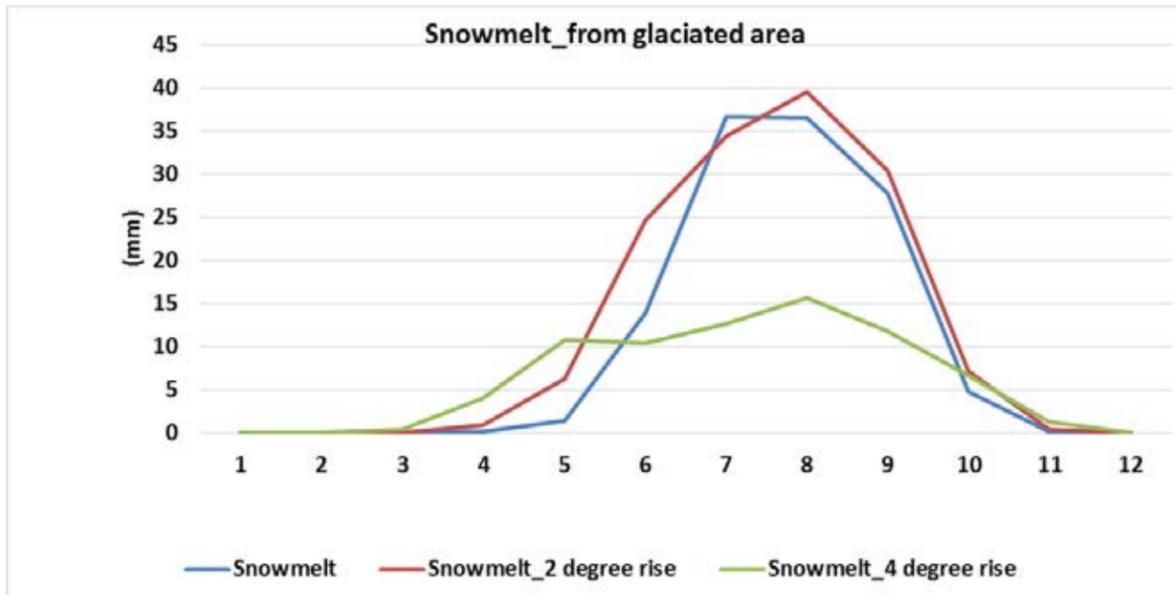
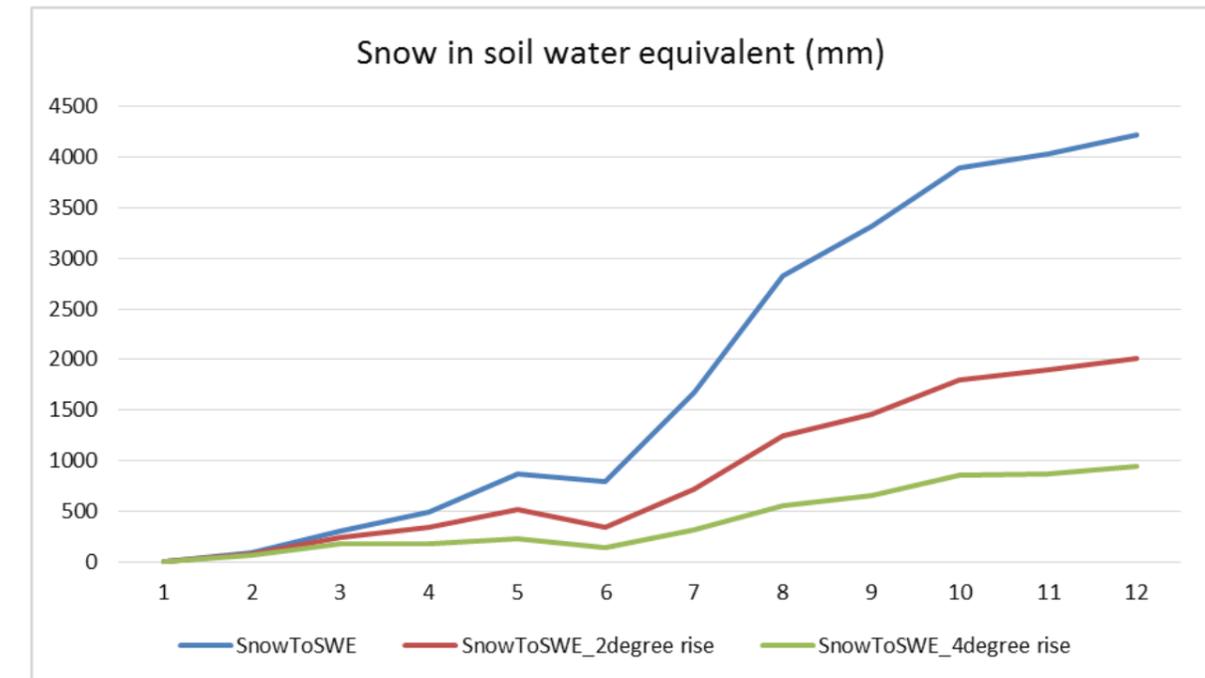


FIGURE 119 SNOW WATER EQUIVALENT FOR A 2- AND 4-DEGREE RISE IN TEMPERATURE



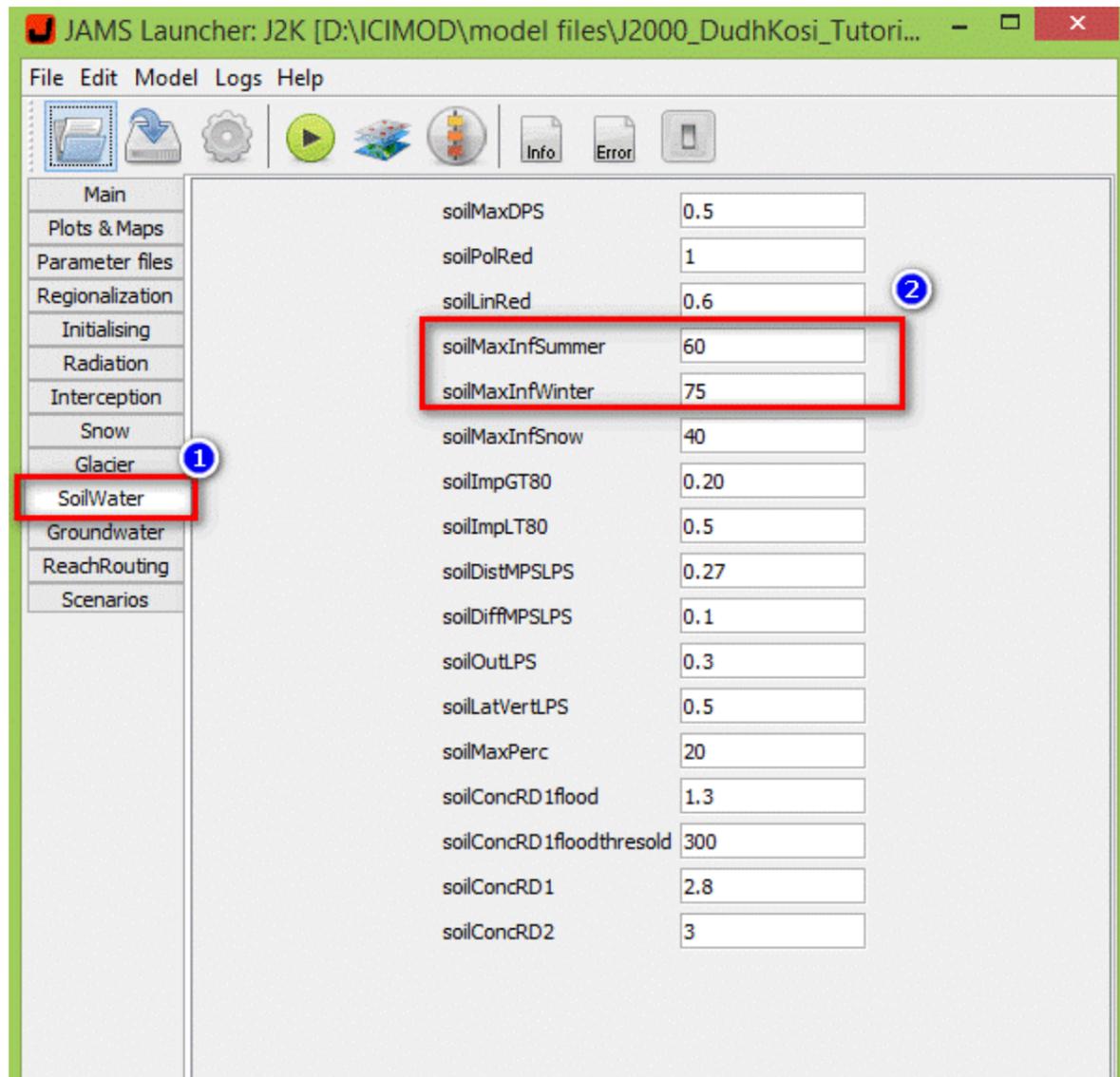
Exercise 13: Impact of summer and winter infiltration on discharge

Objective: To understand the roles of summer and winter infiltration on discharge

Procedure:

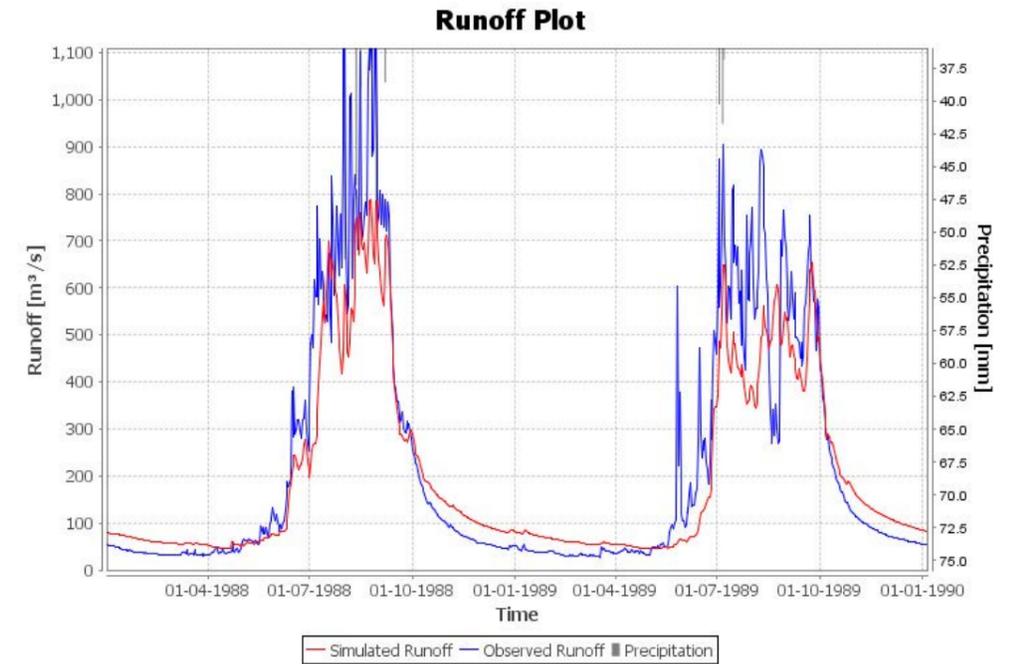
1. Open the model in JAMS Launcher.
2. Go to the 'SoilWater' module (Figure 120, Box 1).
3. Change the values of maximum infiltration in summer ('soilMaxInfSummer') and maximum infiltration in winter ('soilMaxInfWinter') (both in mm) (Box 2).

FIGURE 120 MAXIMUM SOIL INFILTRATION RATE DURING SUMMER AND WINTER IN THE SOIL-WATER MODULE



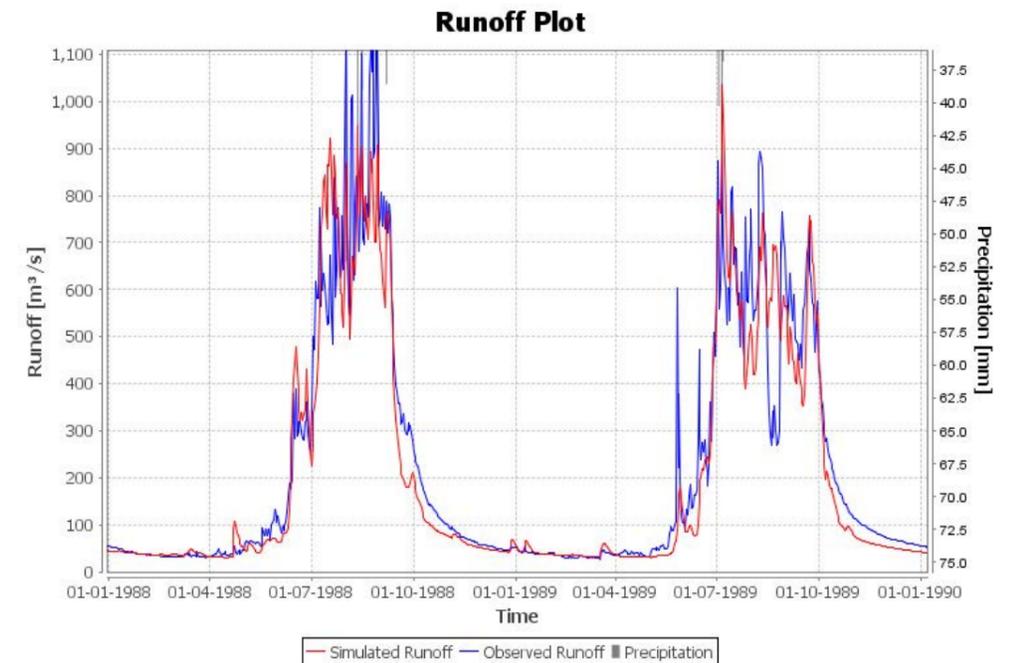
4. Change the value of 'soilMaxInfSummer' to 160 and 'soilMaxInfWinter' to 175 (Figure 121). Run the model and observe the run-off plot.

FIGURE 121 RUN-OFF PLOT WITH SOILMAXINFSUMMER AS 160 AND SOILMAXINFWINTER AS 175



5. Now reduce the value of 'soilMaxInfSummer' to 10 and 'soilMaxInfWinter' to 20 (Figure 122). Run the model and observe the run-off plot.

FIGURE 122 RUN-OFF PLOT WITH SOILMAXINFSUMMER AS 10 AND SOILMAXINFWINTER AS 20



6. Visualize the changes in the graphs. Fill in the table for different values of 'soilMaxInfSummer' and 'soilMaxInfWinter' (Table 15).

S. No	Value of 'soilMaxInfSummer'	Value of 'soilMaxInfWinter'	Where did you observe the change in the plot?	What type of difference was there?	Why do you think it happened?
1.	160	175	Run-off plot	The simulated discharge in most of the monsoon period was higher	More rainfall and snowmelt are allowed to go through the soil water module per time step. It drains out of the module in the form of groundwater especially after the monsoon
2.	10	20	Run-off plot	The peaks of the simulated discharge are higher	Overland flows are higher as most of the input drains as surface run-off
.....
4.	.....	.....	.....	.....	.....
5.	.....	.....	.....	.....	.....

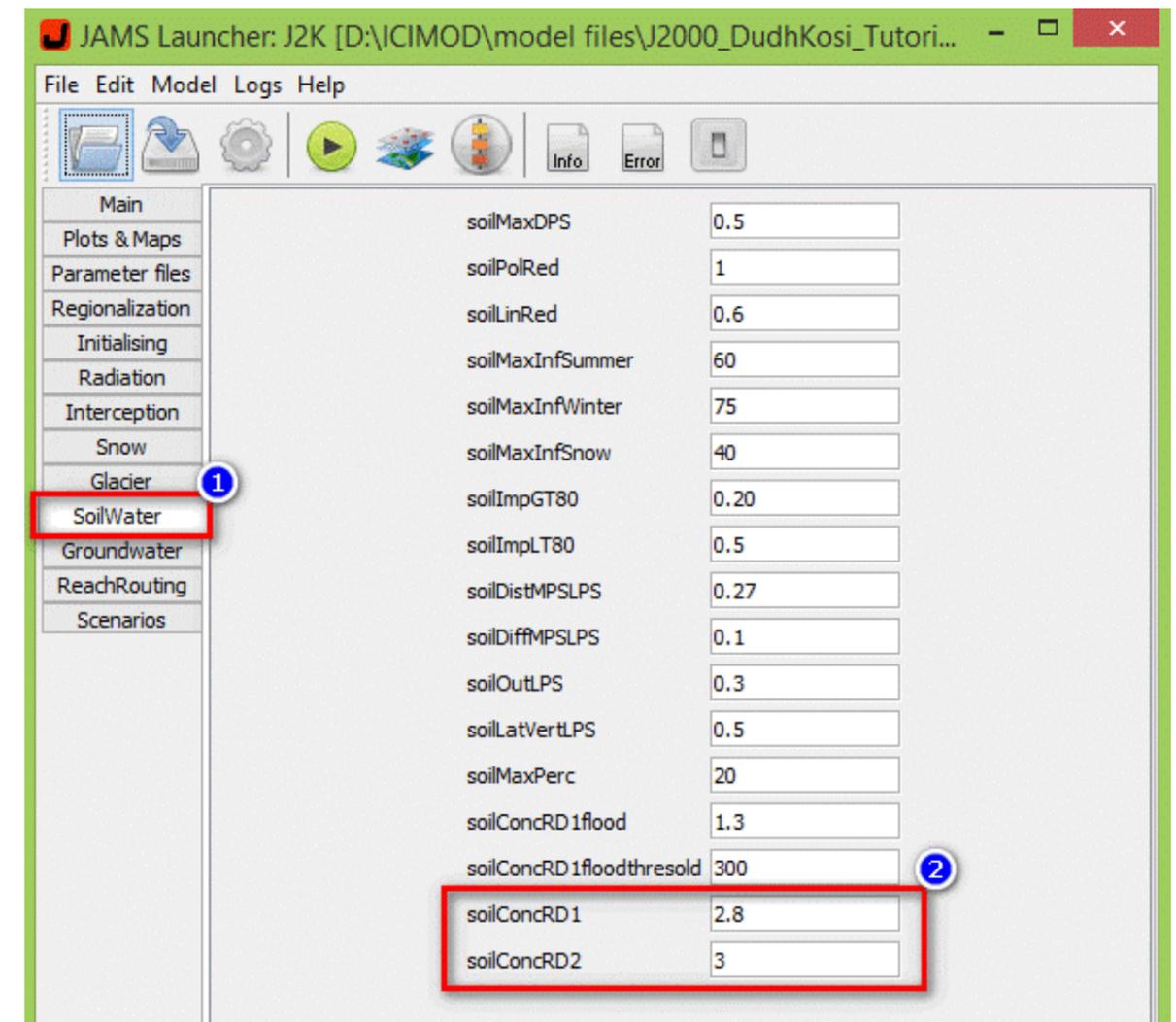
Exercise 14: Changing the values of the recession coefficient for overland flows and interflow, and visualizing the difference in plots

Objective: To understand the role of recession coefficients

Procedure:

1. Open the model in JAMS Launcher.
2. Go to the 'SoilWater' module (Figure 123, Box 1).

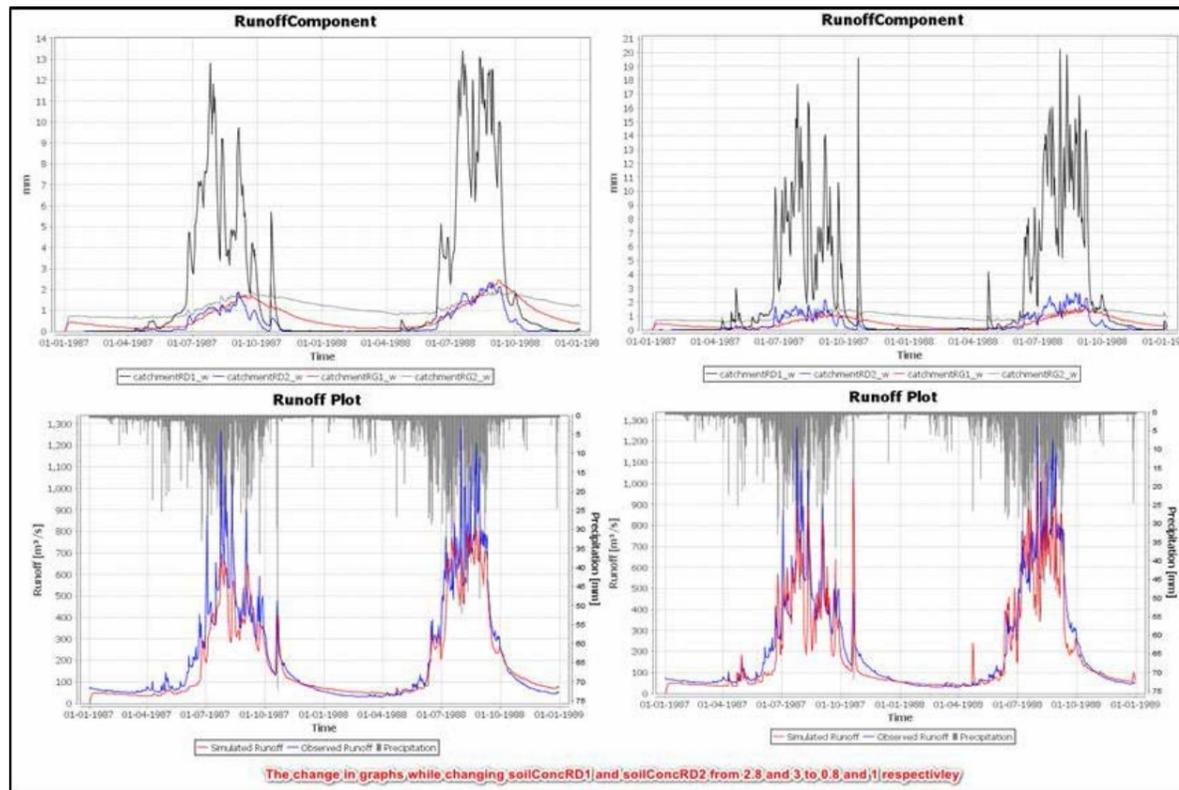
FIGURE 123 CHANGE OF VALUES FOR SOILCONCRD1 AND SOILCONCRD2



3. Change the values of the recession coefficient for overland flow ('soilConcRD1') and for Interflow ('soilConcRD2') (Box 2).

- SoilConcRD1 and soilConcRD2 are among the sensitive parameters in the module. On changing the value of 'soilConcRD1' from 2.8 to 0.8, and 'soilConcRD2' from 3 to 1, one can observe its effects on the run-off and runoff components (Figure 124).

FIGURE 124 COMPARATIVE GRAPHS ON CHANGING THE VALUES OF SOILCONCRD1 AND SOILCONCRD2



- Now raise the values of both 'soilConcRD1' and 'soilConcRD2' to the highest level (10.00) and observe the change in the graphs.
- Visualize the change in the graphs and fill in the table for different values of soilConcRD1 and soilConcRD2 (Table 16):

TABLE 16 OBSERVATION TABLE FOR CHANGES IN THE VALUES OF SOILCONCRD1 AND SOILCONCRD2

S. No	Value of SoilConcRD1	Value of SoilConcRD2	Where did you observe the change in the plot?	What type of difference was there?	Why do you think it happened?
1.	0.8	1	Run-off plot and run-off component	Increase in the overland flow	The recession coefficient to hold the water was low
2.	.....	.....	.....	.....	.....
3.	.....	.....	.....	.....	.....
4.	.....	.....	.....	.....	.....

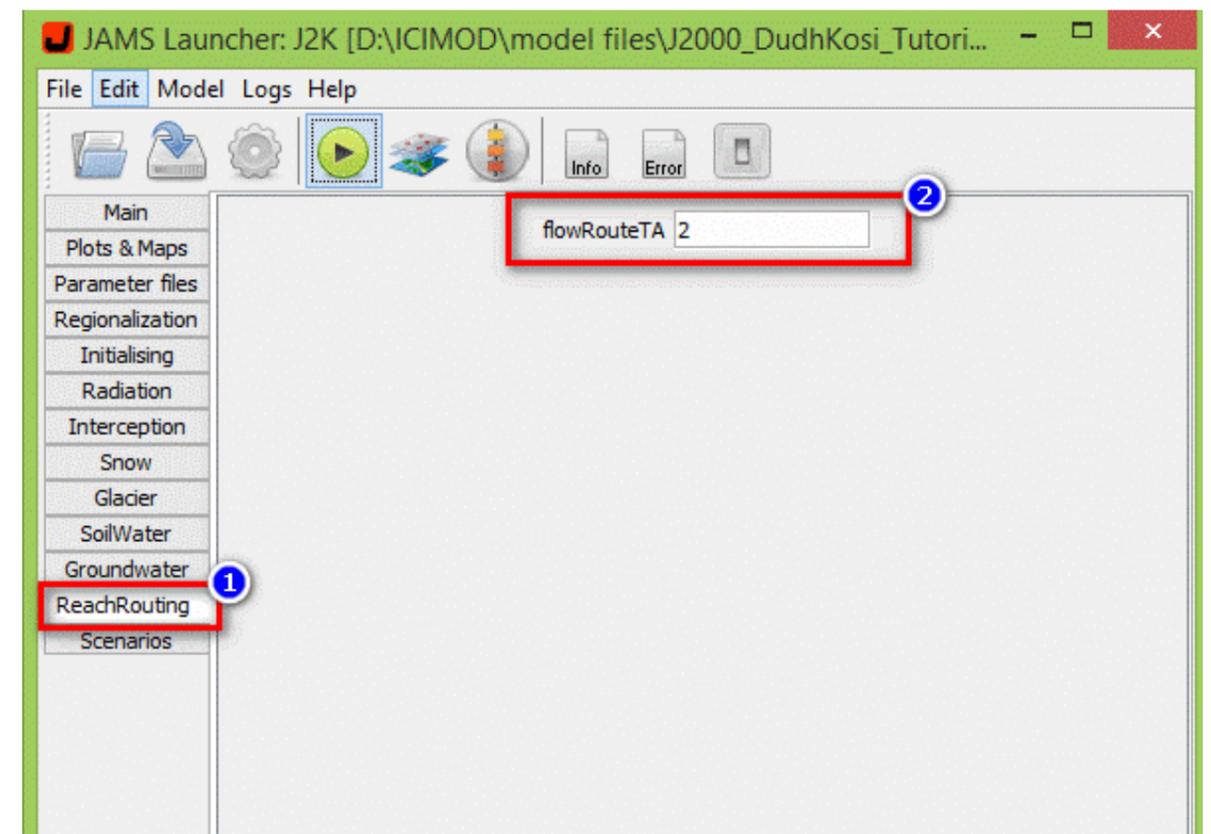
Exercise 15: Observing the effect of the flood routing coefficient

Objective: To visualize the influence of the flow route in the discharge

Procedure:

- Open the model in JAMS Launcher.
- Run the model with the 'flowRouteTA' value as 2 and save the result.
- Go to the 'ReachRouting' module (Figure 125, Box 1).

FIGURE 125 REACH ROUTING AND CHANGE IN ITS VALUE



- Adjust the value of 'flowRouteTA' (Box 2).
- Run the model with the 'flowRouteTA' value as 80 and save the result.
- Observe the graphs and identify the part of the hydrograph that has been influenced by the change in the value of 'flowRouteTA' (Figures 126 and 127) and fill in Table 17.

FIGURE 126 RUN-OFF PLOT WITH THE FLOWROUTETA VALUE AS 2

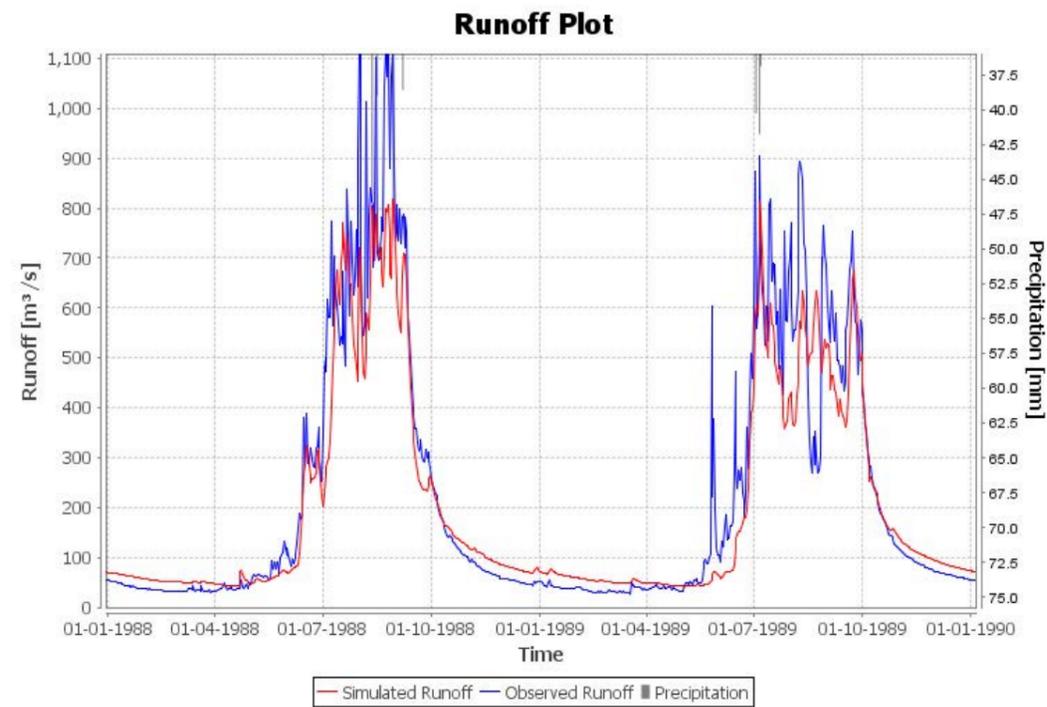
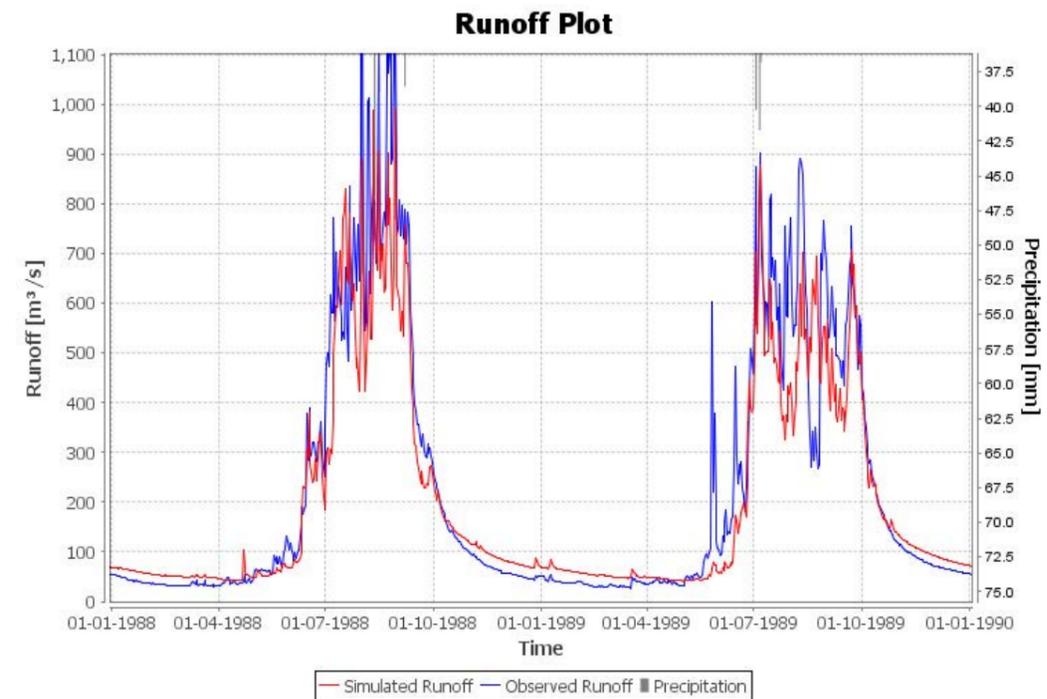


TABLE 17 OBSERVATION TABLE FOR A CHANGE IN THE FLOWROUTETA VALUE

S. No	Value of flowRouteTA	Where did you observe the change in the plot?	What type of difference was there?	Why do you think it happened?
1.	2	Groundwater plot	Catchment RG2_w line is not smooth	The lower value decreases the velocity of run-off, resulting in more water going into the groundwater module
2.		Run-off plot	The peak discharge is lowered	The lower value decreases the velocity of run-off, leading to lower peaks
3.	80	Groundwater plot	The line of 'Catchment RG2_w' is smoother than when the value is 2	A higher value increases the velocity of run-off waves; more water flows from the channel.
4.	.....	.....	.....	.....
5.	.....	.....	.....	.....
6.	.....	.....	.....	.....

FIGURE 127 RUN-OFF PLOT WITH THE FLOWROUTETA VALUE AS 80



Exercise 16: Checking how a variable is being passed through different modules in the model

Objective: To understand how the model xml file works

Procedure:

1. Open the model in JAMS Builder.
2. Click on the search button (Figure 128).
3. Search for a variable by typing it in the search button (here we take 'precip').
4. Fill in Table 18 (some of the components are filled).

FIGURE 128 SELECTING THE SEARCH BUTTON IN JAMS BUILDER



TABLE 18 OBSERVATION TABLE TO SEE HOW THE PRECIPITATION VARIABLE IS PASSED THROUGH DIFFERENT MODULES

S. No.	Module name	Input/Output variables (W)	R=Read W=Write	Functions
1.	precipdatareader	J2K.dataArrayPrecip	W	
2.	RCRichter	J2K.dataArrayPrecip	R	
3.	PrecipRegionaliser	HRULoop.precip	W	
4.	CalcRainSnowParts	HRULoop.precip	R	
		HRULoop.rain/snow	W	
5.	Interception			
6.	.....	.....	.....	.....
7.	.....	.....	.....	.....
8.	.....	.....	.....	.....

Exercise 17: Identifying major components of the water balance

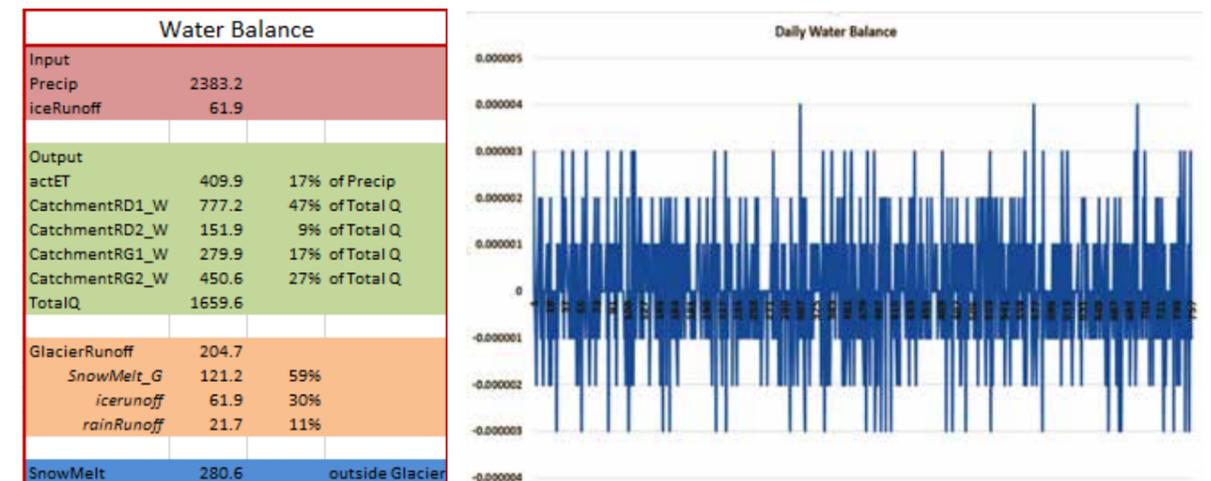
Objective: To understand the role of different variables in water balance

Procedure:

1. Run the model on the desired period and open the output file 'Timeloop.dat' in Excel.
 - Hint:** The inputs are 'precip' and 'iceRunoff'.
2. Identify the inputs.
 - Hint:** 'actET', 'CatchmentRD1_W', 'CatchmentRD2_W', 'CatchmentRG1_W, and CatchmentRG2_W'.
3. Identify the outputs.
 - Hint:** To calculate the water balance of the second day ('Day2'), you can add the values of the following attributes (Day2-Day1 intercStorage) + (Day2-Day1 snowTotSWE) + (Day2-Day1 snowStorage_G) + (Day2-Day1 actMPS) + (Day2-Day1 actLPS) + (Day2-Day1 actRG2) + (Day2-Day1 actRG1) + (Day2-Day1 channelStorage_w) + (Day2 GlacStorage) + (Day2-Day1 actDPS).
4. Identify the major storages
5. Calculate the value of major components of the water balance (e.g., Figure 129)

Do you have Input = (Output+Storage)?

FIGURE 129 WATER BALANCE AND QUANTIFICATION OF COMPONENTS OF THE WATER BALANCE



If the water balance is closed, the input to the model should be equal to output and storages. i.e. Input = (output+storages). See Figure 129.



References

- Ahouansou, D. M. M., Agodzo, S. K., Kralisch, S., Sintondji, L. O. C., & Fürst, C. 2015. Analysis of the hydrological budget using the J2000 model in the Pendjari River Basin, West Africa. *Journal of Environment and Earth Science*, 5(19), 24–37.
- Anderson, M. G., & Burt, T. P. 1985. Modelling strategies. In M. G. Anderson and T. P. Burt (Eds.), *Hydrological Forecasting* (pp 1–13). New York: John Wiley & Sons.
- Armstrong, R. L. 2010. *The glaciers of the Hindu Kush-Himalayan region: A summary of the science regarding glacier melt/retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan mountain ranges*. Kathmandu: ICIMOD.
- Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. 1998. Large area hydrologic modeling and assessment part I: Model development 1. *J. Am. Water Resour. Assoc.*, 34, 73–89.
- Bergstrom, S. 1976. Development and application of a conceptual runoff model for Scandinavian catchments. *SMHI Rep RO7*, Norrköping, Sweden: Swedish Meteorological and Hydrological Institute.
- Beven, K. 2001. How far can we go in distributed hydrological modelling? *Hydrol. Earth Syst. Sci.*, 5(1), pp. 1–12. doi:10.5194/hess-5-1-2001
- Beven, K. & Binley, A. 1992. The future of distributed models: Model calibration and uncertainty prediction. *Hydrol. Process.* 6, 279–298.
- Beven, K. & Freer, J. 2001. Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE methodology. *J. Hydrol.*, 249(1), 11–29. doi:10.1016/S0022-1694(01)00421-8
- Bicknell, B. R., Imhoff, J. C., Kittle Jr, J. L., Donigan Jr, A. S., & Johanson, R. C. 1996. *Hydrological simulation program-FORTRAN: User's manual for release 11*. Washington, DC: US EPA.
- Bratley, P., Fox, B. L. & Schrage, L. E. 1987. *A Guide to Simulation*. New York: Springer-Verlag.
- Chapra, S. & Pelletier, G., & Tao, H. 2003. H. QUAL-2K a Model. Framew. simulating river stream water Qual. Doc. users manual. Medford: Tufts University.
- Cunderlik, J. M. & Simonovic, S. P. 2003. Assessment of water resources risk and vulnerability to changing climatic conditions: Hydrologic model selection for the cfcas project. Report No. I, London, Ontario, Canada: University of Western Ontario.
- Daniel, E. B., Camp, J., LeBouef, E., Penrod, J., Dobbins, J., & Abkowitz, M. 2011. Watershed modeling and its applications: A state-of-the-art review. *Open Hydrol. J.* 5, 26–50.
- DeCoursey, D. G., Shaake Jr, J. C., & Seely, E. H. 1982. Stochastic models in hydrology. In C. T. Haan, H. P. Johnson, and D. L. Brakensiek (Eds.) *Hydrol. Model. small watersheds* (pp 19–78). Michigan: American Society of Agricultural Engineers.
- Dickinson, R. E. 1984. Modeling evapotranspiration for three-dimensional global climate models. *Clim. Process. Clim. Sensit.*, 29, 58–72.
- Fink, M., Fischer, C., Führer, N., Abm, F., Viet, T. Q., Laux, P., & Flügel, W.-A. 2013. Distributed hydrological modeling of a monsoon dominated river system in Central Vietnam. Paper presented at the 20th International Congress on Modelling and Simulation. December 2013, Adelaide. 1832 [what is this?].
- Fink, M., Krause, P., Kralisch, S., Bende-Michl, U., & Flügel, W.-A. 2007. Development and application of the modelling system J2000-S for the EU-water framework directive. *Adv. Geosci.*, 11, 123–130.
- Flügel, W. 1995. Delineating hydrological response units by geographical information system analyses for regional hydrological modelling using PRMS/MMS in the drainage basin of the River Bröl, Germany. *Hydrol. Process.*, 9, 423–436.
- Flügel, W. A. (2009). Applied geoinformatics for sustainable IWRM and climate change impact analysis. *Technology, Resource Management and Development*, 6, pp. 57–85.
- Gao, T., Kang, S., Krause, P., Cuo, L., & Nepal, S. 2012. A test of J2000 model in a glacierized catchment in the central Tibetan Plateau. *Environ. Earth Sci.*, 65, 1651–1659.
- Gupta, H. V., Beven, K. J. & Wagener, T. 2006. Model calibration and uncertainty estimation. *Environ. Earth Sci.* <http://doi.org/10.1002/0470848944hsa138>
- Hock, R. 1999. A distributed temperature-index ice-and snowmelt model including potential direct solar radiation. *J. Glaciol.*, 45, 101–111.
- Hornberger, G. M. & Spear, R. C. 1981. Approach to the preliminary analysis of environmental systems. *J. Environ. Mgmt.*, 12, 7–18.
- Immerzeel, W. W., Van Beek, L. P. H., & Bierkens, M. F. P. 2010. Climate change will affect the Asian water towers. *Science*, 328, 1382–1385. Retrieved from <http://dx.doi.org/10.1126/science.1183188>.
- Jajarmizadeh, M., Harun, S., & Salarpour, M. 2012. A review on theoretical consideration and types of models in hydrology. *J. Environ. Sci. Technol.* 5, 249–261.
- Jansson, P., Hock, R., & Schneider, T. 2003. The concept of glacier storage: A review. *J. Hydrol.* 282, 116–129.
- Jayatilaka, C. J., Storm, B., & Mudgway, L. B. 1998. Simulation of water flow on irrigation bay scale with MIKE-SHE. *J. Hydrol.*, 208, 108–130.
- Julian, M. M., Fink, M., Fischer, C., Krause, P., & Flügel, W. A. 2013. Implementation of J2000 hydrological model in the western part of Java Island, Indonesia. In *Proceedings of the MacroTrend Conference on Applied Science, Paris, France* (pp 20–21).
- Klemes, V. 1986. Operational testing of hydrological simulation models. *Hydrol. Sci. J.*, 31, 13–24.
- Knauf, D. 1976. Run-off formation in snow-covered catchment areas of the middle mountains. Graz: Institut für Hydraulik und Hydrologie.
- Kralisch, S. & Krause, P. 2006. JAMS—A framework for natural resource model development and application. Third International Conference on Modelling and Software. 9–13 July, Burlington, Vermont, USA.
- Kralisch, S., Krause, P., Fink, M., Fischer, C. & Flügel, W. A. 2007. Component based environmental modelling using the JAMS framework. *MODSIM Int. Congr. Model. Simul.* [Is this meant to be the International Congress on Environmental Modelling and Software? Place?]
- Krause, P. 2001. Das hydrologische Modellsystem J2000: Beschreibung und Anwendung in großen Flußgebieten. Forschungszentrum Jülich: Zentralbibliothek.
- Krause, P. 2002. Quantifying the impact of land use changes on the water balance of large catchments using the J2000 model. *Phys. Chem. Earth, Parts A/B/C*, 27, 663–673.
- Leavesley, G. H., Lichty, R. W., Troutman, B. M., & Saindon, L. G. 1983. *Precipitation-runoff modeling system: User's manual*. Washington, DC: USGS).
- Lutz, A. F., Immerzeel, W. W., Shrestha, A. B., & Bierkens, M. F. P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature Climate Change*, 4(7), 587.
- McCuen, R. H. 1973. The role of sensitivity analysis in hydrologic modeling. *J. Hydrol.*, 18(1), 37–53. doi:10.1016/0022-1694(73)90024-3
- McCuen, R. H. 2005. Accuracy assessment of peak discharge models. *J. Hydrol. Eng.*, 10, 16–22.
- Montanari, A. 2005. Large sample behaviors of the generalized likelihood uncertainty estimation (GLUE) in assessing the uncertainty of rainfall-runoff simulations. *Water Resour. Res.*, 41, W08406. doi:10.1029/2004WR003826, 2005
- Nepal, S. (2012). Evaluating upstream–downstream linkages of hydrological dynamics in the Himalayan region (Doctoral dissertation, Faculty of Chemical and Earth Sciences, University of Jena, Jena, Thuringia, Germany). Retrieved from https://www.db-thueringen.de/servlets/MCRFileNodeServlet/dbt_derivate_00025985/Diss/Santosh_Nepal.pdf

- Nepal, S., Flügel, W.-A., & Shrestha, A. B. 2014. Upstream-downstream linkages of hydrological processes in the Himalayan region. *Ecol. Process.* 3, 19. <http://www.ecologicalprocesses.com/content/3/1/19>.
- Nepal, S., Krause, P., Flügel, W. A., Fink, M., & Fischer, C. 2014. Understanding the hydrological system dynamics of a glaciated alpine catchment in the Himalayan region using the J2000 hydrological model. *Hydrol. Process.*, 28(3), 1329–1344. doi:10.1002/hyp.9627
- Noilhan, J. & Mahfouf, J.-F. 1996. The ISBA land surface parameterisation scheme. *Glob. Planet. Change*, 13, 145–159.
- Noilhan, J. & Planton, S. 1989. A simple parameterization of land surface processes for meteorological models. *Mon. Weather Rev.* 117, 536–549. (1989).
- Power, M. 1993. The predictive validation of ecological and environmental models. *Ecol. Modell.*, 68, 33–50.
- Refsgaard, J. C. & Knudsen, J. 1996. Operational validation and intercomparison of different types of hydrological models. *Water Resour. Res.* 32, 2189–2202.
- Refsgaard, J. C. & Storm, B. 1996. Construction, calibration and validation of hydrological models. In M. B. Abbot and J. C. Refsgaard (Eds.), *Distributed Hydrological Modelling* (pp. 41–54). New York: Springer.
- Refsgaard, J. C., van der Sluijs, J. P., Højberg, A. L., & Vanrolleghem, P. A. 2007. Uncertainty in the environmental modelling process: A framework and guidance. *Environ. Model. Softw.* doi:10.1016/j.envsoft.2007.02.004
- Saltelli, A. & Sobol, I. M. 1995. About the use of rank transformation in sensitivity analysis of model output. *Reliab. Eng. Syst. Saf.*, 50, 225–239.
- Scott, C. A., Zhang, F., Mukherji, A., Immerzeel, W., Mustafa, D., & Bharati, L. (2019). Water in the Hindu Kush Himalaya. In P. Wester, A. Mishra, A. Mukherjee, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* (pp. 257–299). Cham: Springer Nature Switzerland AG.
- Singh, V. P. & Frevert, D. K. (Eds.). 2002. *Mathematical Models of Small Watershed Hydrology and Applications*. Colorado: Water Resources Publication, LLC.
- Tessema, S. M. 2011. Hydrological modeling as a tool for sustainable water resources management: A case study of the Awash River Basin. Trita-LWR. LIC NV - 2056. Stockholm: KTH Royal Institute of Technology.
- Uhlenbrook, S., Seibert, J. A. N., Leibundgut, C., & Rodhe, A. 1999. Prediction uncertainty of conceptual rainfall-runoff models caused by problems in identifying model parameters and structure. *Hydrol. Sci. J.*, 44, 779–797.
- Wagener, T., Boyle, D., Lees, M., Wheeler, H., Gupta, H., & Sooroshian, S. 2001. A framework for development and application of hydrological models. *Hydrol. Earth Syst. Sci.*, 5(1), 13–26.
- Weichel, T., Pappenberger, F., & Schulz, K. 2007. Sensitivity and uncertainty in flood inundation modelling? Concept of an analysis framework. *Adv. Geosci.*, 11, 31–36.
- Wijngaard, R. R., Lutz, A. F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A. B., & Immerzeel, W. W. (2017). Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. *PloS ONE*, 12(12), e0190224.

About ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD), is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

REGIONAL MEMBER COUNTRIES





ICIMOD gratefully acknowledges the support of its core donors: the Governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden, and Switzerland.

© ICIMOD 2020

International Centre for Integrated Mountain Development

GPO Box 3226, Kathmandu, Nepal

T +977 1 5275222 | **E** info@icimod.org | www.icimod.org

ISBN 978 92 9115 695 5 (electronic)