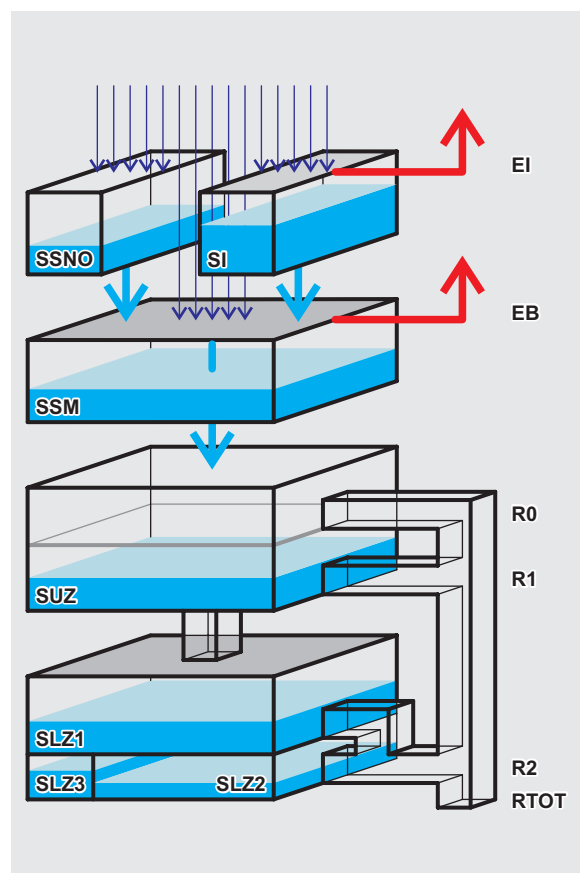


The Hydrological Modelling System PREVAH

Part I – Overview and Selected Applications

Daniel Viviroli,
Joachim Gurtz,
and Massimiliano Zappa



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This publication contains an overview of the hydrological modelling system PREVAH and selected application examples. It is Part I of the extensive PREVAH model documentation and is complemented by the physical model description (Part II), the user manual (Part III) and a sample PREVAH project (Part IV).

<i>Publication Part</i>	Part I	Part II	Part III	Part IV
<i>Contents</i>	Overview and selected applications	Physical model description	User manual	Sample project and selected executables
<i>Availability</i>	Printed only	On-line only (pdf)	On-line only (pdf)	On-line only (zip)

The PREVAH modelling system is available for academic and research purposes exclusively. It must not be used commercially. Please read the "Terms of use" on page 3 of Part III for further inquiries.

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 The Hydrological Modelling System PREVAH. Part I – Overview and Selected Applications

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1. Introduction

For a well-founded simulation of hydrological processes at catchment scale, physically congruous hydrological models are required, including their careful parameterisation, calibration and evaluation. In the past decade, spatially distributed modelling became an established tool for studying both components and possible changes of the hydrological cycle. The availability of geographic information systems (GISs) and digital elevation models (DEMs), the improved reliability, precision and resolution of meteorological and hydrological networks, combined with the availability of remotely sensed data, allowed the development and application of spatially distributed hydrological models within mountainous landscapes and their calibration and evaluation with respect to observed time series and spatial patterns of hydrometeorological variables.

Especially mountainous catchments are characterised by highly variable morphology, soil and vegetation types as well as by pronounced temporal and spatial variations of the climatic elements. Depending on the location and elevation of a watershed, mountain discharge regimes are influenced by glacial melt, snowmelt, rainfall and their spatial and temporal superposition. The quality of a hydrological simulation depends on the ability of the underlying model to describe and accurately represent the heterogeneity of such hydrological systems at the different spatial and temporal scales.

The distributed hydrological catchment modelling system PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotone Model) has been developed to suit these conditions. Its main purpose is to describe the hydrological processes in mountain environments in their high spatial and temporal variability. With a view to keeping computational cost and complexity of process descriptions within reasonable bounds, PREVAH implements a conceptually oriented approach. With its modular set-up, the modelling system offers a model core as well as a large number of tools. The latter provide easy-to-use solutions for handling the large amounts of data involved in preprocessing and postprocessing tasks, model parameterisation, calibration and evaluation as well as visualisation of results.

This brochure presents a brief overview of the most important components of PREVAH, while a number of applications are selected to demonstrate its abilities. An extensive description of the physics underlying the model, the complete user manual as well as data of a sample catchment including selected PREVAH executables are available at www.hydrologie.unibe.ch/PREVAH.



2 Basics of the PREVAH modelling system

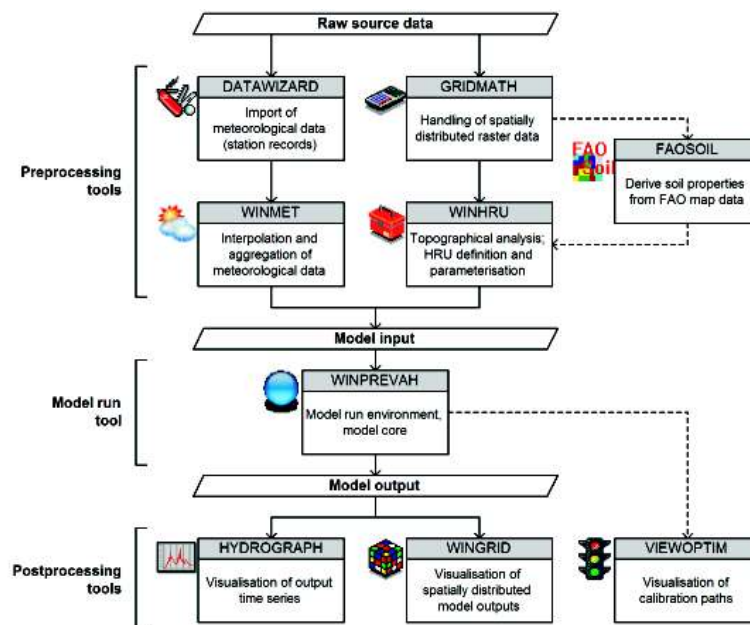
The hydrological modelling system PREVAH is a collection of user-friendly, tailor-made tools which have been developed in order to facilitate and speed up data preprocessing and postprocessing tasks involved in the operation of the semi-distributed hydrological model PREVAH (Precipitation-Runoff-Evapotranspiration HRU-related Model). PREVAH was originally intended to improve the understanding of the spatial and temporal variability of hydrological processes in catchments with complex topography. The spatial discretisation of PREVAH relies on the aggregation of gridded spatial information into clusters showing similar hydrological response, the hydrological response units (HRUs).

PREVAH is fed with standard meteorological variables with high temporal resolution. For its application, data on air temperature, precipitation, water vapour pressure, global radiation, wind speed and sunshine duration are required.

PREVAH relies to a high degree on conceptual representations of hydrological processes. It incorporates several sub-models, such as for snow accumulation and snowmelt, glacial melt, interception, soil water storage and depletion by evapotranspiration, runoff and baseflow generation as well as for discharge concentration and flood-routing.

This hydrological modelling system contains the following tools:

- GRIDMATH provides basic GIS functions. It has been specifically developed for managing spatially distributed data. Amongst other features, GRIDMATH allows for mathematical operations between raster data and for conversion of raster data into formats compatible with common commercial GIS and remote sensing applications.
- FAOSoil is used when information on soil properties is not available; this tool processes data from the FAO/UNESCO Soil Map of the World.
- WINHRU has been developed to generate all spatial information required for running PREVAH. WINHRU is able to delineate hydrological catchments and performs a detailed topographical analysis. Hydrological response units (HRUs) are created as specified by user-defined criteria, and the corresponding information is summarised in tables. By assimilating the information from these tables, PREVAH is able to "understand" the physiogeographical complexity of the catchment under investigation. WINHRU also generates a default control file for initialising PREVAH and its graphical user interface



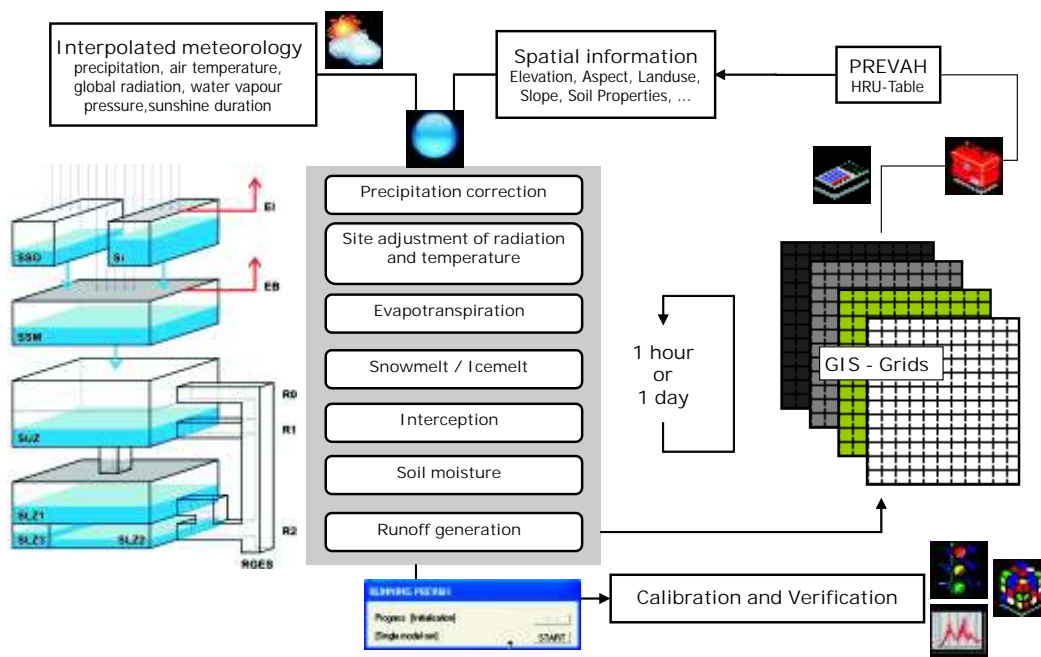
Preprocessing and postprocessing tools of the PREVAH modelling system.

- DATAWIZARD assimilates and manages hydrometeorological data, which is an important prerequisite for the distributed hydrological modelling. In this way, DATAWIZARD provides a link between hydrometeorological raw data and the spatial interpolation tool WINMET. It is designed for the stepwise assimilation of raw meteorological information from a network of stations. A small database is created and maintained. Besides assimilation, DATAWIZARD is also able to verify hydrometeorological data.
- WINMET handles the spatial interpolation of the meteorological variables. This tool extracts the relevant hydrometeorological information from a database and creates elevation-dependent regressions of the variables analysed. Various approaches are available for the spatial interpolation of hydrometeorological data, such as elevation-dependent regression, Kriging and inverse distance weighting.
- WINPREVAH constitutes the PREVAH model core. It assimilates both spatial data and hydro-meteorological information and simulates the complete hydrological cycle of a catchment. WINPREVAH is equipped with a monitored calibration routine which has been designed

specifically for PREVAH and implements a number of objective efficiency scores. Furthermore, WINPREVAH is able to generate Monte Carlo simulations with random allocation of the most sensitive free model parameters; this enables estimation of parameter uncertainty.

- HYDROGRAPH draws time series of observed and modelled data and of modelled water balance components.
- WINGRID is used to visualise grid maps such as spatially distributed model outputs.
- VIEWOPTIM facilitates interpretation and assessment of a calibration procedure.
- Finally, the LAUNCHER toolbar provides one-click access to all components of the hydrological modelling system PREVAH.

WINPREVAH and its companion tools have been programmed in FORTRAN, the respective graphical user interfaces run on every Windows computer. The FORTRAN-based PREVAH model core is integrated in WINPREVAH but has also been compiled for application under MS-DOS, Unix and Linux.



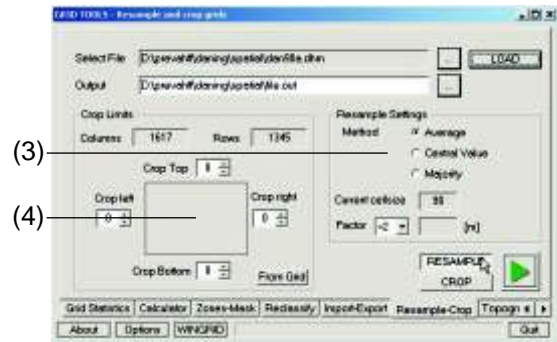
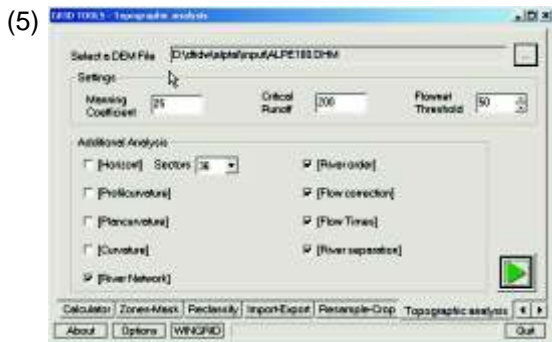
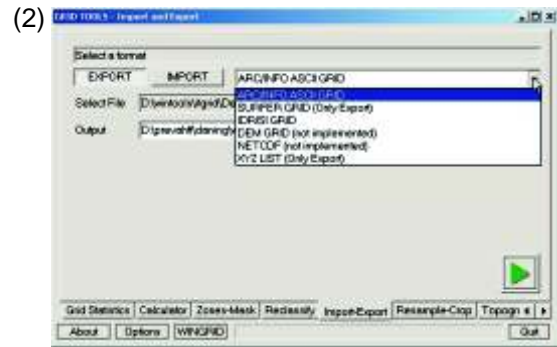
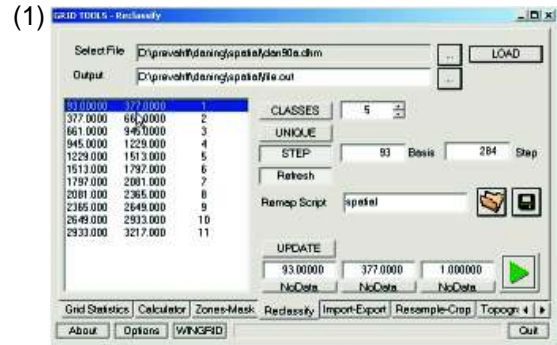
Data flow to the core of the PREVAH modelling system.

3 Preprocessing

3.1 Grid processing: GRIDMATH

Ease of management regarding digital representations of spatially distributed physiogeographical information is an important requirement for the development, parameterisation and initialisation of GIS-based spatially distributed hydrological models such as PREVAH. The GRIDMATH tool allows the user to manage spatially distributed data stored in grid format as required for using the PREVAH modelling system. The grid format of PREVAH is binary, while being structured similarly to the ASCII format used in ESRI GIS systems such as ArcMAP and Arc/INFO. GRIDMATH implements a number of operations with and between raster grids:

- Computation of statistical values
- Simple mathematical calculations
- Overlaying a grid mask to a grid
- Zonal statistics
- Reclassifying the data into categories (1)
- Importing grids from and exporting grids to other grid formats (2)
- Reducing the resolution of a grid (resample) (3)
- Reducing the size of a grid by cropping the borders (4)
- Conducting a topographical analysis of a digital elevation model according to Schulla and Jasper (2000) (5)



TEXT REFERENCES

- Export of maps to GIS:
see Part III, Chapter A.4.6
- Binary format:
see Part II, Chapter 3.2

LITERATURE

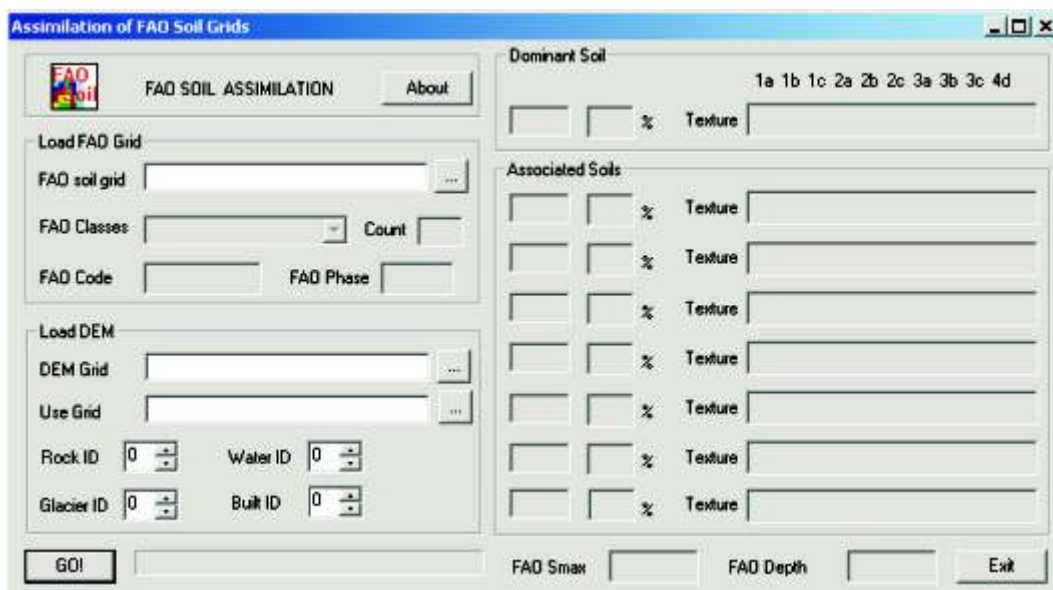
Schulla J, Jasper K (2000): *Model Description WaSiM-ETH*. Zürich: Institute for Atmospheric and Climate Science, ETH Zürich.

3.2 Soil data assimilation: FAOSoil

The sound parameterisation of soil properties is essential for accurate water balance and runoff simulations. The most important parameters for PREVAH are soil depth and plant available field capacity. These two soil properties are required to estimate how much water is available for evapotranspiration. In general, the information for deriving soil depth, hydraulic conductivity and field capacity is obtained from local soil maps. If no such information is available, it may be possible to process information from the FAO/UNESCO Soil Map of the World. The FAOSoil tool allows for the parameterisation of soil property grids from information on the spatial distribution of FAO soil classes within the investigated domain. The FAO soil classes can be generated from the Digital Soil Map of the World (<http://www.fao.org/ag/agl/agll/dsmw.htm>). The Digital Soil Map of the World consists of the following map sheets: Africa, North

America, Central America, Europe, Central and Northeast Asia, Far East, Southeast Asia, and Oceania. Data on all the continental surface areas are provided by FAO upon request.

A simple index based on slope elevation and land use is adopted in order to spatially disaggregate the soil properties according to soil depth and plant available field capacity classes in the different FAO soil units. It is assumed that the deepest soils and the soils with highest plant available field capacity are located at lower altitudes and in flat areas of the domain. Additional restrictions depend on land use. Shallow soil should be assigned to grid cells representing water bodies, rocky areas, urban areas and glaciers. For the use of FAOSoil, the following spatially distributed data are required: digital elevation model, land use map, and a map with information on the FAO classes.



The graphical user interface of FAOSoil.

LITERATURE

FAO-UNESCO (1988): Soil Map Of World, Revised Legend. World Soil Resources Report 60. Rome: FAO.

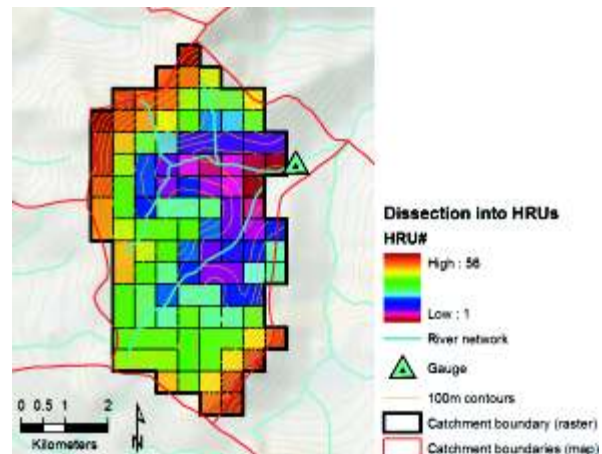
Sonderegger C (2004): Rainfall/Runoff Modelling of a Sub-Catchment of the Yangtze in China. Diploma Thesis at the ETH and University Zürich.

3.3 Spatial discretisation: WINHRU

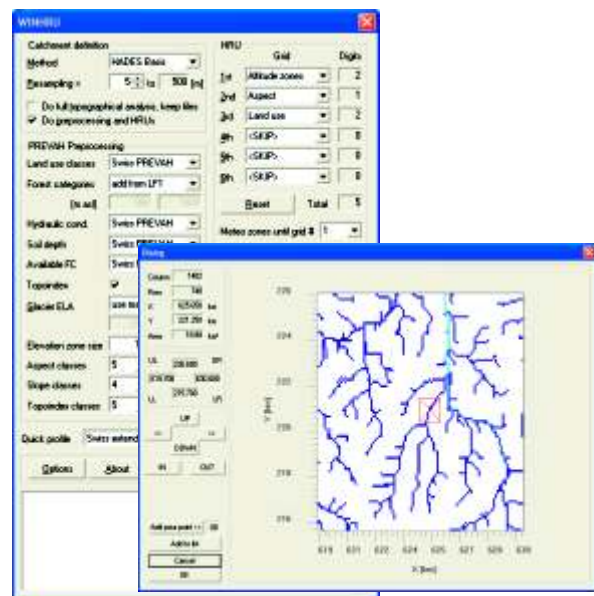
Instead of a uniform raster-cell resolution, PREVAH uses the concept of hydrological response units (HRUs) by default. This means aggregating spatially distributed grid cells according to a set of structural and statistical characteristics. The goal is to aggregate cells with similar and homogeneous hydrological response. Consequently, the criteria applied for differentiation are related to the processes that most significantly influence runoff generation and evapotranspiration (e.g. elevation, land use, aspect). Essentially, this concept corresponds to a dynamical spatial resolution: the higher the spatial variability of soil, land surface and topographical characteristics, the lower the average size of the HRU.

WINHRU is the PREVAH modelling system's comprehensive tool for efficient aggregation of hydrological response units (HRUs). First of all, the boundaries of a catchment have to be defined. Various methods are available for this: On the one hand, the boundaries may be derived from the digital elevation model's flow directions by either selecting a standard gauge location or by defining an arbitrary pour point. On the other hand, they may be transferred from maps such as from the Hydrological Atlas of Switzerland or from any other GIS-formatted file. A total of 12 criteria are available to differentiate the HRUs, of which a maximum of 6 may be used at a time. Required input data include raster-formatted files for elevation, land use and soil properties; they may be complemented with extra information layers regarding, for example, geology or hydrogeology. Once all other settings such as resolution, number of altitude zones, etc. have been defined, preprocessing takes but a few moments to complete and results in an HRU properties table, a grid map of HRU identifiers and a PREVAH control file – all that is needed in terms of physiographical information to run PREVAH.

While this tool, by default, is set up for application in Switzerland, it can be easily used for other regions of the world as well. The input raster data required for this are created with additional tools such as FAOSoil and GRIDMATH.



Example of HRU discretisation in a Swiss alpine catchment.



The graphical user interface of WINHRU used for aggregation of hydrological response units (HRUs).

TEXT REFERENCES

- Preprocessing, spatial data: see Part III, Chapter C
- Raster map display: see Part III, Chapter H
- Raster map processing: see Part III, Chapter A
- Sample preprocessing data: see Part IV (PREVAH project)

LITERATURE

- Engel BA (1996):** Methodologies for development of response units based on terrain, land cover and soils data. **Goodchild MF, ed.** *GIS and environmental modeling*. Fort Collins, CO, US: GIS World Books, p. 123–128.
- Flügel W-A (1997):** Combining GIS with regional hydrological modelling using hydrologic response units (HRUs): An application from Germany. *Mathematics and Computers in Simulation* **43**:297–304.
- Zappa M (1999):** *Untersuchungen zur Aufbereitung unterschiedlicher Rauminformationen für die flächendifferenzierte Einzugsgebietsmodellierung*. Diploma thesis, Department of Geography, ETH Zürich.

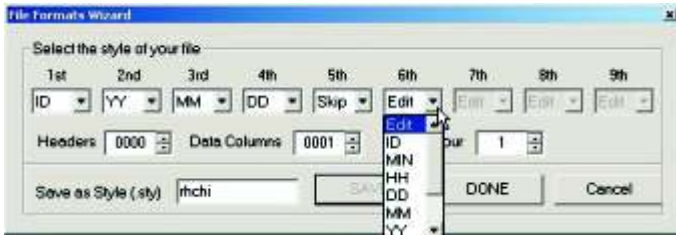
3.4 Meteorological data assimilation: DATAWIZARD

The assimilation and management of hydro-meteorological data from a network of stations is crucial for the application of distributed hydrological models. DATAWIZARD is a tool allowing the assimilation and simple verification of hydro-meteorological data; it provides a link to WINMET, the spatial interpolation tool of the hydrological modelling system PREVAH.

DATAWIZARD has been specifically developed to manage the hydrometeorological information required for running PREVAH. The software is designed for the stepwise assimilation of raw meteorological information available as ASCII tabular data. DATAWIZARD is able to process the following hydrometeorological variables: precipitation, air temperature, wind speed, global radiation, relative humidity, water vapour pressure, sunshine duration, runoff and two user-defined variables.



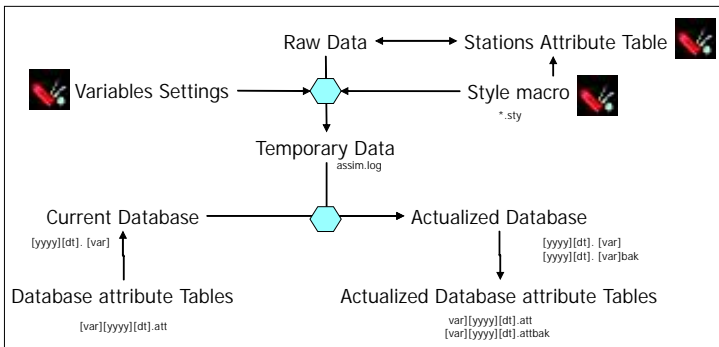
Check for data completeness.



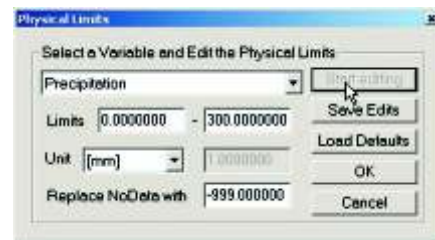
Definition of scripts for assimilation of ASCII tables.



Update station attributes.



Creation, management and update of a simple database.



Definition of physical limits.

TEXT REFERENCES

– Meteorological model input:
see Part II, Chapter 3.4

3.5 Meteorological data interpolation: WINMET

In PREVAH, the distributed hydrological modelling is based on observations of meteorological variables at different gauging stations. The stations used are located within or near the area under investigation. WINMET has been developed to interpolate meteorological information as required by PREVAH. Currently, WINMET integrates two versions. The Swiss version has been designed specifically for applications based upon the hydrometeorological data provided by the Swiss meteorological service. The international version is more generalised and has been designed to interact with DATAWIZARD.

WINMET extracts meteorological data from a database which is usually created and maintained by DATAWIZARD.

The selection of meteorological stations to be used for interpolation is assisted automatically with the help of a search radius; this preliminary choice is then completed interactively and entered in a station list.

Compatibility with the current PREVAH modelling project is achieved by adopting the grids generated by WINHRU; this specifically concerns the digital elevation model, the basin watershed mask and a map of the relevant meteorological zones. Meteorological zones are generally defined

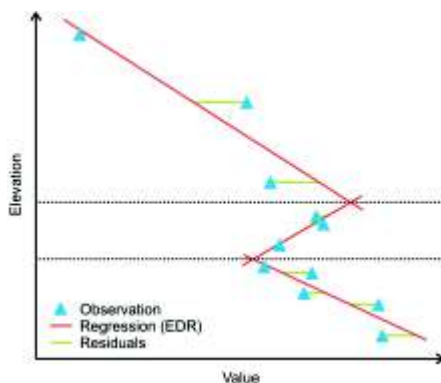


Selection of stations from a list.

according to sub-basins and 100-metre elevation bands. After interpolation, WINMET creates ASCII-formatted tables of meteorological data required to run PREVAH. An average interpolated value is provided for each time step and for each meteorological zone.

The basic procedures adopted for the spatial and temporal interpolation of observed meteorological information are elevation-dependent regression (EDR), inverse distance weighting (IDW), Kriging and laps-rate (only for temperature data).

It is possible to combine EDR with Kriging or IDW, resulting in a procedure called detrended interpolation: For this, the residuals (difference between interpolated and observed values) of the EDR method are spatially interpolated with IDW or Kriging. By adding this interpolated residual map to the map interpolated with EDR, altitude biases in the station values are accounted for (see Garen and Marks, 2001).



Elevation-dependent regression.

TEXT REFERENCES

– Meteorological model input:
see Part II, Chapter 3.4

LITERATURE

Garen DC, Marks D (2001): Spatial fields of meteorological input data including forest canopy corrections for an energy budget snow simulation model.
Dolman AJ, Halla J, Kavvas ML, Oki T, Pomeroy JW, eds. *Soil-Vegetation-Atmosphere Transfer Schemes and Large Scale Hydrological Models*. IAHS publication 270. Wallingford, UK: International Association of Hydrological Sciences, p. 349–353.

4. Running the model

4.1 Model input and free parameters: WINPREVAH (I)

Three types of input data are required to run PREVAH:

1) Physiographical information for the hydrological response units (HRUs): On the one hand, this contains an ASCII-formatted table listing the physiographical properties of each HRU. These properties are used in PREVAH to parameterise various HRU properties, such as maximum storage contents and behaviour of evapotranspiration. On the other hand, a PREVAH-grid-formatted map locates the individual HRU positions for spatially distributed output. Both inputs are generated by WINHRU.

2) Meteorological input for the altitude zones: After interpolation of the station values, the spatially distributed meteorological data are aggregated to altitude zones. An ASCII-formatted table lists these values for each time step. Details required include precipitation, temperature, wind speed, vapour pressure (or relative humidity), global radiation and sunshine duration. Station selection, interpolation and aggregation are handled by WINMET.

3) A control file containing all site-specific information required for modelling, e.g. number of HRUs and altitude zones, free model parameter values, initial storage contents, time step and application timeframe, output options, etc. An initial control file is generated by WINHRU, changes are made using WINPREVAH.

A number of free parameters are available to adjust PREVAH to the specific modelling site. Depending on module specifications (e.g. evapotranspiration modelling scheme), this number typically ranges between 14 and 19. These parameters can be subdivided into six groups:

1) Water balance adjustment: with PKOR and SNOKOR, precipitation input is adjusted in order to reduce the total volume error of the model as observed at the catchment outlet. Gauge error correction is already effected during preprocessing.

2) Differentiation of precipitation into liquid (rain) and solid (snow) fractions with the help of both

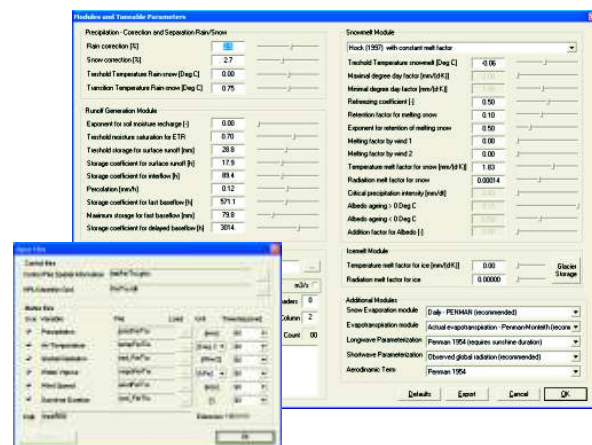
threshold temperature (TGR) and temperature range (TTRANS).

3) Snowmelt module: threshold temperature for snowmelt (T0), temperature melt factor (TMFSNOW; if variable: TMFMIN and TMFMAX), radiation melt factor (RMFSNOW), coefficient for re-freezing (CRFR). Retention of meltwater in snow (SLIQMAX) is usually set to a fixed value of 10%.

4) Glacier module (if applicable): radiation and temperature melt factors (ICETMF and ICERMF). Additional parameters for storage and translation times in firn, snow and ice are available.

5) Soil moisture module: non-linearity parameter for infiltration as a function of actual soil moisture (BETA). Various other important characteristics (e.g. maximum soil moisture storage) are parameterised by PREVAH with the help of soil and land use parameters.

6) Runoff generation module: storage coefficients for fast and delayed runoff (K0H, K1H) and baseflow (CG1H, K2H), threshold for generation of fast runoff (SGR), threshold for fast baseflow storage (SLZ1MAX), percolation rate (PERC).



Parameter settings and meteorological input data dialog in WINPREVAH.

TEXT REFERENCES

- Model input, physiography: see Part II, Chapter 3
- Model input, meteorology: see Part II, Chapter 3.4
- Model structure, modules, parameters: see Part II, Chapter 2
- Calibration of free parameters: see Part II, Chapter 6

LITERATURE

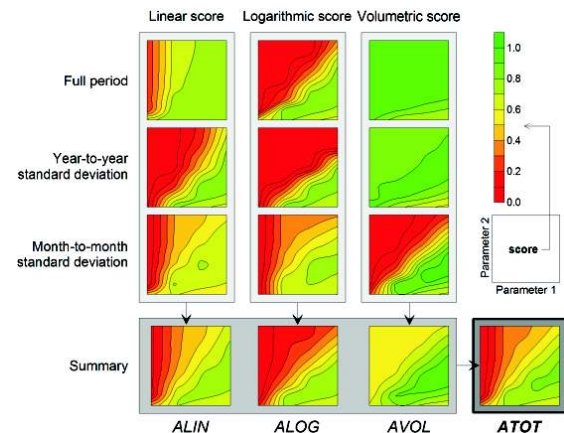
- Bergström S (1976):** *Development and Application of a Conceptual Runoff Model for Scandinavian Catchments*. Bulletin Series A, 52, University of Lund.
- Gurtz J, Baltensweiler A, Lang H, Menzel L, Schulla J (1997):** *Auswirkungen von klimatischen Variationen auf Wasserhaushalt und Abfluss im Flussgebiet des Rheins*. Projektschlussbericht im Rahmen des Nationalen Forschungsprogrammes "Klimaänderungen und Naturkatastrophen", NFP-31. Zürich: vdf Hochschulverlag.

4.2 Model calibration: WINPREVAH (II)

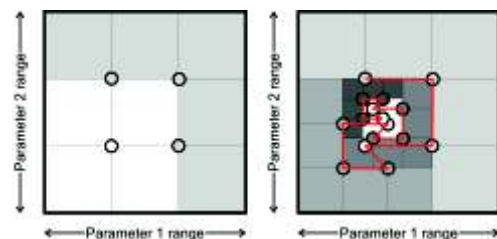
PREVAH contains a number of free parameters which are used to adjust the model to the conditions prevailing in a specific catchment. A suitable set of free model parameters is sought, maximising the extent to which the simulated and observed hydrographs correspond to each other. As an alternative to time-consuming and partially subjective trial-and-error calibration, PREVAH comprises an automatic calibration procedure.

Determining the model efficiency is essential for successful automatic calibration. Gauged data for runoff are usually the only measurement available to assess model efficiency. Consequently, it is of paramount importance to extract the maximum possible amount of information from a comparison of observed and simulated runoff. For this purpose, PREVAH combines three standard efficiency scores with three different temporal viewpoints: Linear and logarithmic Nash-Sutcliffe efficiency as well as the volumetric deviation are assessed over the entire calibration period and in their annual and monthly variations. Each of these 9 scores is mapped to a user-defined score range and then weighted to give a total score. The purpose of this procedure is to find a parameter set which not only achieves high efficiency scores, but also shows a high degree of stability and representativity.

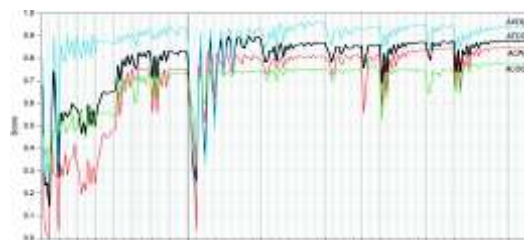
For establishing a suitable parameter set, the automatic calibration procedure uses an interactive search algorithm. First of all, the parameters to be calibrated have to be grouped in pairs of related parameters (e.g. storage coefficient for interflow and percolation). These pairs are then processed consecutively: After dividing the parameter space into nine sections, the model is run for each of the four resulting intersection points. The four sections surrounding the point with the best model performance are retained, the other five discarded. In a next step, the remaining parameter space is processed similarly, until a user-defined number of such iterations is reached or until calibration improvements remain below a certain threshold.



A set of multi-objective efficiency scores is used to guide the automatic calibration procedure.



PREVAH's iterative calibration algorithm minimises computational cost.



Evolution of PREVAH summary scores during an automatic calibration.

TEXT REFERENCES

- Model calibration:
see Part II, Chapter 6
- Calibration visualiser:
see Part III, Chapter I

LITERATURE

- Nash JE, Sutcliffe JV (1970):** River flow forecasting through conceptual models: Part I – a discussion of principles. *Journal of Hydrology* **10**:282–290.
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5 Postprocessing

5.1 Hydrograph interpretation: HYDROGRAPH

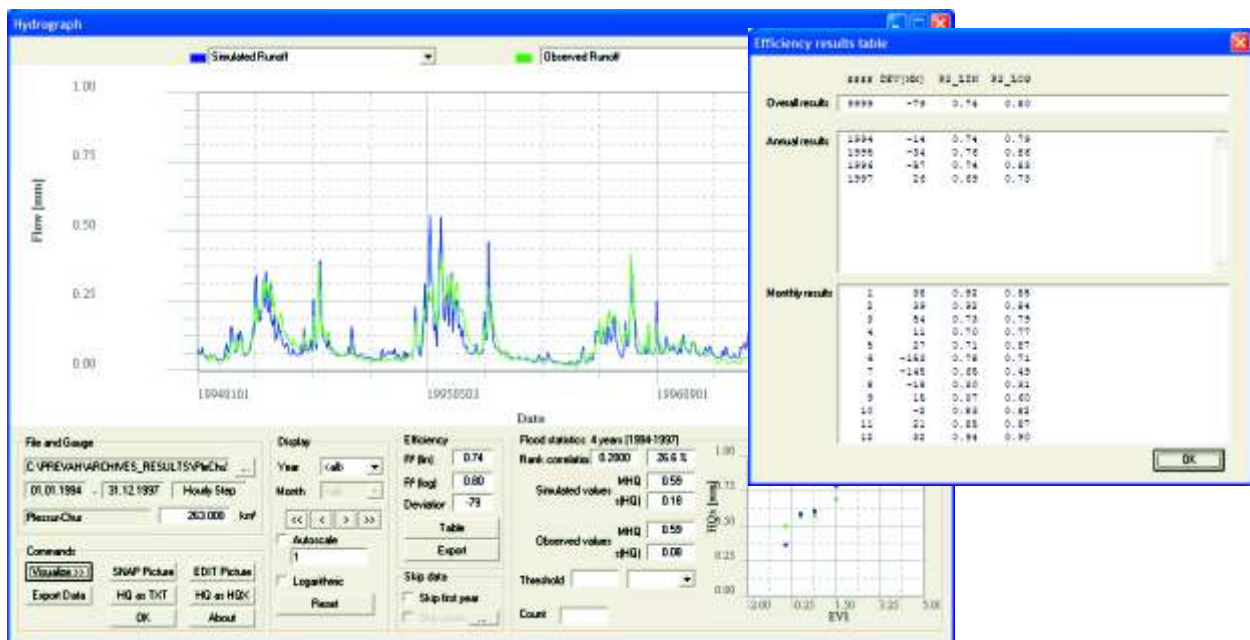
PREVAH delivers its model output in the form of various ASCII-formatted text tables. Depending on the output type and the specifications chosen before running the model, these tables contain observed and modelled runoff data or comprehensive data from model inputs, modelled water fluxes and model storage contents.

Instead of interpreting these tables with commercial data-processing packages, the PREVAH postprocessing feature HYDROGRAPH may be used to quickly visualise and compare model and observation data. A corresponding PREVAH output control file (runoff data or model water balance data) is simply selected from the file open dialogue and visualised by pressing a button. Runoff data are easily screened by scrolling through years and months.

When displaying water balance data, two arbitrary variables may be compared with the help

of a drop-down menu. Rates or fill levels of the following quantities are available: interpolated precipitation (with or without adjustment), snowmelt, ice melt, snow water equivalent, interception storage, plant available soil moisture storage, upper runoff generation storage (unsaturated zone), lower runoff generation storage (saturated zone), water balance components, evapotranspiration (potential and actual), interception evaporation, soil evapotranspiration, surface runoff, interflow, total baseflow (including its three sub-components) and total runoff.

Additionally, statistics on model efficiency and on flood estimation scores are available in the form of tables and graphs. Like the hydrograph itself, these can be exported to text or graphic files.



HYDROGRAPH display of observed and simulated runoff in hourly resolution and efficiency table.

TEXT REFERENCES

- Hydrograph interpretation: see Part III, Chapter G
- Efficiency scores: see Part III, Chapter F.4.9
- Sample output data: see Part IV (PREVAH project)

LITERATURE

- Dyck S, Peschke G (1983):** *Grundlagen der Hydrologie*. Berlin: Verlag für Bauwesen.
- McCuen RH (1998):** *Hydrologic Analysis and Design*. Upper Saddle River, NJ, US: Prentice Hall.
- Nash JE, Sutcliffe JV (1970):** River flow forecasting through conceptual models: Part I – a discussion of principles. *Journal of Hydrology* **10**:282–290.

5.2 Raster map display: WINGRID

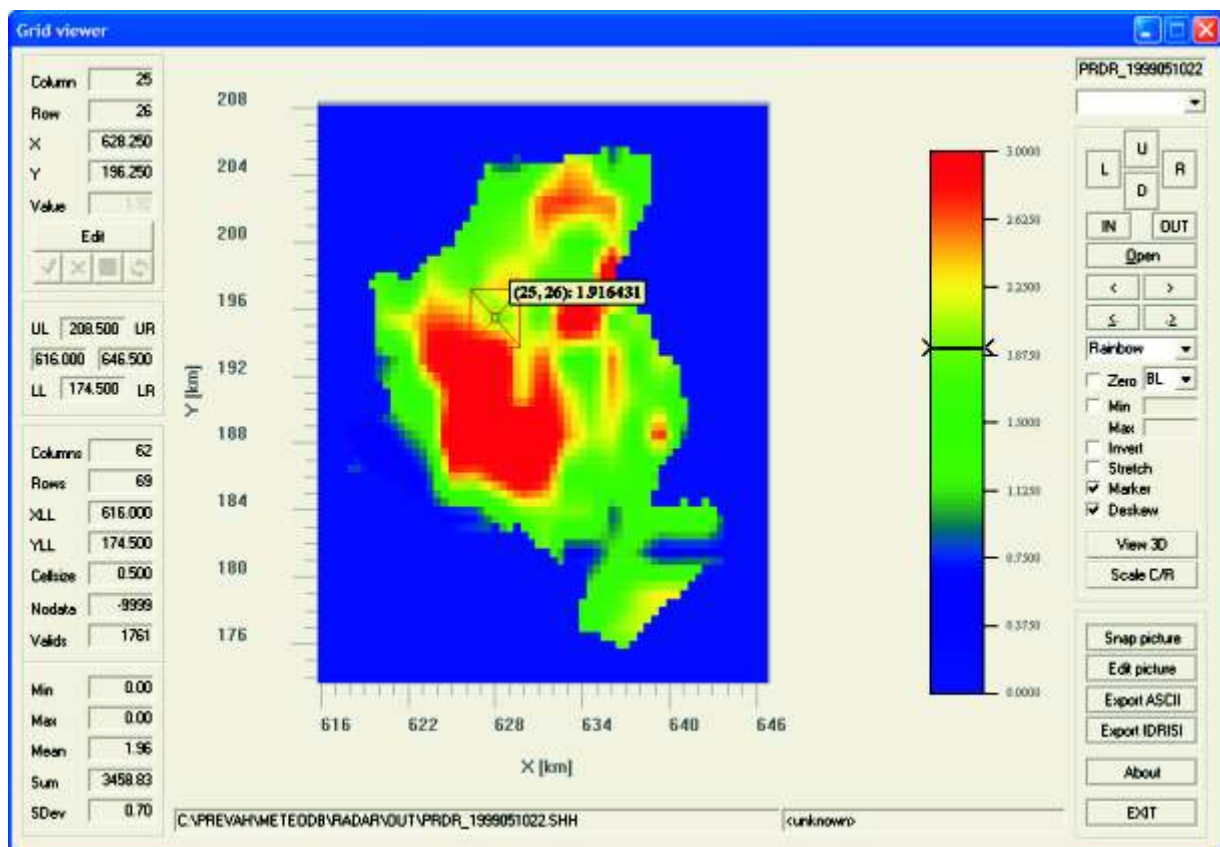
PREVAH implements a binary file format for saving maps to grid raster files. It is used for all preprocessing inputs (see WINHRU and WINMET) as well as for all spatially distributed model outputs. These files are easily re-formatted for use with commercial GIS and image-processing packages.

PREVAH offers straightforward tools to work with the raster files, in particular for displaying (WINGRID) and processing them (GRIDMATH).

WINGRID is used for quick visualisation, verification and interpretation of PREVAH raster data. It recognises and identifies 80 preprocessing and

model file extensions and will handle any binary PREVAH grid map. Besides various display options (e.g. zoom, pan, scale, palette selection, 3D view), it also features a simple grid editor which can e.g. be used to modify preprocessing input data. The extent of the raster file is shown along with elementary data statistics.

PREVAH raster data are exported to ESRI ArcGIS and Clark Labs IDRISI import formats by simply pressing a button, while a built-in screen capture tool allows for the display to be exported to a graphic editor or to a word-processing software.



WINGRID main window with display of PREVAH raster data.

TEXT REFERENCES

- Raster map display:
see Part III, Chapter H
- Raster map processing:
see Part III, Chapter A

5.3 Calibration visualiser: VIEWOPTIM

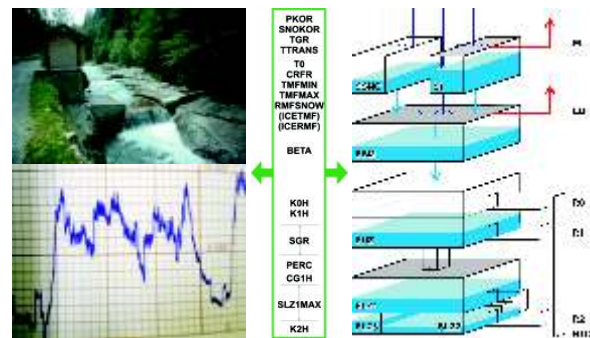
Despite being an automatic procedure, PREVAH's iterative calibration needs to be supervised. For doing so, the modelling system contains a specific calibration visualiser tool: VIEWOPTIM.

VIEWOPTIM enables the user to track the course of a calibration. As described above, PREVAH's calibration scheme treats parameters pair-wise. Consequently, VIEWOPTIM allows various efficiency scores to be displayed for two parameters at a time. This makes it possible to verify whether the iterative process resulted in an increase in efficiency stabilising at a high level. Problems such as parameters reaching the chosen calibration range are easily identified as well.

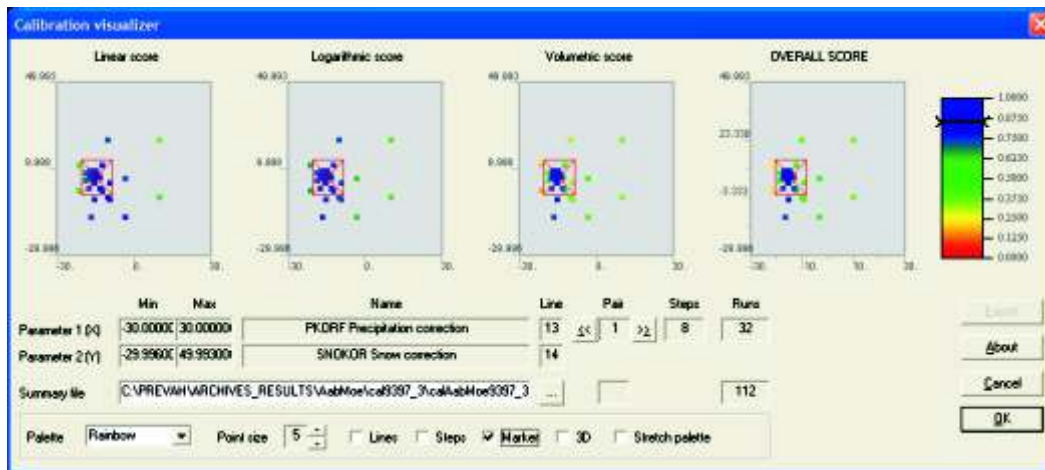
A number of display options extend the interpretation possibilities: For instance, showing the calibration path as a line or with colour markers clarifies the actual iterations computed by PREVAH, and a 3D display of the graphs enhances ease of interpretation.

In addition to verifying the calibration course with VIEWOPTIM, the calibration results should also be verified in more depth. This concerns standard

efficiency scores and a comparison of the curves of simulated and observed discharge. Furthermore, plausible behaviour of the model's conceptual storage modules should be ensured. All of these tasks may be performed using HYDROGRAPH.



Free parameters serve as interfaces between reality and the model. Calibration means finding model parameters which allow adequate simulation of the catchment in question.



After running PREVAH's automatic calibration algorithm, VIEWOPTIM is used to display various efficiency scores for the respective parameter pairs. This allows investigation of calibration plausibility and success.

TEXT REFERENCES

- Calibration procedure: see Part II, Chapter 6
- Hydrograph interpretation: see Part III, Chapter G

LITERATURE

Nash JE, Sutcliffe JV (1970): River flow forecasting through conceptual models: Part I – a discussion of principles. *Journal of Hydrology* **10**:282–290.

6 Selected Applications

6.1 High-resolution water balance for Switzerland

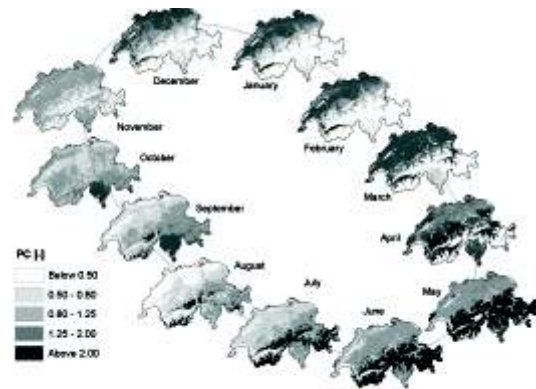
A simulation experiment with PREVAH involving the entire area of Switzerland has been completed. The experiment allowed the simulation of evapotranspiration and natural runoff generation for the 20-year period from 1981 to 2000. PREVAH was fed with daily meteorological data, while the spatial resolution was set to 500×500 m². The results were compared to previous data on the natural water balance of Switzerland (see Table).

To quantify the spatial and temporal dynamics and variability of the natural discharge regimes, monthly Pardé coefficients were computed (see Figure).

Typical alpine regimes show a distinct dependence on elevation as a direct consequence of the timing of the main snowmelt season and of rainfall. At higher elevations, the regimes are governed by both snowmelt (May to July) and, if glaciers are present, melt from the ablation area of alpine glaciers (July to September). Runoff generation from glacierised areas accounts for about 7% of the total runoff generation in Switzerland.

The results show that PREVAH is a reliable tool for detailed hydrological studies in alpine environments. The map of the natural runoff regime of the Swiss Alps allows for the analysis of both gauged and ungauged areas and opens many possibilities for studies dealing with the management of water resources.

Selected maps and analyses have been published in Version 2 of the Digital Atlas of Switzerland (<http://www.atlasderschweiz.ch>).



High-resolution spatial and temporal (monthly) dynamics of the computed Pardé coefficients for Switzerland, as an average for the 1981–2000 period. The monthly maps are arranged in clockwise order, starting with January (top right).

Climate Unit	P [mm·y ⁻¹]	R [mm·y ⁻¹]	ET [mm·y ⁻¹]	DS [mm·y ⁻¹]
Wallis	1573	1276	344	-47
Ticino	1955	1479	476	0
Alpine Rhine	1435	1060	387	-13
Engadin	1199	942	290	-33
Alpine Aare	1771	1347	461	-37
Prealps	1946	1505	448	-7
Jura	1403	806	597	0
East plains	1265	654	608	3
West plains	1282	657	621	4
Switzerland 1981-2000	1518	1044	487	-13
<i>Switzerland^a 1961-1980</i>	<i>1481</i>	<i>961</i>	<i>513</i>	<i>7</i>
<i>Switzerland^b 1961-1990</i>	<i>1458</i>	<i>991</i>	<i>469</i>	<i>-2</i>

^a Schädler & Bigler (1992), ^b Schädler & Weingartner (2002)

Simulated mean annual water balance components (P = precipitation, ET = evapotranspiration, R = runoff, DS = storage change) within the 20-year period from 1981 to 2000. Estimations from other authors are indicated in italics.

TEXT REFERENCES

- Export of maps to GIS:
see Part III, Chapter A
- Evapotranspiration:
see Part II, Chapter 4.4
- Runoff generation:
see Part II, Chapter 4.5

LITERATURE

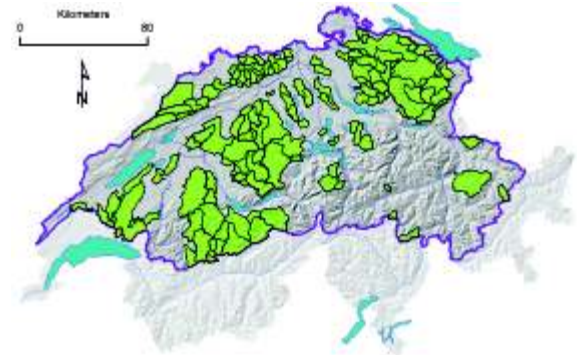
- Pfaundler M, Zappa M (2006):** Die mittleren Abflüsse über die ganze Schweiz – Ein optimierter Datensatz im 500×500 m² Raster. *Wasser, Energie, Luft* 98(4):291–298.
- Schädler B, Weingartner R (2002):** The components of the natural water balance 1961–1990. Hydrological Atlas of Switzerland, Plate 6.3. Berne: Federal Office for the Environment.
- Zappa M (2002):** *Multiple-Response Verification of a Distributed Hydrological Model at Different Spatial Scales*. Ph.D. Thesis 14895, Institute for Atmospheric and Climate Science, ETH Zürich.

6.2 Flood estimation in ungauged catchments of Switzerland

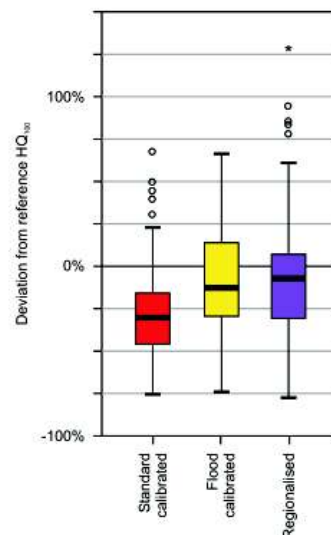
Successful flood protection requires sound estimations of floods of various return periods, a demand that is especially difficult to meet in ungauged catchments. Experience shows that the empirical methods used today still carry large errors. Therefore, the approach of deterministic long-term modelling is now adopted in Switzerland, using the hydrological modelling system PREVAH to simulate the discharge of a 20-year period in hourly resolution. These simulations are then analysed conventionally by means of extreme value statistics, resulting in estimations for peak discharge and flood discharge volume.

In order to enable the free model parameters to be determined in catchments without gauge records and therefore without any possibility for calibration, a regionalisation module was developed (Viviroli, 2007). This was based on 140 mesoscale Swiss catchments (approx. 20–1000 km²) which were successfully calibrated using the semi-automatic calibration scheme included in PREVAH. Additional flood-sensitive scores were used to tweak modelled peak runoff values (Viviroli, 2007). Regionalisation of the free model parameters was then obtained through a combination of three approaches: Nearest Neighbour uses a number of most similar catchments as donors for model parameters, Kriging performs an interpolation of parameters in space and Regression establishes relations between model parameters and independent catchment attributes.

Results show that this approach of long-term simulation is indeed able to produce plausible flood estimations for ungauged Swiss catchments. For a 100-year return period flood, the median error from 49 regionalised test catchments with long-term gauge data is only -7%, while the error for half of these catchments ranges between -30% and +8%. This approach adds significant information to the already existing methods and is suitable to complement and extend flood estimation procedures used in Switzerland today.



140 mesoscale catchments in northern-alpine Switzerland successfully calibrated for application of PREVAH.



Deviation in extrapolated HQ_{100} from reference, shown for standard and flood calibrated as well as for regionalised parameter sets. The box plot refers to data from 49 representative test catchments with long-term gauge data.

TEXT REFERENCES

-Model calibration procedure:
see Part II, Chapter 6

LITERATURE

Viviroli D (2007): *Ein prozessorientiertes Modellsystem zur Ermittlung seltener Hochwasserabflüsse für ungemessene Einzugsgebiete der Schweiz.* Geographica Bernensia **G77**. Berne: Institute of Geography, University of Berne.

6.3 Analysis of the August 2005 flood in Switzerland

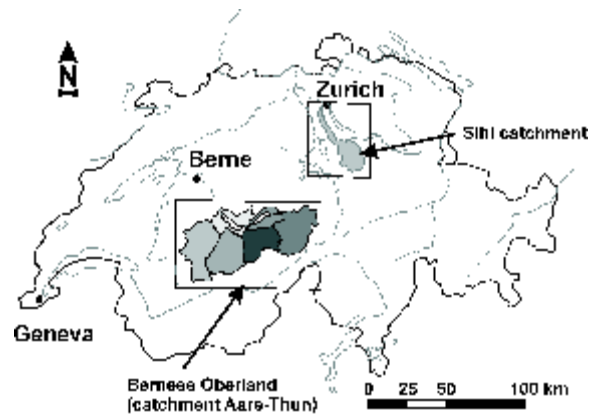
In August 2005, a severe rainfall event caused flood damage in the Swiss northern-alpine region, with a damage total of about 3 billion Swiss Francs. This devastating event once more showed the vulnerability of structures built close to rivers and lakes. An adequate knowledge of flood risk therefore constitutes the most important prerequisite to minimise or prevent future damage.

Using the PREVAH, the effects of several extreme advective rainfalls were analysed with regard to flood generation in two regions with complex topography. While the Bernese Oberland (i.e. the Aare River catchment as far as Thun) was directly affected by the August 2005 flood, the Sihl River catchment was investigated on account of highly flood-vulnerable infrastructure located in Zurich. For this modelling task, both catchments had to be divided into smaller sub-areas, of which some could be calibrated and others had to be regionalised before starting the investigation.

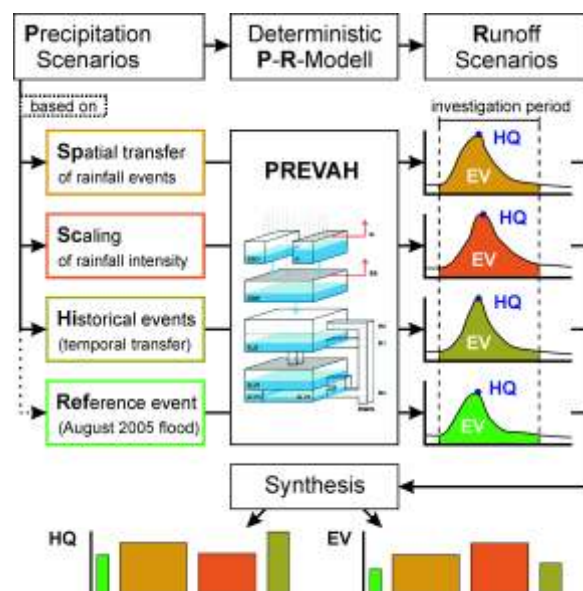
Extreme precipitation scenarios were designed on the basis of three methodologies: (1) Spatial transfer of precipitation events which have occurred outside of the catchment under investigation and were moved to different locations within the catchment; (2) Scaling of precipitation events due to modification of precipitation intensity while spatiotemporal distribution was retained unchanged; (3) Historical extreme precipitation events were temporally transferred and thus combined with different boundary conditions.

After transformation of precipitation scenarios into runoff, hydrographs (hourly resolution) are available for further analysis. Flood events more severe than the one of August 2005 have to be expected for both Sihl-Zurich and Aare-Thun catchments.

This analysis shows that model-based flood risk estimation complements statistical estimation methods, such as frequency analysis, as well as simpler deterministic approaches. However, the results call for prudential interpretation, because of uncertainties related to the input data on the one hand and the model system on the other hand.



Location of main catchments under investigation.



Flowchart showing the work flow: Generation of precipitation scenarios, which are transformed into hydrographs by PREVAH. Finally, summarisation by comparison of maximum peak-flow (HQ) and total flood discharge during the investigation period (EV).

TEXT REFERENCES

–Model calibration procedure:
see Part II, Chapter 6

LITERATURE

Schwanbeck J, Viviroli D, Weingartner R: Modellgestützte Sensitivitätsanalysen. **Hegg C, Bezzola GR, eds.** Ereignisanalyse Hochwasser 2005, Teil 2 – Analyse von Prozessen, Massnahmen und Gefahregrundlagen. Berne: Federal Office for the Environment, forthcoming.

Viviroli D (2007): Ein prozessorientiertes Modellsystem zur Ermittlung seltener Hochwasserabflüsse für ungemessene Einzugsgebiete der Schweiz. Geographica Bernensia **G77**. Berne: Institute of Geography, University of Berne.

6.4 Ensemble flood forecasting for large Swiss catchments

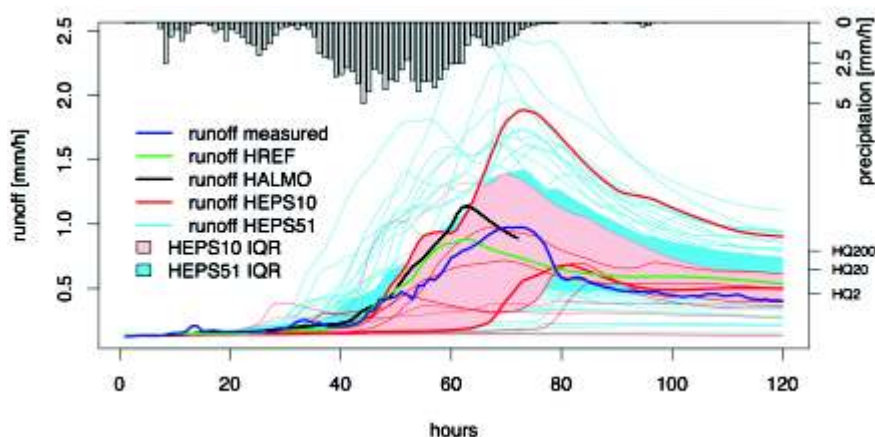
In both meteorological and hydrological forecasting, long lead times are required for planning appropriate measures in the case of flood occurrences. This in turn is inherently connected with an increased uncertainty which cannot be accounted for by deterministic forecasts. An attractive way of addressing this issue is the use of probabilistic forecasts driven by meteorological ensemble prediction systems (EPSs), as the meteorological input is considered to represent a main source of uncertainty.

Several meteorological ensemble prediction systems are operationally available at the global scale, one of them being the ECMWF EPS with 51 members. The differences between the 51 forecasts forming the ensemble represent the initialisation uncertainty of the meteorological model. The output of the large-scale model is dynamically downscaled by means of a limited area model, the COSMO-LEPS (Marsigli et al., 2001). Owing to high computational time requirements, it is not feasible to downscale the full global ensemble in everyday operational applications and therefore only a subsample of 10 (16 since February 2006) representative ECMWF ensemble members selected by cluster analysis is processed. The full ensemble is available, though, for selected case studies. With regard to PREVAH, six parameters (temperature, precipitation, humidity, wind,

sunshine duration, global radiation) from each member of this ensemble are used to drive the hydrological model with hourly time steps. A reference simulation (HREF) driven by meteorological observations serves to generate the initial conditions of PREVAH.

The figure shown, a hindcast from 20 August 2005 at the Hagneck gauge (Aare), illustrates what ideally would be expected from a probabilistic forecast system: The observed runoff is captured well by the interquartile range (IQR) of both the full (HEPS51) and the reduced ensemble (HEPS10). The HEPS10 IQR only slightly differs from the HEPS51 IQR, which indicates a proper representation of the full ensemble. The spread of the ensemble can also be interpreted as the uncertainty of a deterministic simulation, given that the deterministic and probabilistic runs are based on the same model chain.

Established in meteorological sciences and for operational meteorological forecasts, the ensemble approach is now increasingly applied to hydrological problems. Case studies of selected extreme flood events such as spring 1999, November 2002 (Verbunt et al., in press) and August 2005 have shown the suitability of such forecast systems to complement deterministic forecasts.



Hydrological hindcast, starting on 20 August 2005 at Hagneck gauge (Aare). HEPS10 (red) and HEPS51 (blue) are shown, with corresponding IQR and median; in addition, a deterministic simulation (HALMO: black, only 72 h), measured runoff (dark blue) and HREF (green). Spatially interpolated observed precipitation (catchment mean) plotted from top.

LITERATURE

Marsigli C, Montani A, Nerozzi F, Paccagnella T, Tibaldi S, Molteni F, Buizza R (2001): A Strategy for high-resolution ensemble prediction. II: Limited-area experiments in four Alpine flood events. *Quarterly Journal of the Royal Meteorological Society* **127**:2095-2115

Verbunt M, Walser A, Gurtz J, Montani A, Schär C: Probabilistic flood forecasting with a limited-area ensemble prediction system: Selected case studies. *Journal of Hydrometeorology*, forthcoming.

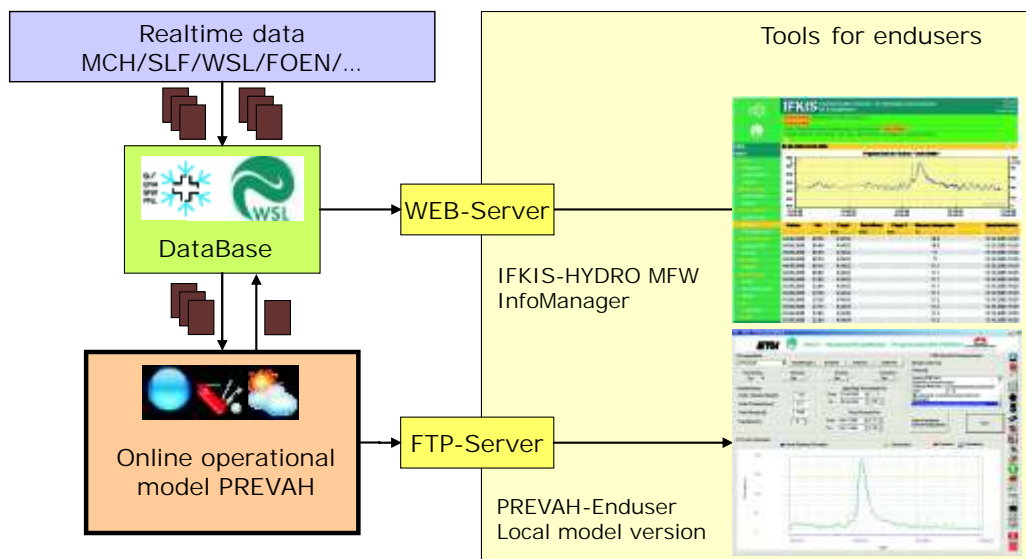
6.5 Flood forecasting in the Canton of Glarus, Switzerland

In 2004, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and the Swiss Federal Institute for Snow and Avalanche Research (SLF) started developing an information and early warning system for hydrological hazards in small to medium-sized catchments (ranging from 1 to 500 km²). The system refers back to the successful experience with the Swiss avalanche warning system IFKIS (Bründl et al., 2004) and was therefore named IFKIS-Hydro. An operational version of PREVAH was developed (Zappa et al., 2006) as part of an information system delivering real time information; this allows decisions to be made on emergency measures in small mountainous catchments.

This operational version of PREVAH is embedded in a complex system ensuring the real time flow of the required meteorological information (see Figure). PREVAH obtains real-time data from a database operated at the SLF in Davos. This

database integrates information from different observation networks: the Swissmetnet network of MeteoSwiss (MCH), the IMIS network of SLF/WSL, the hydrometric network of the Swiss Federal Office for the Environment (FOEN), and other local data sources. At the end of the operational model run, the results (precipitation, runoff, snow water equivalent, and others) are uploaded to a database and can be accessed via a web platform (INFO-MANAGER).

Furthermore, the metadata for running a 13-day simulation are uploaded to a dedicated FTP server. The end-user can access this server and use these data to make local model runs with a specific desktop version of PREVAH. This desktop version enables the end-user to prepare tailor-made forecasts and flood scenarios. The nowcasting system is currently implemented for the Linth basin up to the Mollis gauge (600 km²) in the Canton of Glarus (Central Switzerland).



Work flow of the forecast model PREVAH, as implemented in the Canton of Glarus for real time runoff nowcasting and forecasting. Screen shots of the IFKIS-Hydro web platform.

TEXT REFERENCES

- Data assimilation:
see Part II, Chapter 3.4
- Interpolation:
see Part II, Chapter 3.4.2

LITERATURE

- Bründl M, Etter H.J, Steiniger M, Klinger C, Rhyner J, Ammann WJ (2004):** IFKIS – a basis for managing avalanche risk in settlements and on roads in Switzerland. *Natural Hazards and Earth System Sciences* 4:257–262.
- Zappa M, Rhyner J, Gerber M, Egli L, Stöckli U, Hegg C (2006):** IFKIS-HYDRO MountainFloodWatch – Eine endbenutzer-orientierte Plattform für Hochwasserwarnung. *Risikomanagement extremer hydrologischer Ereignisse*, Beiträge zum Tag der Hydrologie 2006, 22–23 März 2006. *Forum für Hydrologie und Wasserbewirtschaftung* 15, Band 2, pp. 189–200.

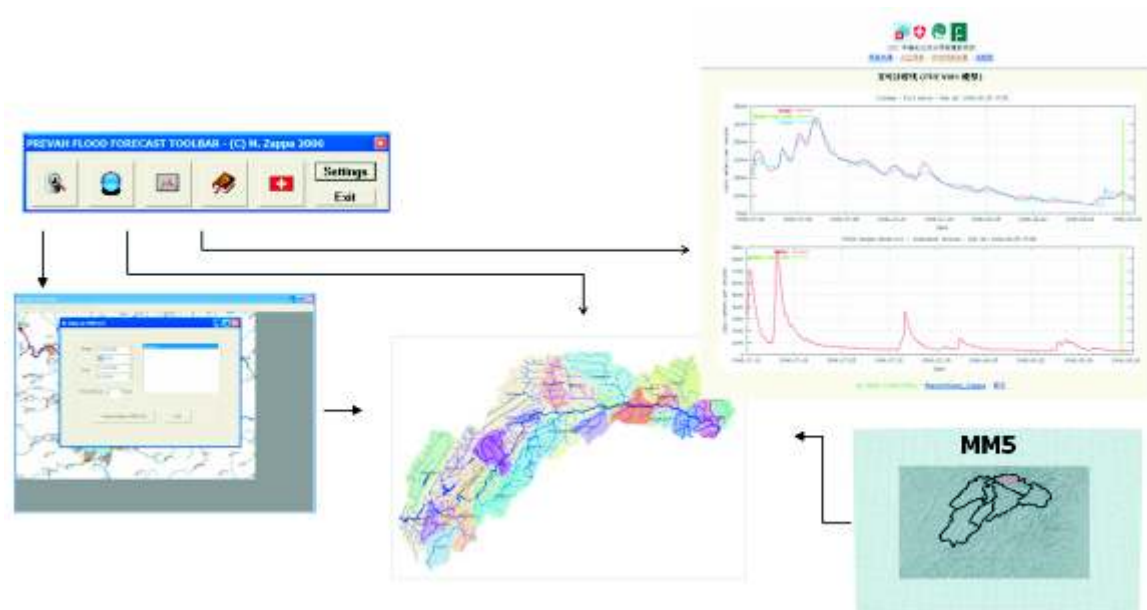
6.6 Flood forecasting for the Yangtze River, China

The Changjiang (Yangtze) is the largest river in the People's Republic of China, as well as one of the biggest in the world. In its catchment area, there are abundant rainfalls with uneven distribution in space and time. Floods mainly occur from April to October following rainstorms. Flooding disasters have been frequent.

PREVAH has been implemented as a flood forecasting model in the framework of the Changjiang Flood Forecasting Assistance Project (2003–2007). This project aims to enhance the flood-forecasting standard for the middle part of Changjiang River. The project is assisted by the Swiss government through the Swiss Agency for Development and Cooperation (SDC), and by the Changjiang Water Resources Commission (CWRC). A know-how and technology transfer from the Swiss partners to the CWRC collaborators has been completed. This includes training of CWRC staff in GIS, remote sensing and hydrological modelling, as well as the installation of a

satellite receiving station together with the required computer hardware and image-processing and GIS software at CWRC in Wuhan (China).

PREVAH has been installed at CWRC for estimating discharge from poorly gauged contributing areas of the Three Gorges dam reservoir (56,000 km², about 15,000 km² larger than Switzerland). For operational forecasting, a set of 34 sub-basins has to be processed in a predefined order, from the upstream headwaters to the last sub-area, which includes the region close to Yichang city. The processing chain also includes automatic consideration of two inflows from large upstream basins: the Yangtze River, upstream from Chongqing (basin of 866,559 km²), and the Wulong River (basin of 83,035 km²). PREVAH is coupled in real time to the database of CWRC (data for nowcasting) and to the numerical weather prediction (NWP) model MM5, which provides operational 72-hour forecasts.



Work flow of the forecast model PREVAH, as implemented in the Three Gorges Area (PR China).

TEXT REFERENCES

–Data assimilation:
see Part II, Chapter 5

LITERATURE

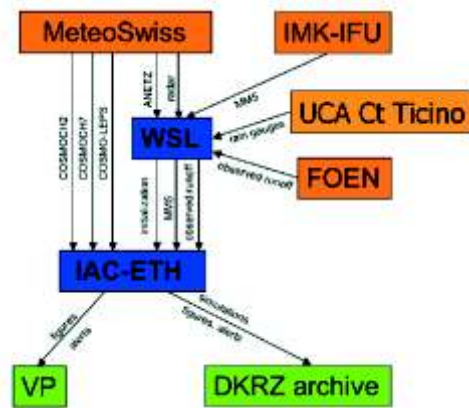
Zappa M, Werhahn J, Song Zhi Hong, Baumgartner MF, Gurtz J, Kunstmann H, Schädler B (2006): Vermittlung von Know-how zur Verbesserung der Hochwasservorhersage im Yangtze-Einzugsgebiet des Drei-Schluchten-Stausees (China). In „Risikomanagement extremer hydrologischer Ereignisse“, Beiträge zum Tag der Hydrologie 2006, 22–23 März 2006. *Forum für Hydrologie und Wasserbewirtschaftung* 15, Band 3, pp. 227–230.

6.7 Ensemble flood forecasting for MAP D-PHASE

Appropriate dispositions in the case of flood occurrences require longer lead times in hydrological forecasting. This in turn implies an increased uncertainty which cannot be accounted for by a deterministic simulation. The operational use of (probabilistic) ensemble prediction systems (EPSs) to assess the level of uncertainty involved in forecasting precipitation is an established practice in the atmospheric modelling community. In contrast, most hydrological forecasts rely on input from deterministic atmospheric models or are driven by observations alone. Setting up an advanced hydrometeorological forecast system capable of transferring the probabilistic information and the related uncertainty from observations and atmospheric EPSs into the hydrological models used is one of the main goals of MAP D-PHASE (Demonstration of Probabilistic Hydrological and Atmospheric Simulation of Flood Events in the Alps). D-PHASE is an example of a research effort which aims to demonstrate the potential of EPSs for improving the quality of forecasting heavy precipitation and related (flash) flood events in the Alps.

Within MAP D-PHASE, PREVAH has been set up as a quasi-operational system for ensemble forecasts of river streamflow, covering the River Ticino catchment as a study area. The model is fed with data from an operational global atmospheric EPS (ECMWF) which is dynamically downscaled using a limited-area atmospheric EPS (COSMO-LEPS). From the 51 ECMWF/COSMO-LEPS ensemble members available, a sub-sample of 16 representative members is used to produce daily forecasts with a range of 120 h.

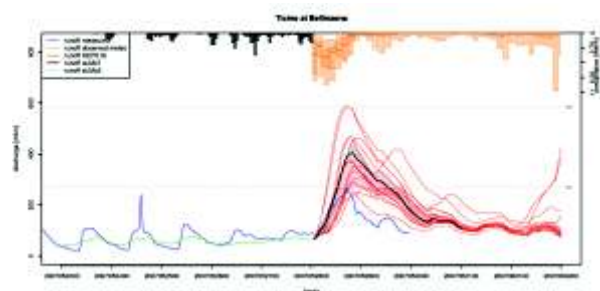
The application of this model framework in MAP D-PHASE aims at demonstrating the potential of hydrological EPSs while exploring their strengths and weaknesses. In order to provide reference values, PREVAH is also operated with three deterministic numerical weather prediction models (COSMO-7, COSMO-2 and MM5).



Data flow for running PREVAH on quasi-operational mode during MAP D-PHASE.



MAP D-PHASE PREVAH basins.



Operational ensemble streamflow forecasts for the Ticino basin as far as Bellinzona (May 2007).

LITERATURE

Ranzi R, Zappa M, Bacchi B (2007): Hydrological aspects of the Mesoscale Alpine Programme: findings from field experiments and simulations. *Quarterly Journal of the Royal Meteorological Society* **133**:867–880.

Verbunt M, Walser A, Gurtz J, Montani A, Schär C: Probabilistic flood forecasting with a limited-area ensemble prediction system: Selected case studies. *Journal of Hydrometeorology*, forthcoming.

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- Gurtz J, Baltensweiler A, Lang H (1999):** Spatially distributed hydrotape-based modelling of evapotranspiration and runoff in mountainous basins. *Hydrological Processes* **13**:2751–2768.
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- Jaun S:** *Hydrological Modelling for Short-Range Probabilistic Forecasting and Climate Change Scenarios*. Ph.D. Thesis, ETH Zürich. Zürich: Institute for Atmospheric and Climate Science, ETH Zürich, in preparation.
- Klok EJ, Jasper K, Roelofsma KP, Gurtz J, Badoux A (2001):** Distributed hydrological modelling of a heavily glaciated Alpine river basin. *Hydrological Sciences Journal – Journal des Sciences Hydrologiques* **46**:553–570.
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Daniel Viviroli

Ein prozessorientiertes Modellsystem zur Ermittlung seltener Hochwasserabflüsse für ungemessene Einzugsgebiete der Schweiz

Weiterentwicklung und Anwendung des hydrologischen Modellsystems PREVAH

Für einen modernen, differenzierten Hochwasserschutz sind zuverlässige hydrologische Bemessungsgrundlagen von grosser Wichtigkeit. Gleichermassen heikel wie auch wichtig sind insbesondere Abschätzungen in Gebieten ohne Messungen des Abflusses. In der Praxis spielten dabei bisher vor allem empirische Schätzverfahren eine wichtige Rolle. Um methodisch und inhaltlich weitere Verbesserungen zu erzielen, wurde nun der Ansatz der kontinuierlichen Niederschlag-Abfluss-Modellierung für eine Anwendung in der Schweiz weiterentwickelt und praktisch umgesetzt. Unter Verwendung des konzeptuellen, prozessorientierten hydrologischen Modellsystems PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotope Model) wird dabei der Abfluss eines Einzugsgebietes kontinuierlich in stündlicher Auflösung simuliert. PREVAH wurde für 140 mesoskalige Einzugsgebiete erfolgreich kalibriert, für ungemessene Gebiete können die Modellparameter über ein neu entwickeltes Regionalisierungsmodul bestimmt werden. Die Simulationen werden anschliessend extremwertstatistisch ausgewertet. Der vorgestellte Ansatz erlaubt es, die relevanten Hochwasserkenngrossen für beliebige Gebiete abzuleiten, wobei neben den Spitzenwertreihen auch die kompletten Abflussganglinien zur Verfügung stehen.

A Process-based Modelling System for Estimation of Rare Floods in Ungauged Swiss Catchments. Further Development and Application of the Hydrological Modelling System PREVAH

Reliable estimations for floods of various return periods are an indispensable prerequisite for successful flood protection. To elaborate such estimations for ungauged catchments is equally difficult as well as important. So far, empirical methods have mainly been used for this purpose. In order to make further progress in flood estimation, the approach of continuous precipitation-runoff-modelling is further developed and elaborated for practical application in Switzerland. For this, the conceptual process-oriented hydrological modelling system PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotope Model) is used to simulate continuous discharge hydrographs in hourly resolution. While PREVAH was calibrated successfully for 140 meso-scale catchments, parameter values for ungauged catchments are derived with help of a newly developed regionalisation module. The simulations are subsequently analysed by means of extreme value statistics. With this approach, it is possible to derive the relevant flood estimations for an arbitrary catchment, while both peak flow series as well as complete discharge hydrographs are available.

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The Hydrological Modelling System PREVAH

Part II – Physical Model Description

**Daniel Viviroli,
Joachim Gurtz,
and Massimiliano Zappa**

This document contains the physical description of the hydrological modelling system PREVAH. It is Part II of the extensive model documentation by Viviroli, Gurtz and Zappa (2007) and is complemented by Part I, which gives an overview of PREVAH, and Part III, the user manual for the modelling system. Part IV is a sample project containing selected components of the modelling system.

<i>Publication Part</i>	Part I	Part II	Part III	Part IV
<i>Contents</i>	Overview and selected applications	Physical model description	User manual	Sample project and selected executables
<i>Availability</i>	Printed only	On-line only (pdf)	On-line only (pdf)	On-line only (zip)

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1. Introduction

A sound simulation of hydrological processes at catchment scale requires the development and application of physically congruous hydrological models, including careful parameterisation, calibration and evaluation (Gurtz et al., 2003; Refsgaard, 1997; Uhlenbrook and Leibundgut, 2002). In the past decade, spatially distributed modelling became an established tool for studying both the components and the possible changes of the hydrological cycle. Beven (2000) gives a thorough review on the evolution of rainfall-runoff models. Hydrological models were first idealised in distributed configuration in the early 20's (Ross, 1921). The development of the unit hydrograph method (Sherman, 1932) as well as early works on the investigation and calculation of key processes like effective rainfall, saturation excess and infiltration capacity (Horton, 1933) were among the principles leading to the development of more advanced modelling packages as summarised in the blueprint for physically-based hydrological simulations proposed by Freeze and Harlan (1969). An important result of the development was the first easily usable hydrological "Stanford Watershed Model IV" (Crawford and Linsley, 1966). Further model developments – alongside the progress in computer sciences – can be considered as the turning point towards the transition to spatial and temporal distributed modelling approaches (Bergström, 1976 and 1992; Beven and Kirkby, 1979; Ross et al., 1979; Abbott et al., 1986a and 1986b; Singh, 1995). The configuration and structure of developed hydrological models depends on the modelling task and the strong relationship between these tasks and the used temporal and spatial scale (see Figure 1-1 and 1-2; Klemes, 1990).

Mountainous catchments, in particular, are characterised by highly variable morphology, soil and vegetation types and by pronounced temporal and spatial variations of the climatic elements (Klemes, 1990; Gurtz et al., 1999). Mountain discharge regimes depend, according to location and elevation of the watersheds, on glacial melt, snowmelt, rainfall and their spatial and temporal superposition. The quality of the hydrological simulations depends on how well the available models are able to describe and accurately represent the heterogeneity of such hydrological systems at the different spatial and temporal scales (Figure 1-2, see also Blöschl and Sivapalan, 1995; Zappa, 2002).

The availability of geographic information systems (GIS) and digital elevation models (DEM), the improved reliability, precision and resolution of meteorological and hydrological networks and the availability of remotely sensed data allowed the development and application of spatially distributed hydrological models within mountainous landscapes (Gurtz et al., 1999) and their calibration and evaluation with respect to observed time series and spatial patterns of hydro-meteorological variables. The development of the distributed hydrological catchment models PREVAH (Precipitation-Runoff-Evapotranspiration-Hydrotope model; Gurtz et al., 1997a, 1999 and 2003; Zappa et al., 2003) and WaSiM-ETH (Wasserhaushalts-Simulations-Modell, Schulla and Jasper 2000; Klok et al., 2001; Verbunt et al., 2003) has been initiated to allow the application of such new knowledge for mountain hydrology in Switzerland and other basins of the world.

WaSiM-ETH is a model relying on a very solid physically based formulation of the hydrological processes describing the water fluxes within a mountainous watershed. WaSiM-ETH spatial discretisation is based on grids with regular mesh sizes. The entire fluxes are computed for each time step for each grid within the modelled domain. This makes of WaSiM-ETH a computationally highly demanding model.

To allow for more flexibility, and in order to make reliable research with a reduced need of computational resources, a simpler distributed model was needed. PREVAH is such a model. To reduce the computational time, three solutions are implemented:

- The spatial discretisation relies on the Hydrological Response Units (HRU) approach.
- The formulation of the relevant processes is simplified and some algorithms are related to more conceptual approaches.
- The required meteorological information is processed only once and assimilated from tables during each simulation.

In the new century, the computational core of PREVAH has been steadily integrated with new components and tools that allow for a user friendly application of the model. Currently, PREVAH has grown into a fully functional modelling system able to manage all the work needed for its application. Tools are available for

the preprocessing management and interpolation of the required meteorological information. Tools are also available for the transformation, parameterisation and preprocessing of the physiogeographical spatial information. An in-built-calibration routine reduces the need of knowledge of the model structure and sensitivities during the process of calibration. Monte Carlo model runs can be started in order to obtain estimates of parameter uncertainties. Finally, tools have been developed to visualise the output of the model (grids, tables and output of the calibration module). These features have improved the usability of PREVAH and support new users in their first experiences with our model.

This document should provide the basis for comprehension of the content and computational structure of the hydrological catchment model system PREVAH, its parameterisation, calibration and verification, as well as its use for simulation and prediction.

Firstly, a general overview of the elementary structure of the PREVAH model is given in Chapter 2. The preparation of a model application, including preprocessing and parameterisation of spatial data, is described in Chapter 3, along with the respective tools available. Subsequently, the theoretical basis of the model and its modules are explained, describing the specific hydrological processes considered (Chapter 4). The possibilities for processing hydrological data are presented in Chapter 5. A successful application of the model for a specific catchment area requires a thorough calibration and validation, whereon Chapter 6 addresses. All in all, this document is intended to enable the reader to understand and use the complex model system PREVAH for solving a given problem in a most efficient way.

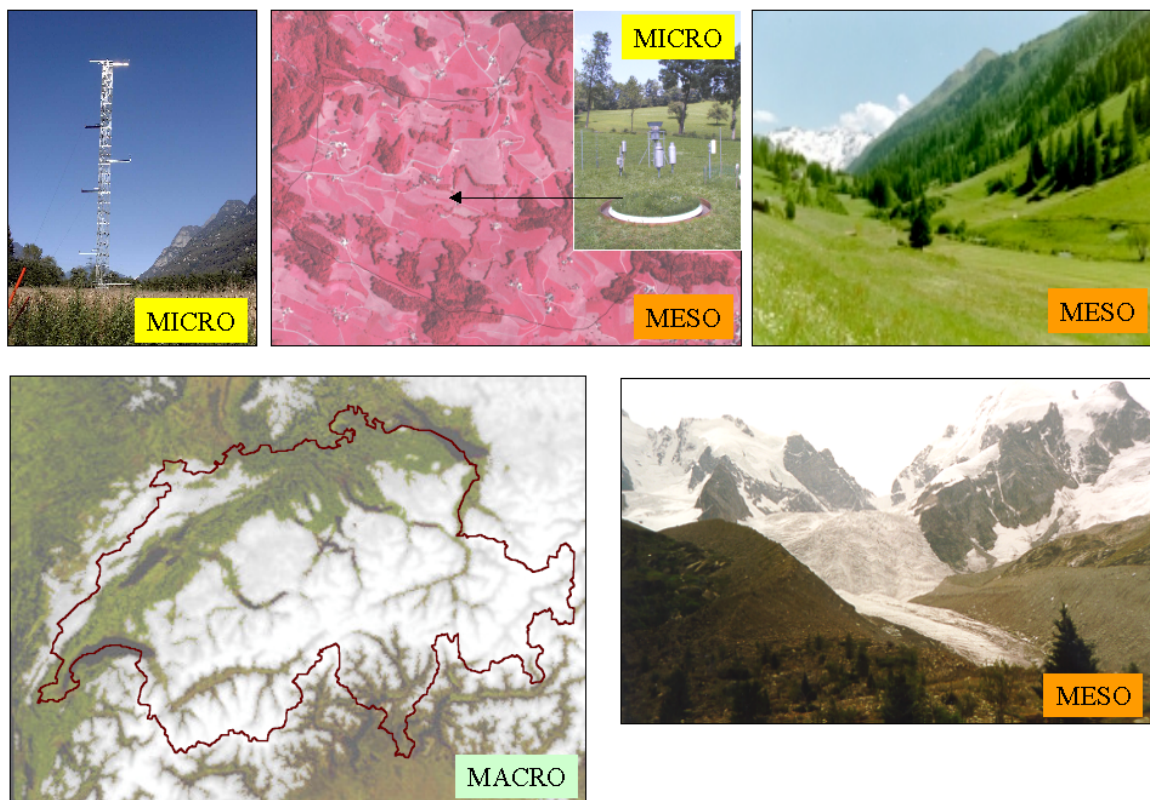


Figure 1-1: Complexity of the hydrological system Alps at different spatial scales. From top left clockwise: a meteorological tower in an alpine valley, an infrared airborne picture of the 3.3 km² hydrological research catchment Rietholzbach, the lysimeter site within the Rietholzbach catchment, a picture of the high alpine valley Dischma, a picture of the partly glaciated catchment of the Rosegbach and a processed satellite shot of the snow cover distribution in Switzerland (Zappa, 2002).

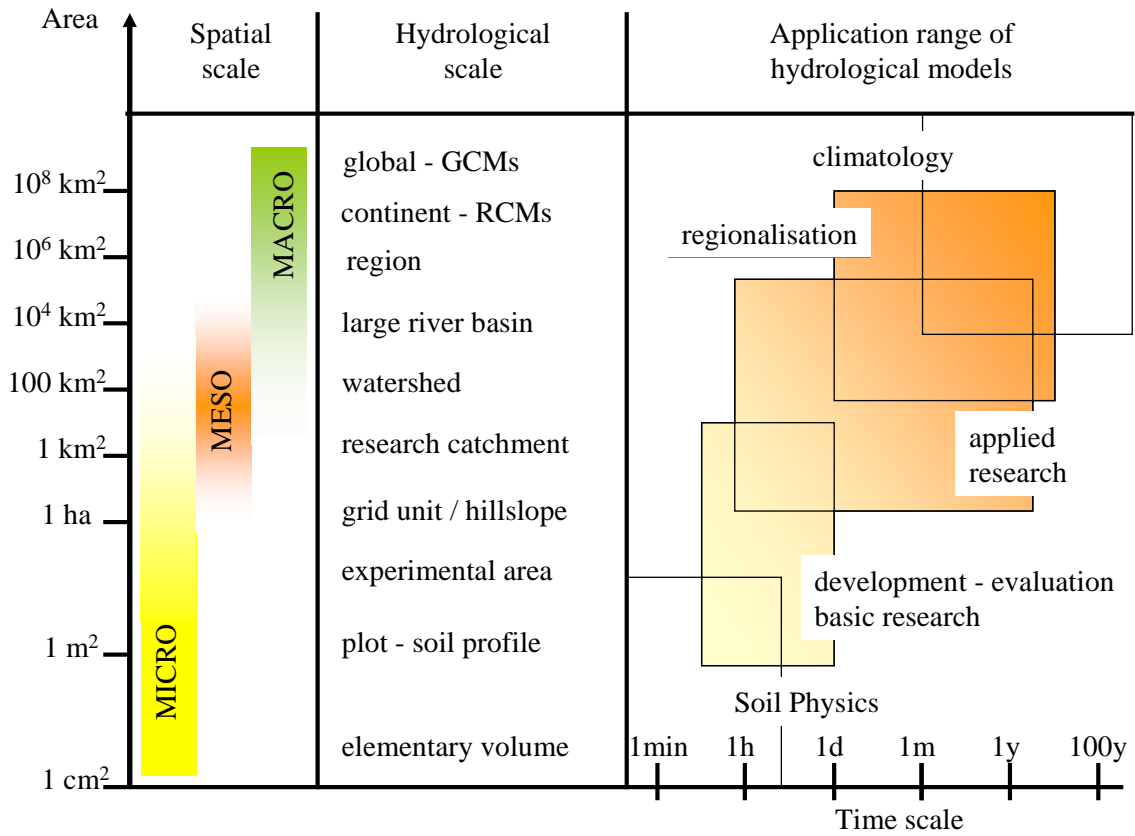


Figure 1-2: Application range of hydrological models at different spatial and temporal scales (Zappa, 2002, based on a concept of Becker and Nemeč, 1987).

2. Basic structure of PREVAH

The heterogeneous character of mountainous areas requires a relatively detailed areal distributed description of the hydrological system and its spatial distributed application. The hydrological catchment model PREVAH (Precipitation-Runoff-Evapotranspiration-Hydrotope model) uses parameters which are based, as far as possible, on physical principles (Gurtz et al., 1997a). The spatial distributed model application is based on the concept of use Hydrological Response Units HRU (Flügel, 1995; Zappa, 2002). The preprocessing of digital information for distributed hydrological models requires the use of GIS-packages. The procedure includes the topographical analysis of the investigated catchments based on a DEM, the aggregation of the land-use classes to hydrologically relevant land-use classes and the parameterisation of the soil properties from digital maps of soil types. Grid based models assimilate the spatial information directly from the grids during model initialisation and apply it for the simulation of the hydrological cycle. HRU-models (Ross et al., 1979; Flügel, 1997; Kouwen et al., 1993) require a further step in the preprocessing since the spatial information has first to be aggregated into HRUs. The most important rules for generating HRUs consist of assigning all the grid elements located in the same meteorological sub-unit to a HRU (e.g. the same range of elevation), as well as showing similar aspect, using the same land-use classification and similar soil properties and, eventually, having the same position with respect to the mass balance equilibrium line of a glacier (Zappa, 1999; Zappa, 2002). The HRU-specific spatial information is stored in a table and assimilated by PREVAH during the model initialisation. The HRU size is smaller where the ensemble of the characteristics of the soils, land surface and topography shows higher spatial variability. Each HRU, and consequently, each grid cell, must be provided with a set of parameters based on information derived from the DEM, from soil maps (plant-available soil field capacity, soil depth, hydraulic conductivity) and from digital maps of land-use and land surface characteristics. The model core consists of several subsystems (Figures 2-1 and 2-2).

- A snow model
- A glacier model
- An interception model
- A model of soil water storage and depletion by evapotranspiration
- A runoff generation model
- A discharge concentration and a flood-routing model

The snow model describing the accumulation and melting of the snow cover relies on the combination of a temperature index (Braun, 1985) and an energy balance approach (Anderson, 1973), distinguishing radiation-dependent melt in periods without precipitation and advectively induced ablation periods. Retention and freezing of liquid water within the snow cover is also taken into account.

The glacier model is based on a distributed temperature-index ice-melt model including potential direct solar radiation, which can also be used for snow-melt modelling (Hock, 1999; Klok et al., 2001; Zappa et al., 2003; Verbunt et al., 2003).

Snowmelt can also be computed by adopting the algorithms physically based snowmelt model ESCIMO (Zappa et al., 2003).

The interception model considers variations in interception storage as a function of vegetation type, including vegetation density (leaf area index, LAI) and the extent of the vegetation cover. Evaporation of intercepted water occurs from plant-covered surfaces at potential rate as long as the reservoir contains sufficient humidity. The surface depression storage capacity of rocky soils and urban areas is also defined for the calculation of direct evaporation.

Particular attention was paid to evaluating evapotranspiration. Potential evapotranspiration is calculated following equations by Penman, Penman-Monteith (Penman, 1948; Penman, 1956) and others. The adjustment to different surface characteristics (i.e. land-use types) is done by varying the albedo. The calculation of actual evapotranspiration is based on the direct relation to the available moisture at the land surface and in soil depending on the soil characteristics. In the case of applying the Penman-Monteith equation (Monteith, 1965), the actual evapotranspiration can be estimated by using temporally changing minimum stomatal re-

sistances for the various vegetation classes (Gurtz et al., 1999). In case of a large soil moisture deficit, the stomatal resistance is decreased depending on soil moisture ranging below a given threshold. The computations of evapotranspiration require the availability of different meteorological input variables. The amount of net radiation is site-adjusted and determined as a function of exposure, slope and albedo of the relevant surface. Further, the temperature is adapted according to the local topographical characteristics.

In the case that only a limited number of meteorological variables are available, PREVAH also offers the opportunity of computing potential evapotranspiration. The formulations of Turc/Ivanov, Wendling and Hamon are implemented (Zappa, 2002; Zappa and Gurtz, 2003).

The important link between the loss of water by evapotranspiration and by runoff is provided through the plant-available water content in the aeration zone of the soil. The respective storage capacity is determined by the soil depth available for the roots and the plant-available field capacity of the soil. Specific rules have been developed for rocky surfaces, bare surfaces, urban surfaces and wet areas. In these cases, the actual evapotranspiration is assumed to be the potential Penman evaporation depending on the moisture available in soils and/or in surface depression storages.

Input to the soil water reservoir and runoff storages are calculated in a spatially distributed manner as a function of soil moisture content and soil characteristics of different HRUs. The sub-models for runoff formation originate in an ETH-version of the HBV-model (Bergström, 1976; Jensen, 1986) but have been strongly modified and adapted to the HRU-based spatially distributed modelling of runoff formation. In the runoff reservoirs of the model, three runoff components are distinguished: quick surface runoff, interflow (delayed runoff) and groundwater flow (baseflow). In detail, there are two groundwater storages representing a fast and a more delayed baseflow component, respectively (Gurtz et al., 2003). Each runoff component is governed by the corresponding specific storage time which holds valid for the whole sub-catchment. The percolation into the baseflow storages is calculated depending on soil conductivity and moisture content of the upper storages. Flood-routing is based on the combination of linear storages and translation components.

To represent the high dynamics typical for runoff formation processes in mountainous regions, a one-hour time interval is recommended. PREVAH always runs at an internal time step of one hour. Depending on the choice of the evapotranspiration scheme, up to six meteorological input variables are required:

- Precipitation [mm per time step]
- Air temperature [°C], corrected for slope and aspect
- Global radiation [W m^{-2}], corrected for slope and aspect
- Relative sunshine duration [-]
- Wind speed [m s^{-1}]
- Relative air humidity [-] or water vapour pressure [hPa]

If only daily values of the meteorological elements are available, 24 identical values are assumed for every hour in the case of air temperature, wind speed, water vapour pressure and relative humidity; precipitation is divided into 24 identical values which sum up to the observed daily total. Daily values of global radiation are subdivided between sunrise and sunset according to the calculated potential clear-sky direct radiation (Schulla, 1997; Hock, 1999).

This assumption of uniform precipitation intensity and air temperature may principally affect the accuracy of the simulation of snow accumulation, snowmelt and runoff-generation. Zappa and Gurtz (2003) discuss this problem in the case of plot-scale simulations of soil moisture and evapotranspiration and conclude that the underestimation of the rain intensities leads to systematic errors in the computation of the soil water content but has a reduced effect on the estimation of daily evapotranspiration rates.

Interpolation is necessary if the data available do not completely cover the domain of interest. In this case, it is used for conversion of the data from sets of sample points, e.g. measured values from rainfall stations, to a discretised, continuous surface. The rationale behind spatial interpolation and extrapolation is the very common observation that, on average, values at points close together in space are more likely to be similar than points further apart (Sonderegger, 2004).

Interpolation methods are distinguished between exact and inexact interpolators. An interpolation method that predicts a value of an attribute at a sample point which is identical to that measured is called an exact interpolator. All other interpolation methods are inexact interpolators. The ideal situations are the exact interpolators, because it is only at the data points that we have direct knowledge of the attribute in question. Inverse distance weighting (IDW), detrended IDW, ordinary kriging (OK) and detrended OK are exact interpolators, but elevation dependent regression is an inexact interpolator (Sonderregger, 2004). All these interpolation techniques are implemented in the preprocessing tools of the PREVAH modelling system and are available for generating the meteorological tables that are required to feed the model core.

The application of PREVAH requires thorough calibration and verification. The most sensitive tuneable parameters are the adjustment factors for scaling snowfall and rainfall (Zappa, 2002), the parameters of the snowmelt module (Zappa et al., 2003), the non-linearity factor controlling the soil moisture recharge (Zappa and Gurtz, 2003) and the parameters of the runoff generation module (Gurtz et al., 2003). In the case of glaciated basins, two additional parameters controlling the melt of glaciated areas are introduced and require calibration (Klok et al., 2001).

PREVAH can be calibrated manually. Model output is compared with observed values and evaluated by means of objective statistical criteria (Nash and Sutcliffe, 1970; Legates and McCabe, 1999). A graphical comparison between observations and simulations can be made in the calibration phase as an additional subjective assessment of model performance. Several hydrometeorological variables may be considered for manual model calibration and verification.

The in-built supervised automatic calibration procedure relies on the maximisation of an index of agreement based on nine different scores derived by comparing observed and simulated discharges (Sonderregger, 2004; Verbunt et al., 2006). A total of about 200 model runs is needed to calibrate PREVAH. The result of all model runs provides information on parameter sensitivity and related uncertainties (Zappa and Kan, 2007). The same index of agreement can be used to sort a series of Monte Carlo model runs, where the parameters requiring calibration are varied randomly. For this kind of analysis, thousands of model runs are required. The computing time for such analyses for a standard medium-size basin is of the order of 3 to 4 weeks.

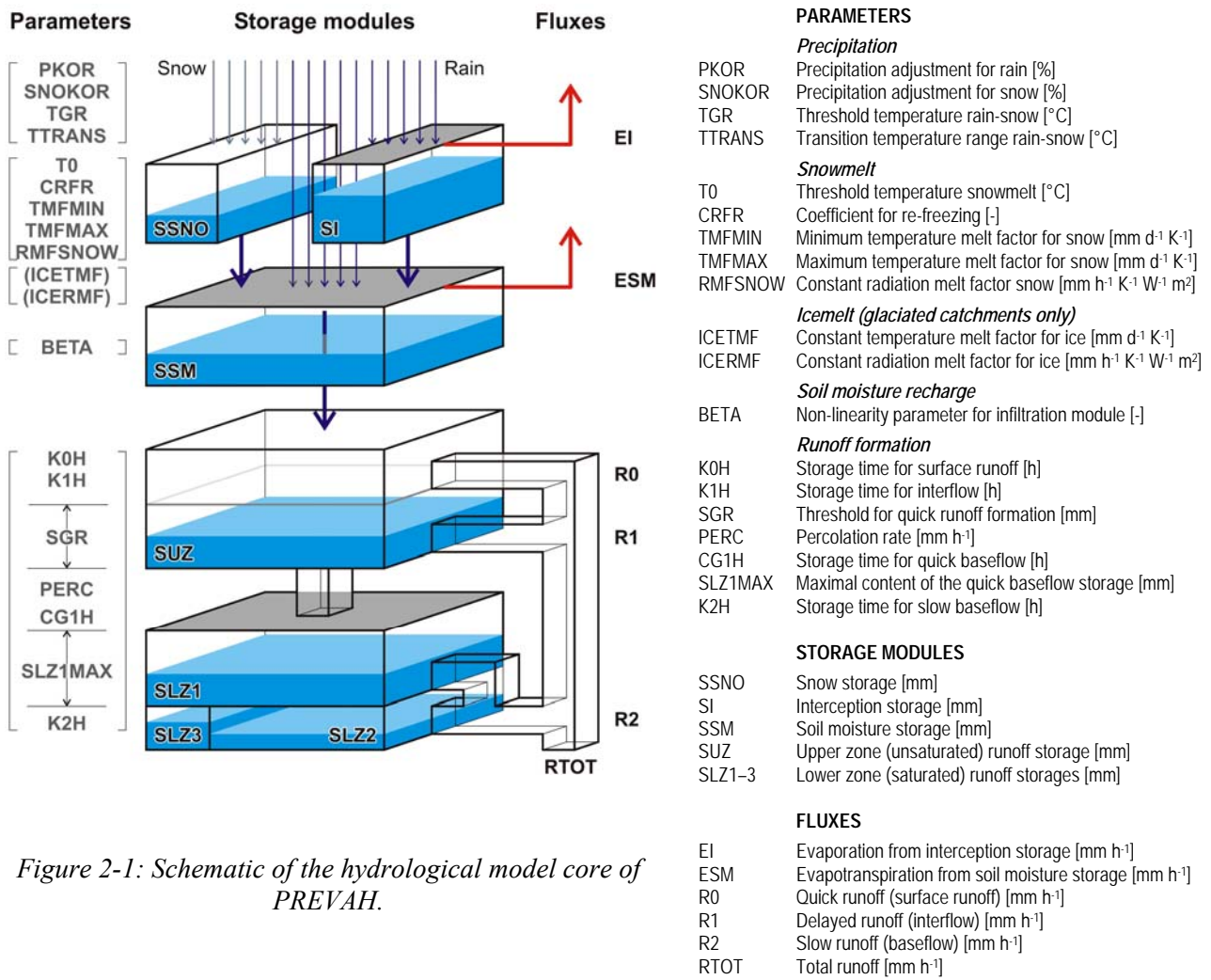


Figure 2-1: Schematic of the hydrological model core of PREVAH.

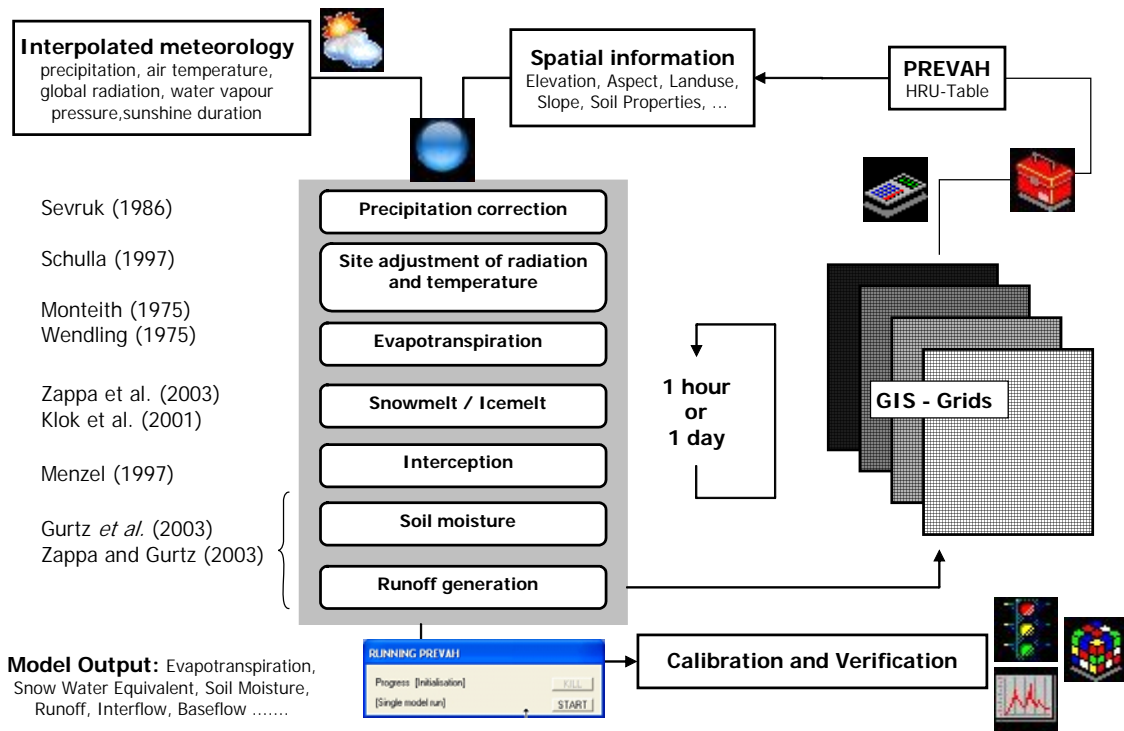


Figure 2-2: Flow chart of the PREVAH modules, including the assimilation of physiographic and meteorological information and the gridded or table-oriented model outputs. Icons refer to the tools of the modelling system linked to the specific tasks in the preprocessing and postprocessing of PREVAH.

3. Preprocessing of spatial information

Two methods are most commonly adopted for the spatial discretisation of a watershed (Singh, 1997): the grid-oriented approach and the response units approach (Ross et al., 1979; Moore et al., 1993). Grid-oriented hydrological models (Abbott et al., 1986a and 1986b; Klok et al., 2001) assimilate the spatial information for cell-by-cell simulations from grids with a prescribed spacing. Response units based models (Flügel, 1995 and 1997; Gurtz et al., 1999; Becker and Braun, 1999) rely on a physiographically-oriented discretisation of the investigated domain into irregular-shaped hydrologically similar areas as determined by the ensemble of the soils, land surface and topographic characteristics. The needed spatial information can be assimilated from a database consisting of: a digital elevation model (DEM), a land use map and soil maps.

The basic concept of the spatial distribution used in hydrological models is the subdivision of the model domain into a regularly spaced grid. This is a very effective subdivision for computational purposes. Further, the development and application of such a model is relatively easy because of the broadly available databases in gridded formats like digital elevation models and images from remote sensing devices. Compared to other methods, e.g. a subdivision into triangles, a disadvantage of a regular grid is the inflexibility in following small but important landscape features like river beds, valleys or ridges.

The preprocessing of the spatial digital information includes a complete topographic analysis (determination of slope, aspect, elevation zones, digital river network and other topographic characteristics), the possibility of summarising the land use classes to hydrological relevant classes and of assigning the parameterisation of the soil properties from the map of soil types.

3.1 Model requirements

Physiogeographical data are usually temporally constant, spatially distributed data describing the properties of the basin. Most of the spatial data can be derived from three basic data sets:

- The digital elevation model (DEM)
- The land use data
- The soil type data (e.g. FAO Soil classes)

DEMs and land use data are relatively exact and high resolution data whereas the soil types with their related soil properties are only more or less rough estimates. For a full functionality, the PREVAH modelling system needs at least these three aforementioned data. Most of the other data sets can be derived from these grids during the preprocessing with WINHRU (see separate documentation). If, for each of the 3 basic data sets, a specific spatial resolution would be used, the data sets could be combined only after a resample of all data. This should be completed using a geographical information system GIS or similar software during the preprocessing. For all the tools of our modelling system, it is imperative that all grids are in the same format (same number of columns and rows, same co-ordinates, same cell spacing, same *NoData* value). The spatial resolution of the model grids must be chosen depending on the modelled basin. Typically, mountainous basins require a finer resolution than low land basins. In the case of catchments with an area ranging between 10 and 500 km², the critical resolution for a sound simulation of the discharge from mountainous environments is 500x500 m² (Figure 3.1-1). The resolution depends also on the computer's capacity of installed memory and processor performance.

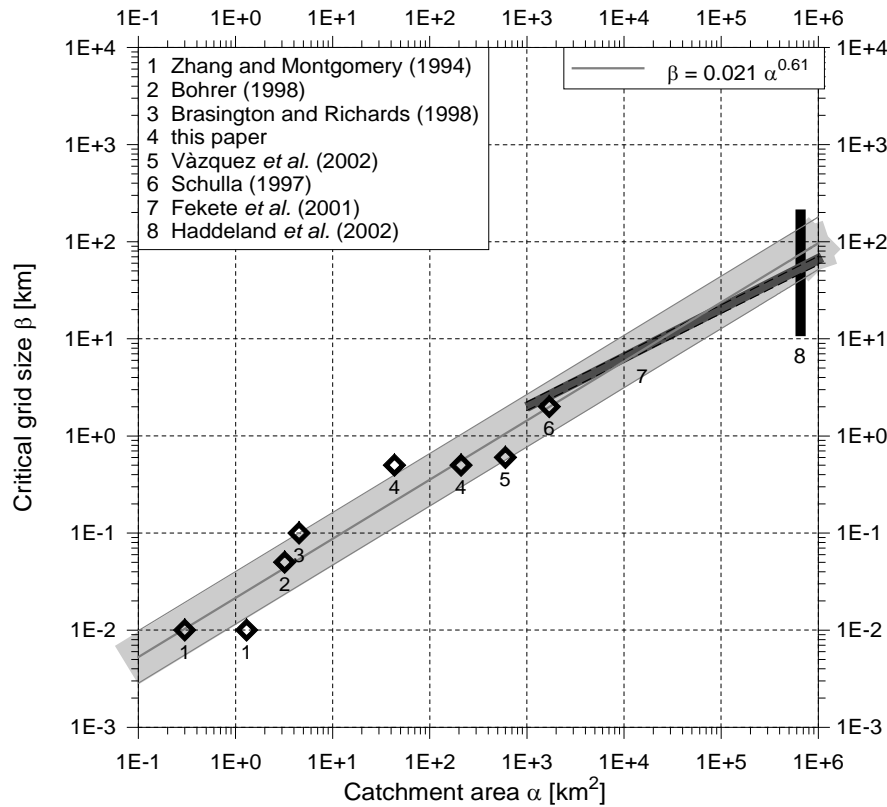


Figure 3.1-1: Visualisation of the critical grid size β as a function of the catchment area α . A grid size below the value indicated by the computed regression (thick grey line) indicates an increase of computational time without increase of model ability (from Zappa, 2002). A grid size above the value diagnosed by the proposed log-log regression may cause a significant reduction in ability in the simulation of hydrological processes within the investigated catchment. The dark grey area indicates the recommended grid size proposed by Fekete et al. (2001). The black area represents the range of grid sizes adopted by Haddeland et al. (2002) for the simulation of the discharge from two macroscale basins.

3.1.1 Digital elevation model

One of the most important data sets for using hydrological models is a digital elevation model (DEM), especially when applying the model to mountainous regions. The DEM can be used to calculate a number of derived data sets, such as local slope and aspect. It is also useful to determine some important hydrological information by using this derived information. These include, for example, flow directions, flow accumulations (for a specific catchment area), the river network and the sub-basin structure. It is also possible to calculate topographic shading and sky view factors for parameterising radiation sensitive models. The DOS program TANALYS (Schulla, 1997) performs a complex analysis of the DEM. The data sets are generated in a series of steps, as shown in Figure 3.1-2.

Only the shaded data sets are essential for the hydrological model PREVAH. Aspect and slope are required for the radiation correction, temperature modification, and the characterisation of hydrological response units.

Slope, aspect and curvatures are determined using the algorithms given by e.g. Binley and Beven (1993) or Tarboton et al. (1993). A 3×3 moving window is used to construct a 2nd-order parabolic surface fitting the 9 points. For each of the 9 points, Equation (3.1-1) holds:

$$z = Ax^2y^2 + Bx^2y + Cxy^2 + Dx^2 + Ey^2 + Fxy + Gx + Hy + I \quad (3.1-1)$$

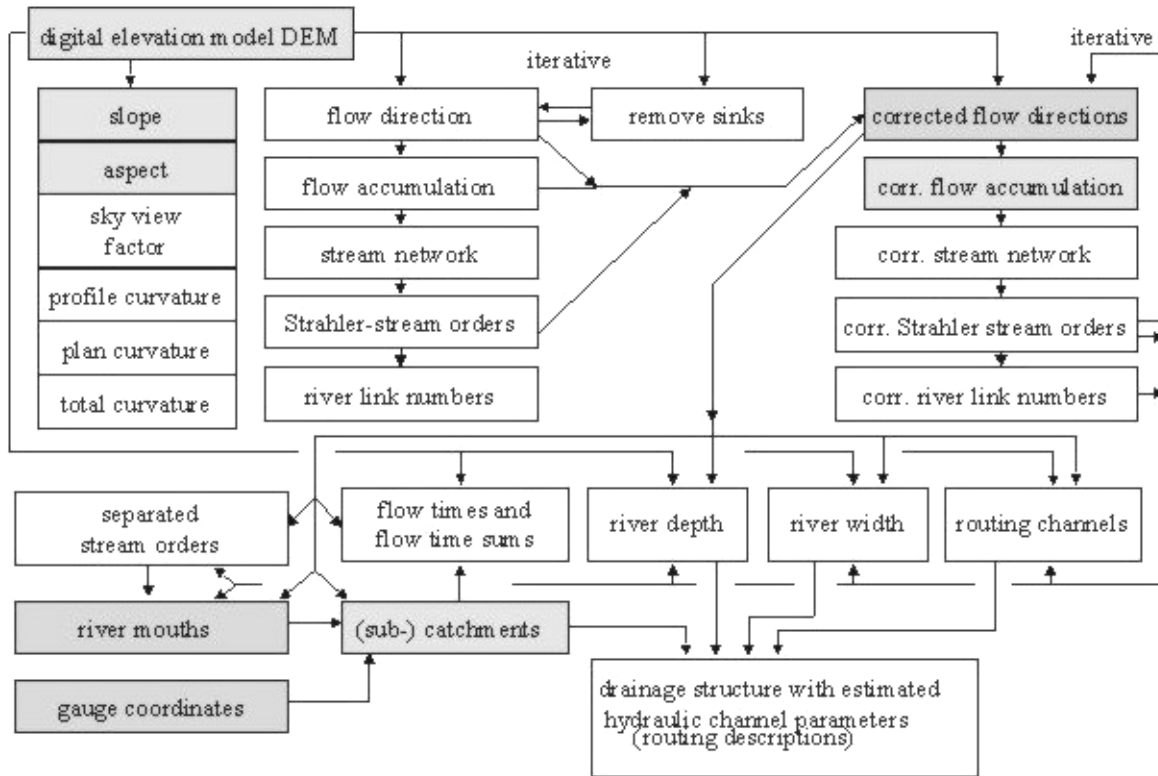


Figure 3.1-2: Topographic analysis of a digital elevation model by TANALYS. Arrows are indicators that a data set can only be generated if the arrow source already exists.

If local co-ordinates are used with (1, 1) in the upper left cell, and if the distance between the points is normalised and set to $L=1$ (which is allowed for quadratic grid cells), it is easy to derive a solution of the linear equation system (co-ordinates $x, y \in \{1, 2, 3\}$). The coefficients A to I are then given by:

$$I = z_{2,2}$$

$$H = (z_{2,1} - z_{2,3}) / (2L)$$

$$G = (z_{3,2} - z_{1,2}) / (2L)$$

$$F = (-z_{1,1} + z_{3,1} + z_{1,3} - z_{3,3}) / (4L^2)$$

$$E = [(z_{2,1} + z_{2,3}) / 2 - z_{2,2}] / L^2$$

$$D = [(z_{1,2} + z_{3,2}) / 2 - z_{2,2}] / L^2$$

$$C = [(-z_{1,1} - z_{1,3} + z_{3,1} + z_{3,3}) / 4 + (z_{1,2} - z_{3,2}) / 2] / L^3$$

$$B = [(z_{1,1} + z_{3,1} - z_{1,3} - z_{3,3}) / 4 - (z_{2,1} - z_{2,3}) / 2] / L^3$$

$$A = [(z_{1,1} + z_{1,3} + z_{3,1} + z_{3,3}) / 4 - (z_{1,2} + z_{2,1} + z_{2,3} + z_{3,2}) / 2 + z_{2,2}] / L^4$$

	x=1	x=2	x=3
y=1	$z_{1,1}$	$z_{1,2}$	$z_{1,3}$
y=2	$z_{2,1}$	$z_{2,2}$	$z_{2,3}$
y=3	$z_{3,1}$	$z_{3,2}$	$z_{3,3}$

(3.1-2)

Some local parameters can be derived directly from these parameters by:

$$\text{slope angle} \quad \hat{\beta} = \arctan\left(\sqrt{G^2 + H^2}\right) \quad (3.1-3)$$

$$\text{aspect angle} \quad \hat{\Omega} = 180 - \arctan(H/G) + 90(G/|G|) \quad (3.1-4)$$

$$\text{profile-curvature} \quad \varphi = -2(DG^2 + EH^2 + FGH)/(G^2 + H^2) \quad (3.1-5)$$

$$\text{plan-curvature} \quad \omega = 2(DH^2 + EG^2 - FGH)/(G^2 + H^2) \quad (3.1-6)$$

$$\text{total curvature} \quad \chi = \omega - \varphi = 2E + 2D \quad (3.1-7)$$

Flow directions are determined from the steepest slope observed in the maximum 8 neighbouring cells. Flow is allowed into only *one* of these cells. Artefacts like sinks or flat areas, which may be the result of generating the elevation model, but can also be real, natural sinks, e.g. in karst regions, are filled iteratively. Sinks are removed by finding the lowest point of all points outside but connected to the border of the sink which has a higher elevation than the sink itself. This elevation is then used to replace the value for all cells within the sink. If, after filling all boundary cells of the sink, which has grown by at least one cell, there is still no gradient to the outside of the sink, the filling is redone, now looking for the next higher elevation of the surrounding cells. This is completed iteratively until at least one cell of the (usually now much larger) sink has a flow gradient to the sink's outer side or until the growing sink reaches a *NoData* value or the boundary of the grid, which are both handled as pour points. Then, the sink has become a "flat region". Now, the flow directions within the flat regions are directed to the one or more pour points in an iterative way starting at the pour points and looking for undefined flow directions in their neighbourhood.

After calculating the flow directions and filling the sinks, the flow accumulation can be calculated. Flow accumulation is the catchment area for each grid cell in units of grid cells draining directly or indirectly through each cell. The accumulation is completed by following the flow directions of each cell until the grid boundary or a *NoData* value have been reached and summing up the number of touched cells. The result includes the cell itself, so the cells at the catchment boundary already have a flow accumulation value of 1 to avoid errors e.g. in calculating the topographic index. For calculating the topographic index, the flow accumulation value should be scaled by the cell size, in order to obtain grid scale independent results.

By setting a threshold for the flow accumulation, the river network can be extracted as a first approximation. The extraction of river networks is a rather complicated task; see e.g. Tarboton et al. (1993). The river network is used together with the flow direction grid to determine the flow orders after Strahler (1952) and to identify each river link with a river link number.

If the extracted stream network still shows artefacts like parallel rivers in neighbouring grid cells, these artefacts can be removed by applying a flow direction correction algorithm. This is also an iterative task. In a first step, rivers of Strahler order 1 are checked (head waters). If they are flowing alongside a river of higher order or alongside a river of the same order but with a larger catchment and if there is at maximum of 1 no-river grid cell between the rivers (which must have an elevation less or equal to the lower of the river cells), then the smaller river's flow direction is redirected by 45° to the larger river. After processing the entire grid, the same procedure is completed for rivers of Strahler order 2 and then for rivers of Strahler order 3. Then, the correction is completed again for rivers of Strahler order 1 and 2, respectively, in order to correct new artefacts which may have been introduced by the correction of higher order flow directions. After each single correction step, a recalculation of the flow accumulations, river network and Strahler orders has to be performed.

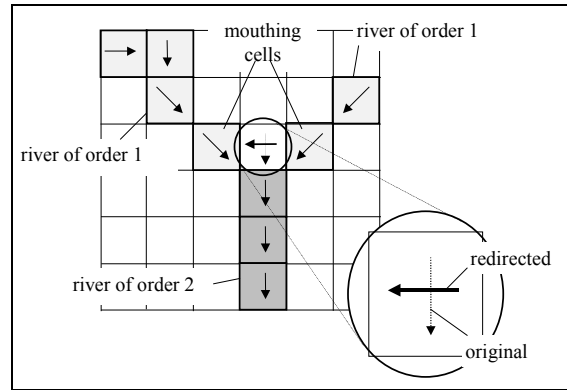


Figure 3.1-3: Flow direction correction at mouths.

A further correction may be necessary if grid cells drain between the mouthing points of two rivers directly into the higher order river. In this case, a redirection of flow directions has to be performed. Figure 3.1-3 shows the principle of this correction. Without this correction, the sub-basin for a river of order 2 would extend upstream between the catchments of the mouthing rivers of order 1. This is an artefact which does not reflect reality. Therefore, the flow direction of the last in-between-grid-cell is redirected to the last cell of the nearest or, if both mouthing rivers have the same distance to the redirected cell, to the larger river.

By separating rivers of order 2 and higher or order 3 and higher and so on, the stream network can be limited to rivers of a given minimum order (or corresponding catchment area). The separated rivers are newly numbered and then the mouths are determined, where these rivers are flowing to higher order rivers. Mouthing points are the last grid cells of a river when observing it in flow direction (Figure 3.1-3).

Sub-catchments are delineated using the mouthing points or any other pour points given in separate grids, e.g. locations of gauging stations as numbered grid cell codes in a pour point grid. The flow times for crossing the grid cells are now also summed for each cell until the next pour point is reached. Grid cells which are part of a routing channel are coded with the number of the largest of its tributaries.

The soil-topographic index (TI) is determined using the local catchment area a , the local transmissivity T_0 and the local slope angle β .

$$TI = \ln \frac{a}{T_0 \tan \beta} \quad (3.1-8)$$

Since it is very difficult to obtain spatially distributed information on the thickness of an aquifer, we approximate the transmissivity through the hydraulic conductivity. In opposition to the usual definition of the soil topographic index, a is the local catchment, not the local specific catchment (this is a program restriction). In order to compare our topographic index results to the topographic indices of other software developers, the value $\ln(\text{cellsize})$ must be subtracted from all grid cells. The hydraulic-topographic index is not influenced by the transmissivity; in this case, a grid with constant cell values of 0.001 is used for T_0 .

3.1.2 Land use – land cover map

The land use is a key physiographical property for spatially distributed application of hydrological models. Remote sensing platforms are fundamental for the large scale detection of the spatial distribution of different land use types. Land use (or land cover) can be determined by digitalisation, analysis and interpretation of remotely sensed images. A short definition of land use and land cover is:

Land cover:

Land cover is defined as the observed physical cover including the vegetation (natural or planted) and human constructions which cover the earth's surface. Water, ice, bare rock or sand surfaces count as land cover. Changes in land cover drive changes in the climatic system and are affected by climate change either directly or indirectly through human response. Land cover determines water, energy, and trace gas balances.

Land use:

Land use is based on the function of the land, i.e. the purpose for which the land is being used. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one or more pieces of land and several land uses may occur on the same piece of land.

Land use is needed by PREVAH for the a priori parameterisation of vegetation specific parameters, which are linked to several processes of the hydrological cycle.

- *Surface roughness*: Roughness is a vegetation and topographical, structural variable and is important in models since it is used to calculate wind effects on evapotranspiration, which effects the rate of moisture transfer from the vegetation to the atmosphere. Hence, atmospheric and hydrological models require accurate estimates of surface roughness. For the same reason, hydrological models require the accurate estimation of the vegetation-atmosphere linkage. The *surface roughness* shows minimal temporal variation. Only meadows and crops show a seasonal course. The average height of the different types of vegetation is assumed as the index for the surface roughness. The surface roughness of forests, rocky areas, urban areas and water bodies must also be estimated.
- *Minimal stomata resistances*: Water evaporates at cell surfaces inside the leaves. A prerequisite for this evaporation is that the air inside the stomata cavities is released to the ambient air outside the leaves. The stomata regulate this pathway to the atmosphere. During the night, stomata are closed and transpiration is practically zero. However, as solar radiation falls on the leaves after sunrise, chemical processes take place in the stomata guard cells and the stomata open. The efficiency by which the driving force (the vapour pressure difference) moves water vapour molecules out of the leaves depends on the degree of stomata opening. This efficiency is expressed as a stomatal resistance (a resistance is the reciprocal of the conductance; see Figure 3.1-4). As the solar radiation increases, the resistance decreases. The stomatal resistance of the whole canopy, i.e. the stomata resistance expressed per unit of soil surface, also depends on the number of stomata, which is in turn related to the leaf area. Since the resistances are coupled in parallel, the stomata resistance of the canopy decreases with leaf area index (LAI). The stomata resistance is a parameter which has to be estimated for each class of vegetation. Its value is strongly related to the physiological and biological characteristic of a specific type of vegetation. This specific parameter of vegetated surfaces is related to the reaction of stomata on changes in the available moisture content in the soil. The closure of stomata causes a reduction in transpiration, and therefore a limitation in potential evapotranspiration. Stomata resistances increase during dry periods and are equal to the defined minima if enough water is available for transpiration. Increased stomata resistances cause a limitation in actual evapotranspiration, as compared to the potential value.

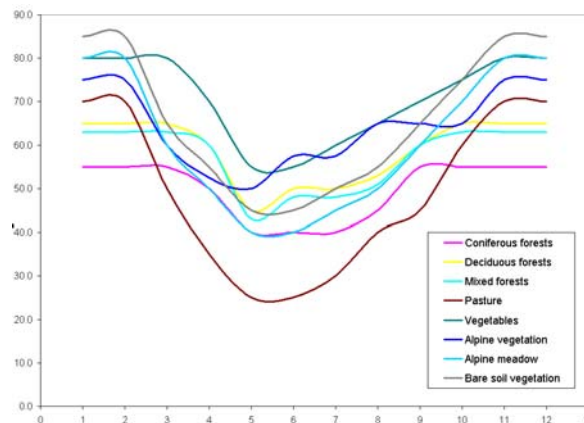


Figure 3.1-4: Monthly changing parameterisation of the minimal stomatal resistances for different standard land use categories of PREVAH.

- *Root depth*: The root depth is defined as the vertical distance from the soil surface up to which 95% of all plant roots are found. Data of rooting depth are important to properly quantify interactions between the climate, soil and plants, as root growth is very sensitive to climate change and soil properties (especially moisture). The soil moisture content available for evapotranspiration is controlled by the actual saturation of the soil and structure of the soil's root zone. The parameter "root depth" is adopted by

PREVAH for the estimation of the depth of the soil horizon that is involved in the exchange processes between soil, vegetation and atmosphere. The plant available soil moisture capacity, soil depth and root depth are used to determine the maximal depth of the water column, which the soil can store as soil moisture and that the vegetation can assimilate through the roots. The root depth has to be estimated and assigned for each class of vegetation.

- *Leaf Area Index (LAI) and vegetation density:* The seasonal cycle of vegetated surfaces can be well described through two seasonally varying parameters: LAI and the density of the vegetation. In this way, it is possible to capture the different phenological behaviour of the different classes of vegetation. LAI (see Figure 3.1-5) is the total area of leaves in relationship to the ground below them. LAI describes a fundamental property of the plant canopy in its interaction with the atmosphere, especially concerning radiation, energy, momentum, and gas exchange. Leaf area plays a key role in the absorption of radiation, in the deposition of photosynthates during the diurnal and seasonal cycles, and in the pathways and rates of biogeochemical cycling within the canopy-soil system. Various soil-vegetation-atmosphere models and hydrological models use LAI. Globally, it varies from less than 1 to above 10 but there is also significant variation within biomes at regional, landscape and local levels. Coniferous forests have high LAI and vegetation density throughout the year. Deciduous forests have a much lower LAI in winter when compared to the summer-half-year. The main hydrological processes related to seasonal development of these vegetation specific parameters are interception and evapotranspiration. Higher LAI means higher water storage capacity on leaves, which determines a higher potential for interception evaporation in the seasons with higher LAI.

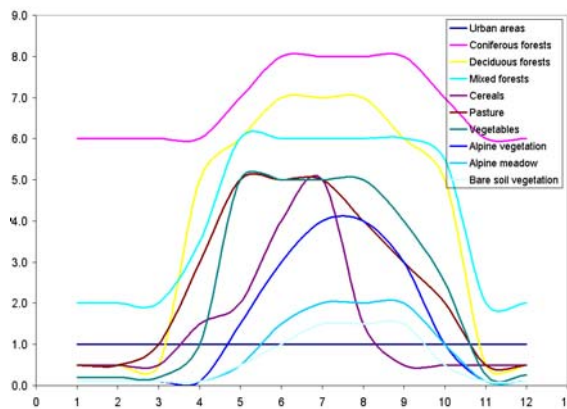


Figure 3.1-5: Monthly changing parameterisation of the leaf area index for different standard land use categories of PREVAH.

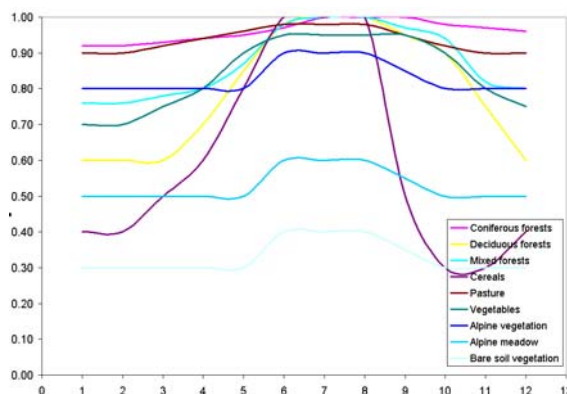


Figure 3.1-6: Monthly changing parameterisation of the vegetation density for different standard land use categories of PREVAH.

- *Albedo:* Albedo is the fraction of radiation that is reflected by the earth's surface. Surface albedo is fundamental to the surface energy balance, as it is the ratio of the downwelling to upwelling short-wave radiative fluxes at the earth's surface. Surface albedo and clouds are two of the most important parameters

modulating the earth's climate, especially over land. Although it does not change temporally as significantly as clouds, surface albedo undergoes considerable variation over space, and shows strong seasonal cycles and inter-annual variability. Surface albedo data have been obtained from in situ observations and space-borne measurements by means of remote-sensing techniques. The former are site-specific as they usually represent very small areas but have high temporal resolution, whereas the opposite is true for the latter. Therefore, the two types of measurements are complementary. Albedo is a key parameter for modellers and analysts concerned with climate, weather, ecosystem and hydrological issues. During short time periods, albedo can show an important dependence on weathering and air temperature. Snowfall causes a large increase in albedo (the albedo of fresh snow is 0.8-0.9). Snow albedo leads to reduced energy reaching the surface. This reduces evapotranspiration. The hydrological model must be able to update the albedo at the surface after snowfall events.

- *Soil heat flux*: Soil heat flux is the rate at which heat is conducted through the soil. A simple parameterisation of the soil heat flux consists of assigning a fraction of the net radiation at the soil surface. While this approximation is fairly crude, and does not recognise the phase difference between the diurnal net radiation and soil heat flux curves, it yields an adequate estimate given that the soil heat flux is typically small in comparison to the other energy budget components.
- *Available water content*: If no reliable parameterisations on soil depth and plant available volumetric water content are possible, the maximal plant-available soil water content has to be parameterised a priori for each type of vegetation.
- *Maximal interception storage*: The interception storage (Figure 3.1-7) represents the storage of moisture on the leaves of trees, grasses etc. Moisture is added to this storage from rainfall or snowmelt. The first call on this storage is for evaporation which, experiments have shown, can take place at more than the potential rate. It is possible to represent this in the model. Any moisture in excess of the storage limit reaches the soil storage. The maximal value of the interception storage may be proportional to the LAI.

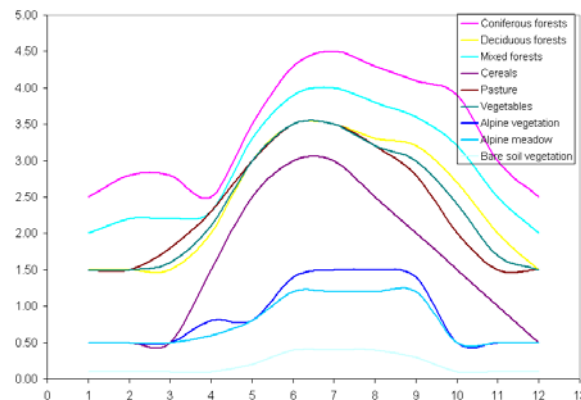


Figure 3.1-7: Monthly changing parameterisation of the maximal interception storage for different standard land use categories of PREVAH.

The PREVAH modelling system uses the information on land use and land cover for the parameterisation of vegetation specific parameters (see the next Sections). Only hydrological relevant land cover classes are currently implemented in PREVAH (see Table 3.1-1). The different types of land use can be aggregated for hydrological considerations into three main families:

- Vegetation: forests, meadows, bushes, agricultural land etc.
- Unproductive land forms: urban areas, rocks, bare soils
- Water bodies: rivers, lakes, snow, glaciers

Table 3.1-1: PREVAH implements parameterisation for following land use types:

Internal ID	Land cover type	Internal ID	Land cover type
1	Water	18	Fruits
2	Urban areas	19	Vegetables
3	Coniferous forests	20	Wheat
4	Deciduous forests	21	Alpine vegetation
5	Mixed forests	22	Wetlands
6	Cereals	23	Rough pasture
7	Pasture	24	Sub-Alpine meadow
8	Bush	25	Alpine meadow
13	Firn	26	Bare soil vegetation
14	Bare ice	28	Corn
15	Rock	29	Grapes

Secondary land cover types have to be aggregated into one of the PREVAH standard land use types. If another identifier is assigned to these categories, then the tools WINHRU and/or GRIDMATH allow the re-classification into the Internal ID required by PREVAH.

3.1.3 Soil map

Institutes and organisations involved in applied research at a global scale have a definite need for soil information because these data are a crucial input in models that simulate crop growth and calculate anticipated yields and water balance, or to assess the environmental impact of different land-use practices. A parameterisation of the soil's characteristics helps analysts, scientist, planners and decision-makers concerned with: development and land use research and planning; assessing and combating soil degradation and desertification; planning, monitoring and evaluating sustainable development; and modelling the interactions between soil, vegetation and atmosphere.

The a priori parameterisation of the soil's specific parameters is based on information derived from digital soil maps. Such maps should allow the classification of hydrologically relevant soil parameters like plant-available soil field capacity, soil depth and soil conductivity. These parameters are assigned during the pre-processing of the spatial data.

Soil depth

Soil depth is the vertical distance between the surface and the parent material of a soil. Soil depth indicates the state of pedogenesis; its changes can indicate degradation and other transformation processes. Soil depth usually remains the same over very long periods of time. Sudden changes will most likely be the result of a change of the soil itself (erosion, soil removal or allocation). The following tables (Table 3.1-2 and 3.1-3) indicate recommended parameterisations for soil depth in meters in the case of categorical data from the Soil Capability Map of Switzerland (BfR, 1980) and FAO "Digital soil map of the world" (FAO-UNESCO, 1988).

Table 3.1-2: Classification of soil depth from the Soil Capability Map of Switzerland.

Category	Soil depth	Parameterisation [m]
6	Very deep	4.00
5	Deep	2.00
4	Norm	1.00
3	Moderately shallow	0.50
2	Shallow	0.25
1	Very shallow	0.10
-	Rock, Glaciers, Urban areas	0.00

Table 3.1-3: Classification of soil depth from the FAO soil map (FAO-UNESCO, 1988).

Category	Soil depth	Parameterisation [m]	Recommended [m]
5	Very Deep	1.5-3.0	2.00
4	Deep	1.00-1.5	1.25
3	Norm	0.5-1.0	0.75
2	Shallow	0.1-0.5	0.35
1	Very shallow	<0.10	0.10

Plant available field capacity

Soil moisture storage capacity (also referred to as field capacity) is the water content of a soil at a defined time after its complete wetting and after free drainage has become negligible. Soil moisture storage capacity is an important soil characteristic for two reasons: together with the permanent wilting point, it defines the ability of a soil to satisfy the vegetation's water needs during periods without precipitation. Thus, the plant-available field capacity is defined as the amount of soil water that can be extracted by the plant, and is the difference in soil moisture content between the field capacity and the wilting point. It is expressed as millimetres of plant-available water within the root zone. Secondly, it describes a soil's effectiveness as a buffer in the vertical transfer of water after precipitation, thus determining a soil's water retention and purification properties. Changes in the soil moisture storage capacity occur very slowly under natural conditions. Significant changes are most probably only found after land use changes or changes to the soil itself. The following tables (Tables 3.1-4 and 3.1-5) indicate the recommended parameterisation for plant available field capacity in percent by volume in the case of categorical data from the Soil Capability Map of Switzerland (BfR, 1980) and FAO "Digital soil map of the world" (FAO-UNESCO, 1988). Table 3.1-5: Classification of maximal plant available field capacity (AFC) from the FAO soil map (FAO-UNESCO, 1988).

Table 3.1-4: Classification of plant available field capacity (AFC) from the Soil Capability Map of Switzerland.

Category	AFC	Parameterisation [Vol%]
6	Very high	24.00
5	High	16.00
4	Norm	11.00
3	Moderately low	8.0
2	Low	4.5
1	Very low	1.5
-	Rock, Glaciers, Urban areas	0.00

Table 3.1-5: Classification of maximal plant available field capacity (AFC) from the FAO soil map (FAO-UNESCO, 1988).

Category	AFC	Parameterisation [Vol%]	Recommended [Vol%]
1	Wetlands	-	-
2	Very High	> 20.0	25.0
3	High	15.0-20.0	17.5
4	Norm	10.0-15.0	12.5
5	Moderately low	6.0-10.0	8.0
6	Low	2.0-6.0	4.5
7	Very Low	<2.0	2.0

Hydraulic conductivity

Saturated hydraulic conductivity of a soil is a measure of a soil's ability to transmit water in a water-saturated state (Table 3.1-6). It is a key variable describing soil water fluxes. The entry of water into soil, movement of

water to plant roots, flow of water to drains and wells and its evaporation are some of the examples in which hydraulic conductivity plays a decisive role.

Table 3.1-6: Classification of saturated hydraulic conductivity from the Soil Capability Map of Switzerland.

Category	Hydraulic conductivity	Parameterisation [m s^{-1}]
7	Extremely high	1.4e-09
6	Very High	1.4e-08
5	High	1.4e-07
4	Norm	1.4e-06
3	Moderately low	1.4e-05
2	Low	1.4e-04
1	Very Low	1.4e-03

Ecologists use the saturated hydraulic conductivity to estimate or model vegetation composition and vegetation structure. Water and agricultural resource managers, hydrological modellers and atmospheric modellers use it for estimating land-atmosphere water fluxes.

3.2 Binary format

In the PREVAH modelling system, a binary grid format is used. In order to exchange grids between different computer platforms and exchange grids with other software, e.g. with ArcInfo, an ASCII-format is required.

The following rows represent the grid data from top left to lower right (rows 1 to 6: grid header including number of columns and rows, co-ordinates of the lower left corner, cell size, *NoData* value).

ncols	7					
nrows	12					
xllcorner	680500					
yllcorner	222200					
cellsize	2000					
<i>NoData</i> _value	-9999					
-9999	-9999	-9999	-9999	-9999	-9999	-9999
-9999	-9999	-9999	-9999	-9999	-9999	-9999
-9999	-9999	586	559	595	601	585
584	-9999	-9999	-9999	-9999	-9999	-9999
-9999	449	-9999	-9999	454	511	551
-9999	561	529	509	498	487	499
521	523	523	534	-9999	-9999	-9999
-9999	-9999	-9999	-9999	-9999	-9999	-9999
-9999	-9999	-9999	-9999	-9999	345	234
567	453	456	478	789	576	482
123	-9999	1252	1211	876	564	825
-9999	-9999	234	1246	-9999	-9999	-9999

The PREVAH binary format is structured similarly to the ASCII-format. All values are stored in single precision (4 bytes in most computer systems, 6 to 7 digits precision). Records 1 to 6 correspond to the data of the ASCII-Format. Then 6 additional records describing the grid statistics follow:

Records 1 to 6: as in the ASCII-format.

Records 7 to 12:

- Count of valid cells (without *NoData*-values)
- Minimum value of all valid grid cells
- Maximum value of all valid grid cells
- Sum of all valid grid cells
- Mean value of all valid grid cells
- Standard deviation of all valid grid cells

After this header, all cells of the grid are following in the same order as in the ASCII-format, i.e. from the top left cell to the lower right cell in a row by row order. The tool GRIDMATH (see particular documentation) is available for format conversion. ASCII-formats can be exchanged between different systems using e.g. Ftp-programs, with an automatic conversion of carriage returns/line feeds. To exchange binary data, the data first have to be converted into ASCII-data, then the exchange can be completed, followed by a re-converting on the target platform.

3.3 Concept of the hydrological response units HRU

3.3.1 Basics

When hydrological modelling is applied to different spatial units, the nature and size of the units must account for the complexity of the landscape and the accuracy required by the modelling task (Gurtz et al., 1999). The spatially distributed hydrological model PREVAH (Gurtz et al., 1999 and 2003a; Zappa et al., 2003) can either be applied to each single grid cell or to an aggregation of spatially distributed grid cells, which are similar according to a set of structural and statistical differentiation characteristics. This implies a similar/homogeneous hydrological response, if the applied criteria for differentiation have a direct feedback with the most important processes controlling evapotranspiration and runoff-generation. Such an aggregation of hydrologically equal surface units is called a 'hydrological response unit' HRU (Ross et al., 1979; Engel, 1996; Moore et al., 1993; Flügel, 1997). The HRU approach allows for the discretisation of a catchment with an internally dynamical spatial resolution. The HRU size is smaller where the ensemble of the characteristics of the soils, land surface and topography shows higher spatial variability (Gurtz et al., 1997b; Zappa and Gurtz, 2002).

3.3.2 Use of the HRU concept in PREVAH

PREVAH and its GUI-based version WINPREVAH rely on the aggregation of grid elements into HRUs. For distributed simulations, a set of HRUs has to be defined.

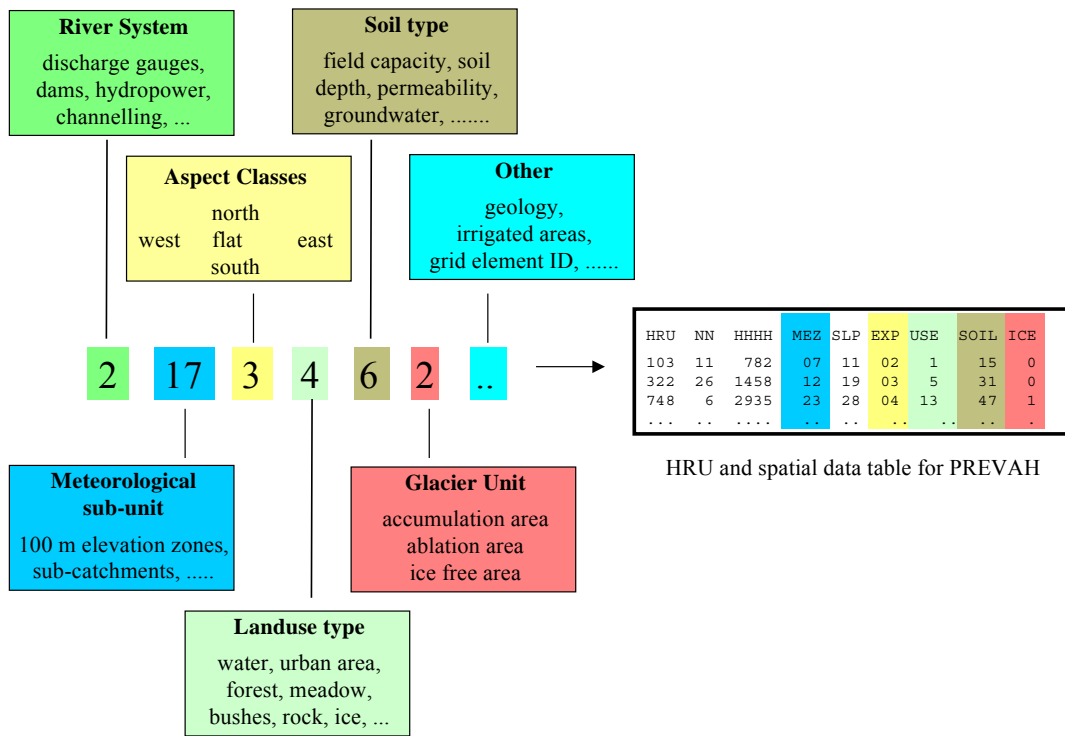


Figure 3.3-1: Preprocessing of spatial information for PREVAH including the possible criteria adopted for the aggregation of the HRUs. The typical rules for generating a code for the definition of HRUs assign, to a HRU, all the grid elements in the same meteorological sub-unit, with similar aspect, same land-use classification and, eventually, same position with respect to the equilibrium line of a glacier.

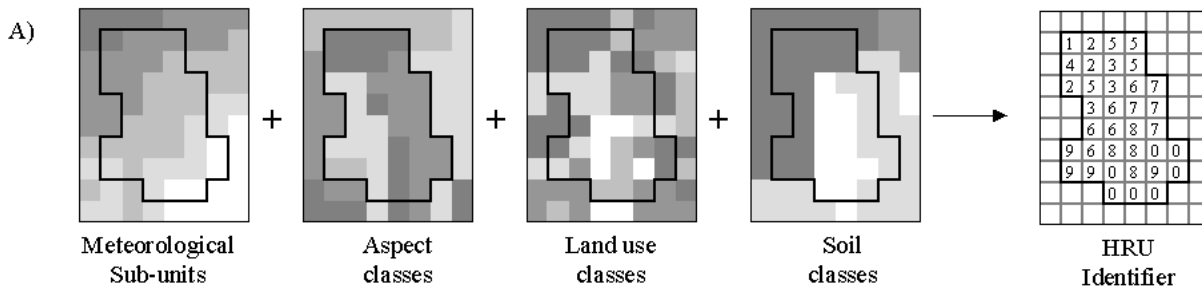


Figure 3.3-2: HRU based discretisation of idealised domain for distributed hydrological simulations in mountainous environments.

Different levels of information classes (Figures 3.3-1 and 3.3-2) are introduced and used to generate the HRUs (Nemec, 1993; Gurtz et al., 1999):

- Level of the *river system*: In particular the sub-catchment areas and channel network can be identified from the topography and position of gauging stations;
- The *topographic* level is characterised by elevation, aspect (typically five classes: north, east, south, west or flat) and slope. The amount of energy available for evapotranspiration is strongly controlled by these factors in combination with surface albedo;
- Level of the *meteorological input variables*: The definition of meteorological sub-units is typically related to the delimitation of 100 meters elevation zones on the basis of the available digital elevation model (DEM). The use of other criteria for such differentiation is possible;
- The level of *land-use characteristics*, which is an important control on evapotranspiration as well as processes involved in runoff-generation. In the case of glaciated catchments, a further classification is

required. The disposition of the grid elements with respect to the equilibrium line of the glacier (accumulation, ablation or ice-free area) has to be determined;

- The level of *soil properties and geology* includes field capacity, soil depth, permeability, groundwater recharge and storage characteristics. The extrapolation of those properties allows the description of the feedback between soils and water balance components.

3.3.3 Algorithm

Figure 3.3-2 shows the recommended rules for generating HRUs in mountainous environments. In the following example, all grid elements located in the same meteorological sub-unit, having similar aspect and soil properties and the same land-use classification are assigned to a HRU. Equations (3.3-1) and (3.3-2) illustrate the formulation of the algorithm adopted for the generation of the code HRU^{ID} :

$$HRU^{ID}_{(i,j)} = \sum_{n=1}^m CLASS^{ID}(n)_{(i,j)} \cdot 10^{D_n} \quad (3.3-1)$$

$$D_n = \begin{cases} \sum_{k=n+1}^m D^{ID}(k) & \text{for } n < m \\ 0 & \text{for } n = m \end{cases} \quad (3.3-2)$$

HRU^{ID} is computed for all grid elements (i,j) located in the investigated domain. i defines the grid columns (e.g. the x co-ordinate in metric units or the longitude in degrees) and j defines the grid rows (e.g. the y co-ordinate or latitude). m is the number of layers (physiographic properties) that are considered for generating HRU^{ID} . n is the identifier of a specific layer (Table 3.3-1). $CLASS^{ID}$ is a grid index where an integer number is assigned to every (i,j) -pair. That integer number represents a classification for a layer's attribute.

Table 3.3-1: Recommended physiographic layers for the discretisation of a mountainous catchment into HRUs. n is the identifier of the layer. $CLASS^{ID}$ is a grid containing, for each (i,j) element, an integer number as an identifier for the attributes of a particular layer. D^{ID} is the required number of digits by a specific layer in the HRU-code. The right-part of the table shows the attributes $CLASS^{ID}_{(x,y)}$ for an arbitrary (x,y) grid point.

n	Layer	$CLASS^{ID}_{(i,j)}$	D^{ID}	(x,y)	$CLASS^{ID}_{(x,y)}$
1	Elevation zone	0-99	2	Valley floor	15
2	Aspect	0-9	1	South-exposed	3
3	Land-use	0-99	2	Pasture	24
4	Soil type	0-99	2	Sand	13

A $CLASS^{ID}$ equal to "3", for example, for the layer "aspect" means that the (i,j) -pairs carrying this $CLASS^{ID}$ are south-exposed. The exponent D_n is required to build HRU^{ID} , appending a layer $CLASS^{ID}$ to the $CLASS^{ID}$ of the layers already defined. D^{ID} is the number of digits occupied by a layer $CLASS^{ID}$ in the HRU^{ID} .

Table 3.3-1 shows a selection of physiographic layers for the generation of HRUs in mountainous catchments. In the presented example, the HRU^{ID} can consider up to 100 meteorological sub-units (all the grid elements in the same 100 m range of elevation, in this experiment), land-use classes and soil types, and up to ten aspect classes.

An idealised (x,y) grid element located in the lower part of the investigated domain (south-exposed, used as a pasture and characterised by sandy soils) can be identified by a HRU^{ID} equal to "1532413", using equation (21), and the idealized $CLASS^{ID}$ reported on Table 3.3-1. Other (i,j) -pairs may share that HRU^{ID} . Thus, they are assumed to have a similar hydrological response to this example.

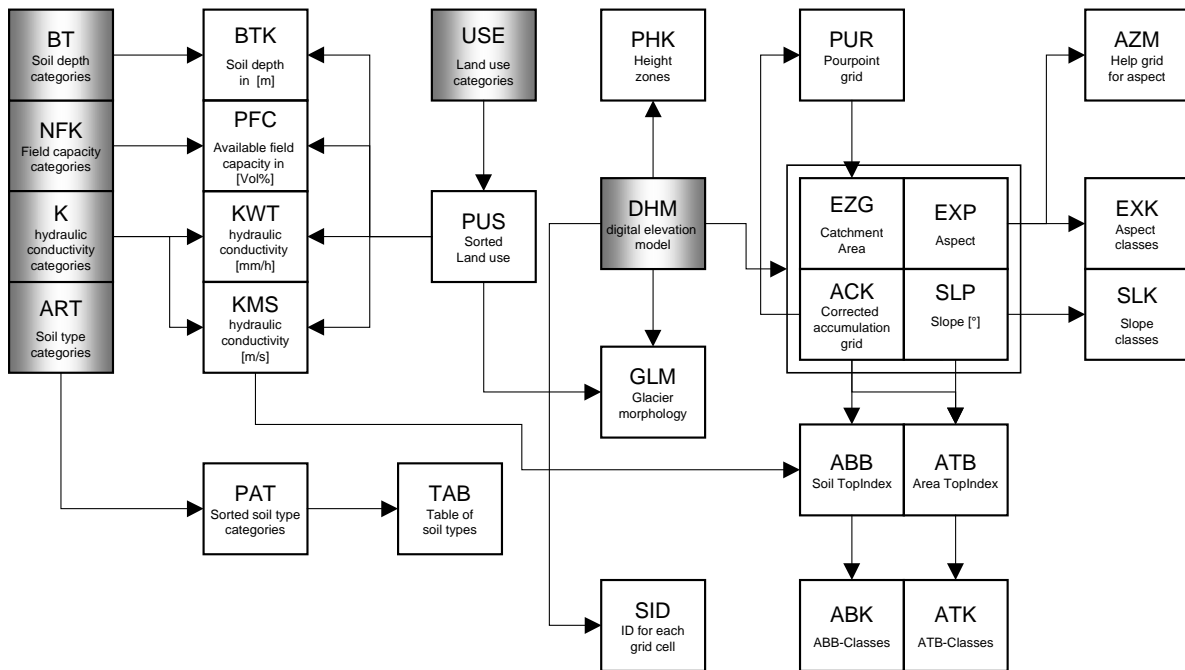


Figure 3.3-3: Project preprocessing with WINHRU. Summary of the required extensions and data flow. Grey boxes are the inputs, white boxes the output.

3.4 Meteorological model input

3.4.1 Required meteorological variables

PREVAH always runs at an internal time step of one hour. Depending on the choice of evapotranspiration scheme, up to six meteorological input variables are required:

- Precipitation [mm per time step]
- Air temperature [°C]. Air temperature is then corrected for slope and aspect
- Global radiation [W m^{-2}]. Global radiation is also corrected for slope and aspect
- Relative sunshine duration [-]
- Wind speed [m s^{-1}]
- Relative air humidity [-] or water vapour pressure [hPa]

Should only daily values of the meteorological elements be available, 24 identical hourly values are assumed for air temperature, wind speed, water vapour pressure and relative humidity. Precipitation is divided into 24 identical values, while global radiation values are subdivided between sunrise and sunset according to the calculated potential clear-sky direct radiation (Schulla, 1997; Hock, 1999).

This assumption of uniform precipitation intensity and air temperature may principally affect the accuracy of the simulation of snow accumulation, snowmelt and runoff-generation. Zappa and Gurtz (2003) discuss this problem in the case of plot-scale simulations of soil moisture and evapotranspiration and conclude that the underestimation of the rain intensities leads to systematic errors in the computation of the soil water content but has a reduced effect on the estimation of daily evapotranspiration rates.

3.4.2 Spatial interpolation of meteorological input data

Interpolation is necessary if the data available do not completely cover the domain of interest. In this case, it is used for conversion of the data from sets of sample points, e.g. measured values from rainfall stations, to a discretised, continuous surface. The rationale behind spatial interpolation and extrapolation is the very com-

mon observation that, on average, values at points close together in space are more likely to be similar than points further apart (Burrough and McDonnell, 2000).

"Interpolation is the procedure of predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region. Predicting the value of an attribute at sites outside the area covered by existing observations is called extrapolation" (Burrough and McDonnell, 2000:98). It is not possible to eliminate the problems associated with extrapolation but it should be considered carefully, perhaps by an investigation of extremes in the model input data plus a comparison with any other independent data.

Interpolation methods can be distinguished between exact and inexact interpolators. An interpolation method that predicts a value of an attribute at a sample point which is identical to that measured is called an exact interpolator. All other interpolation methods are inexact interpolators. The ideal situations are the exact interpolators, because it is only at the data points that we have direct knowledge of the attribute in question (Burrough and McDonnell, 2000). Inverse distance weighting (IDW) detrended IDW, ordinary kriging (OK) and detrended OK are exact interpolators but elevation dependent regression (EDR) is an inexact interpolator.

The pattern of spatial continuity of the variable to interpolate is one the most important facets for the problem of estimation. If the pattern is highly continuous, estimates based on only the closest available samples may be quite reliable, but erratic phenomenon may require the consideration of many more sample data beyond the closest points (Isaaks and Srivastava, 1989). The spatial variability and discontinuity of precipitation fields increases the shorter the reference period (Dyck and Peschke, 1995).

A. Elevation dependent regression (EDR)

The interpolation method Elevation Dependent Regression belongs to the family of polynomial regressions methods. It is a stochastic, global technique which fits the variable of interest to some linear combination of regressor variables. In this case, the variable of interest is fitted to the elevation of the used stations. Typically, the goal when using polynomial regression is to obtain the best fit with the simplest model. Using this method, the interpolation result is estimated using the altitude dependence of a variable. To use this method, it is necessary to generate the appropriate files containing the altitudinal gradients for each variable needed by PREVAH. The gradients can be given for a maximum three variable ranges separated by inversions (Figure 3.4-1). The estimation of the altitude of these inversions is completed semi-automatically by searching for cross sections of the regressions of neighbouring altitudinal ranges.

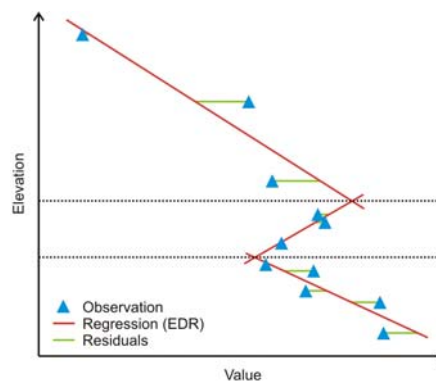


Figure 3.4.1: Elevation dependent regression.

Using this method, the interpolation result is estimated with the altitude dependence of a variable. As initial values, typical altitudinal ranges of inversions are specified for each of the two possible inversions. Separate regressions are then estimated for the range below and the range above the lower inversion. If the regressions intersect between the lower and upper (theoretical) inversion, it is assumed that there is only one inversion. Otherwise, i.e. if the regressions intersect outside the inter-inversion range, a twofold inversion is assumed, making only the lower regression valid below the lower inversion and the upper regression valid above the upper inversion. In-between, a third gradient is assumed to link both regressions linearly.

The interpolation to a specified point in the model is then completed by:

$$T(h_M) = a_{r,i} + b_{r,i} \cdot h_M \quad (3.4-1)$$

with h_M altitude [m a.s.l.]
 T variable (e.g. air temperature)
 i index for lower, medium and upper regression, respectively (i=1..3)
 $a_{r,i}$ $b_{r,i}$ parameter of the respective regression

EDR is an "inexact" interpolation method, as defined above. The interpolated value in the location where an observation is available does not necessarily correspond to the observed value. The difference between interpolated value and observed value is called the "residual". To adopt this interpolation method, it is imperative to know the altitude of all the available meteorological stations. The computation of the altitudinal gradients is currently achieved using WINMET, a preprocessing tool of the PREVAH modelling system.

B. Inverse distance weighting interpolation (IDW)

Methods built on inverse distance interpolation combine the idea of proximity, introduced by the Thiessen polygons, with the gradual change of the trend surface. It is assumed that a value of an attribute z at an unvisited point is a distance-weighted average of data points within the neighbourhood of the unvisited point (Burrough and McDonnell, 2000). The fact that only the neighbourhood is considered in the calculations makes the inverse distance weighted method a local interpolator. The weight assigned to a particular value decreases as distance from the prediction location increases, thus sample data closest to the unmeasured point contribute more to the calculated average. The input data are read in as a table. For the IDW-method, all stations within a specified search radius are used for the interpolation. If all stations have identical values, interpolation is skipped and the constant value is used. If all stations have no-data values, the interpolation is also skipped, and the results from the last time step are used. If the distance is equal to 0 (a point to interpolate is at a gauging station), no interpolation is performed (avoiding division by 0), but the value is simply brought forward causing the IDW to be an exact interpolator. The interpolation result is the sum of all contributing weighted station data. The form of the inverse distance predictor is:

$$\hat{z}(u) = \sum_j (w_j \cdot z(u_j)) \quad (3.4-2)$$

with $w_j = \frac{1}{d(u, u_j)^p} \cdot \frac{1}{C}$ and $C = \sum_j \frac{1}{d(u, u_j)^p}$ follows: $\sum_j w_j = 1.0$

and with $\hat{z}(u)$ interpolated value at location u
 w_j weight of the observed value at station j
 $z(u_j)$ observed value at station j
 $d(u, u_j)$ distance to station j
 p weighting power of the inverse distance (between 1 and 3, 2 is recommended)

The IDW method is an averaging technique that produces highly smoothed surfaces. The original data points are honoured and, therefore, calculated values can never be higher than a local maximum or lower than a local minimum. To adopt this interpolation method, it is imperative to know the northing and easting (y and x co-ordinates) of all the available meteorological stations.

C.1 Geostatistical interpolation methods

Most earth science applications are not understood in sufficient detail to permit a deterministic approach to estimation. There is a large uncertainty pertaining to what happens at unsampled locations. For this reason, the geostatistical approach to estimation is based on a probabilistic model that recognises these inevitable uncertainties. Probabilistic, geostatistical models have been proven in cases where the available sample data is considered to be the result of a random process. They also give some ability to gauge the accuracy of estimates and assign confidence intervals. The strength of geostatistical methods over more classical approaches is their ability to recognise spatial variability at both the large and small scale, or in statistical parlance, it models both spatial trends and spatial correlation. IDW only recognises spatial correlation without spatial trend, whereas elevation detrending (EDR) only recognises horizontal dependency. Parts of the widely available geostatistical package GSLIB (Deutsch and Journel, 1997) were implemented into WINMET.

C.2 Regionalised variable theory

Geostatistical methods for interpolation start with the recognition that the spatial variation of any continuous attribute is often too irregular to be modelled by a simple, smooth mathematical function. Instead, the variation can be better described by a stochastic surface. The attribute is then known as a *regionalised variable*. Regionalised variable theory assumes that the spatial variation of any variable can be expressed as the sum of following three major components:

- A structural component ($m(\vec{x})$), having a constant mean or trend (deterministic function)
- The variation of the regionalised variable ($\varepsilon'(\vec{x})$) (a random, but spatially correlated component)
- A residual error term, "noise" (ε'') (spatially uncorrelated, Gaussian distributed)

These three components result in the random function $Z(\vec{x})$.

$$Z(\vec{x}) = m(\vec{x}) + \varepsilon'(\vec{x}) + \varepsilon'' \quad (3.4-3)$$

To calculate $Z(\vec{x})$ a suitable function for $m(\vec{x})$ has to be defined. If no trend or drift is present, $m(\vec{x})$ equals the mean value in the sampling area and the expected difference between any two places \vec{x} and $(\vec{x} + \vec{h})$ separated by a distance vector \vec{h} .

$$E[Z(\vec{x}) - Z(\vec{x} + \vec{h})] = 0 \quad (3.4-4)$$

$Z(\vec{x} + \vec{h})$ and $Z(\vec{x})$ are the values of the random function Z at locations $(\vec{x} + \vec{h})$ and \vec{x} . It is assumed that the variance of differences depends only on the distance (\vec{h}) between sites and not on the location.

$$E\left[\{Z(\vec{x}) - Z(\vec{x} + \vec{h})\}^2\right] = E\left[\{\varepsilon'(\vec{x}) - \varepsilon'(\vec{x} + \vec{h})\}^2\right] = 2\gamma(\vec{h}) \quad (3.4-5)$$

$\gamma(\vec{h})$ is known as the semivariance. The *intrinsic hypothesis* of the regionalised variable theory is defined by the two conditions: stationarity of difference and variance of difference. Stationarity of difference presumes that the expected outcome of the random variable is only dependent on the distance between two points and not on the location. Thus, stationarity of difference is similar to the unbiasedness condition. Bias is unlike error, which can be defined as the difference between a true value and the prediction, model-based value in that it depends on a statistical model fitted to an ensemble of data values. Bias is most often predicted by the mean error, thus it is an expectation of over- or under- prediction based on some statistical model.

The main gain of probabilistic models is their ability to set the estimation error to zero. The solution derived from the model (attained by the intrinsic hypothesis) is then assumed to apply to reality. This means that, once structural effects have been taken in account, the remaining variation is homogeneous in its variation so that differences between sites are merely a function of the distance between them. For a given distance h , the variance of the random component of $Z(x)$ equals twice the semivariance.

$$\text{var}[\varepsilon'(\vec{x}) - \varepsilon'(\vec{x} + \vec{h})] = 2\gamma(\vec{h}) \quad (3.4-6)$$

If the conditions of the intrinsic hypothesis are fulfilled, the semivariance can be estimated from sample data.

$$\hat{\gamma}(\vec{h}) = \frac{1}{2n} \sum_{i=1}^n \{z(\vec{x}_i) - z(\vec{x}_i + \vec{h})\}^2 \quad (3.4-7)$$

Where n is the number of pairs of observed sample points of attribute z separated by the distance \vec{h} .

C.3 Variogram models

Choosing a variogram model is an important step for the application of kriging. This does make kriging more time consuming than common deterministic approaches but, on the other hand, makes it more flexible as well. Basic variogram models can be conveniently divided into two types: those that reach a plateau (sill), often referred to as transition models, and those that do not. Transitive models have a variation of the spatial correlation structure with the lag h . Models not reaching a sill are often used when there is a trend or drift in the data. In the case study described in this manual, only transitive models were tested.

The advantage of a procedure that can assign weights smaller than 0 or greater than 1 (but still respecting the constraint that weights sum to 1) is that it can yield estimates exceeding maximum or under-running the minimum sample value. This behaviour is eligible because it is unlikely that the sample data set includes the most extreme values. The disadvantage of negative weights is the possibility of producing negative estimates, which is completely unrealistic in most cases, e.g. precipitation interpolation, but can be solved by setting such estimates to 0.

There are four different variogram models: the spherical model; exponential model; Gaussian model; and combination model (Figures 3.4-2 and 3.4-3).

The *Spherical model* is perhaps the most commonly used variogram model. Its standardised equation is:

$$\begin{aligned} \gamma_s(h) &= c_o + c_1 \left\{ 1.5 \frac{h}{a} - 0.5 \left(\frac{h}{a} \right)^3 \right\}, & \text{for } 0 < h \leq a \\ &= c_o + c_1, & \text{for } h > a \\ \gamma_s(0) &= 0 \end{aligned} \tag{3.4-8}$$

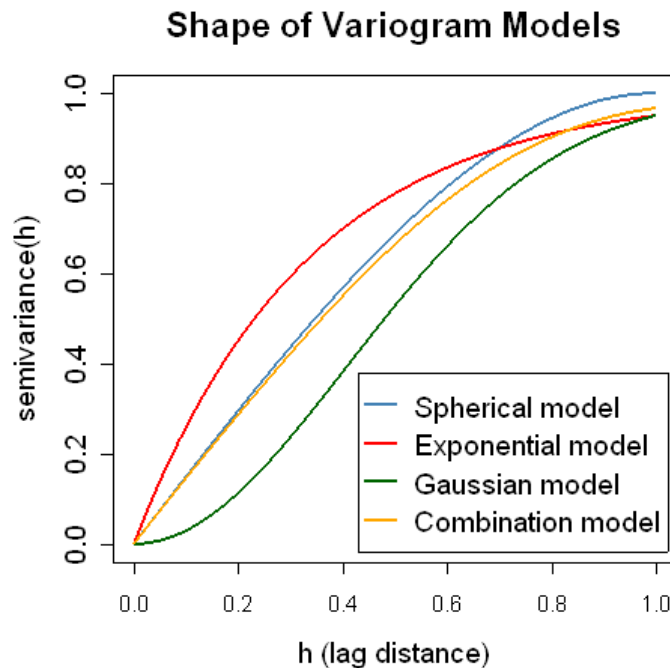


Figure 3.4-2: Shape comparison of the different variogram models. The nugget effect is set to zero for this image.

a is the range, c_o is the nugget effect (noise) and $c_o + c_1$ is the sill. It has a linear behaviour at small separation distances near the origin but flattens at larger distances and reaches the sill at a . If the nugget variance is important but not too large, and there is a clear range and sill, the spherical model usually fits observed variograms with reasonable accuracy.

The *Exponential model* is another commonly used transition model given by:

$$\gamma_e(h) = c_o + c_1 \left\{ 1 - e^{\left(\frac{-3h}{a}\right)} \right\} \quad (3.4-9)$$

This model reaches its sill asymptotically, but is linear at very short distances to the origin as in the spherical model. However, it rises more steeply and then flattens more gradually. It is usually a good choice if there is a clear nugget and sill, but only a gradual approach to the range.

The *Gaussian model* is a transition model often used to model extremely continuous phenomena. The equation of this model is:

$$\gamma_g(h) = c_o + c_1 \left\{ 1 - e^{\left(\frac{-3h^2}{a^2}\right)} \right\} \quad (3.4-10)$$

As in the exponential model, the Gaussian model reaches the sill asymptotically and the parameter a is defined as the practical range or distance at which the variogram value is 95% of the sill. However, its parabolic behaviour near the origin distinguishes it from the exponential model. Samples close to the location of interpolation produce smaller semivariances in the Gaussian model than in the other models. The Gaussian model is indicative of very continuous phenomena so this estimation procedure makes much more use of the closest samples. If a sample falls between a particular sample and the point being estimated, the particular sample will be "screened", resulting in negative stochastic weights. A model with a parabolic behaviour near the origin will cause the screen effect to be much more pronounced. Variogram models with parabolic behaviour near the origin are avoided in practice since the negative weights they may produce tend to make the estimation very erratic.

The *Combination model* is the fourth implemented model. It is a weighted combination of the spherical, exponential and Gaussian model.

$$\gamma(h) = \omega_1 \gamma_s(h) + \omega_2 \gamma_e(h) + \omega_3 \gamma_g(h) \quad (3.4-11)$$

where ω_1 , ω_2 and ω_3 are the weights assigned to each model. Near the origin, the combination model is almost equal to the spherical model, although it flattens earlier than this method.

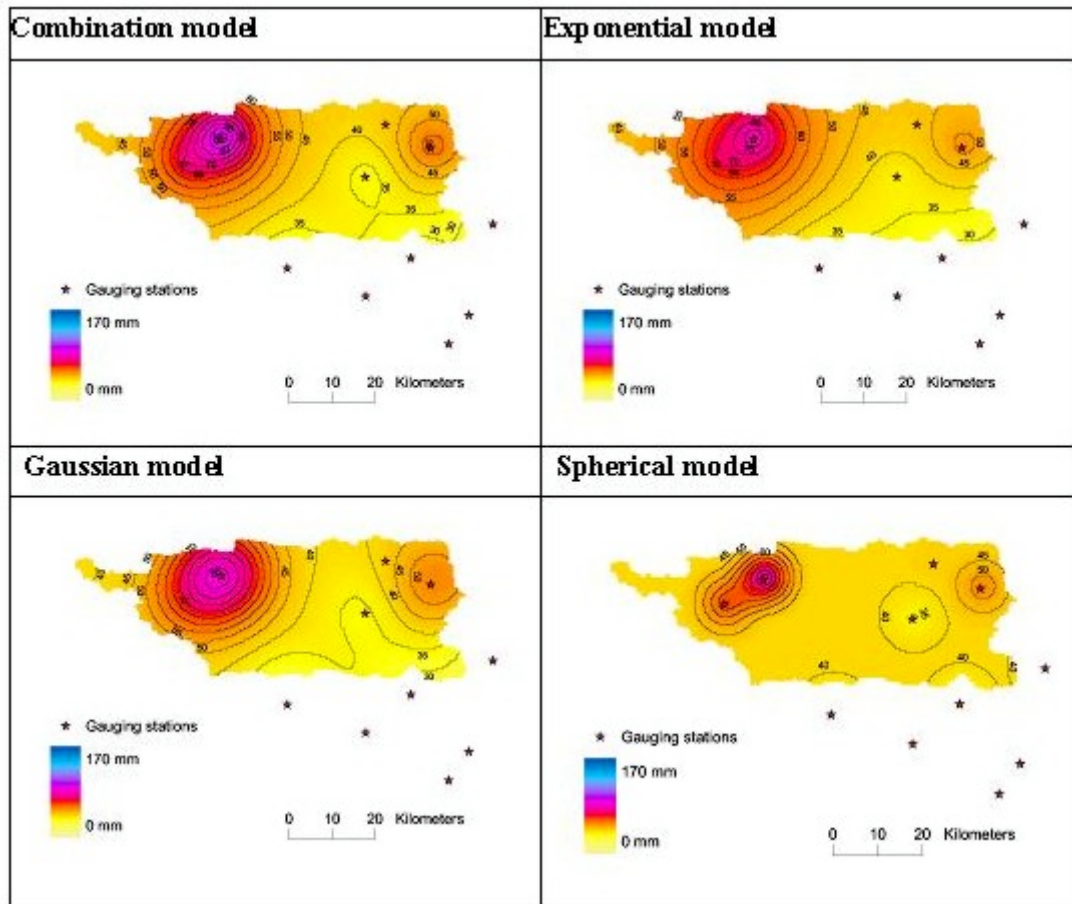


Figure 3.4-3: Resulting map of precipitation interpolation from the 14th May 1990 depicted for a visual comparison of the influence of each variogram model. Data from the Daning River (Sonderegger, 2004).

C.4 Ordinary Kriging (OK)

Ordinary kriging is often associated with the acronym BLUE for "Best Linear Unbiased Estimator". The estimates of ordinary kriging are weighted linear combinations of the available data, thus it is: "linear"; "unbiased", since it attempts to force the mean residual or error equal to 0; and "best" since it aims to minimise the variance of errors, which distinguishes ordinary kriging from most other interpolation methods. To accomplish an estimation error of zero, which leads to the unbiased nature of the interpolation, the weights λ_i for interpolation (according to the IDW interpolation, but using semivariances rather than distances) must sum to one.

$$\hat{z}(x_0) = \sum_{i=1}^n \lambda_i \cdot z(x_i) \tag{3.4-12}$$

with $\sum_{i=1}^n \lambda_i = 1$

$\hat{z}(x_0)$ is the estimated value at location x_0 and $z(x_i)$ are the measured values of the points considered for the estimated value. The prediction error, minimum variance of $[\hat{z}(x_0) - z(x_0)]$ or "Kriging variance" is given by

$$\hat{\sigma}_e^2 = \sum_{i=1}^n \lambda_i \gamma(x_i, x_0) + \phi \tag{3.4-13}$$

and is obtained by

$$\sum_{i=1}^n \lambda_i \gamma(x_i, x_j) + \phi = \gamma(x_j, x_0) \quad \text{for all } j \tag{3.4-14}$$

where ϕ is the lagrangian multiplier. The number of points needed to estimate a location (j) varies with the local density and arrangement of control and the continuity of the regionalised variable.

For the prediction of $\hat{z}(x_0)$, the variogram model with its parameters first has to be chosen. Then, the weights for interpolation must be calculated following Equation 3.1-15:

$$A^{-1} \cdot b = \begin{bmatrix} \lambda \\ \phi \end{bmatrix} \quad (3.4-15)$$

b is a vector containing the semivariances between the point to estimate and each data point included for estimation of the attribute value of that point. The matrix A contains the semivariances of all data point pairs and λ is the weight vector to be derived.

To find the values of matrix A and vector b , a distance h between the point pairs, for which the semivariances have to be calculated, must be computed and inserted into the variogram model equation. To perform detrended Ordinary Kriging, it is first checked whether precipitation was registered at any station during the time step to be interpolated. If the first condition is fulfilled, an EDR is conducted. The variance correlation rate (R^2) for the EDR has to exceed a minimum correlation rate (e.g. 0.3) for an elevation dependency to be accepted. By accepting the elevation dependency, the residuals of the regression are interpolated using OK. Otherwise, an OK interpolation without the EDR, thus without a trend, is conducted. By acceptance of the elevation dependency, the EDR map is superposed to the interpolated OK map resulting in the detrended OK map.

C.5 Simple Kriging

Simple Kriging (SK) is based on three assumptions:

1. Observations are a partial realisation of a random function $Z(\bar{x})$
2. The realisation is second order stationary (mean, spatial covariance and semivariance are independent of \bar{x})
3. The mean m is known.

This are the same conditions as for OK except that the third condition is more restrictive; in OK, the mean only has to be stationary.

The kriging estimator $\hat{Z}(\bar{x}_0)$ is a weighted average of k values at control points $\hat{Z}(\bar{x})$ inside a neighbourhood around the location $\hat{Z}(\bar{x})$ where the estimate is to be made. The SK estimate, which can be derived from the OK estimate, is defined as:

$$\hat{Z}(\bar{x}_0) = m + \sum_{i=1}^k \lambda_i [Z(\bar{x}_i) - m] \quad (3.4-16)$$

The weights λ_i have to be estimated with the requirement that they must result in estimates $\hat{Z}(\bar{x}_0)$ having minimum variance of the errors $\hat{Z}(\bar{x}_0) - Z(\bar{x})$.

Simple kriging should not be used for the estimation of precipitation because of the violation of the third condition, the known mean. The precipitation mean of the gauging stations is an estimate of the mean of the measurements and not a known parameter of the distribution.

D. Detrended Inverse Distance Weighting (DTIDW) and Detrended Kriging (DTKRI)

The residuals (difference between interpolated and observed values for the considered meteorological stations) of the EDR-method can be spatially interpolated with the Inverse Distance Weighting (IDW^{RES}) and/or Kriging (KRI^{RES}) technique. Thus, a map of residuals is obtained. Through the addition of the map interpolated by regression and residuals map, the bias derived by the Elevation Dependent Regression method at the observation points can be accounted and corrected:

$$DTIDW_{(x,y)} = EDR_{(x,y)} + IDW_{(x,y)}^{RES} \tag{3.4-17}$$

or $DTKRI_{(x,y)} = EDR_{(x,y)} + KRI_{(x,y)}^{RES}$

This procedure is called detrended interpolation. The idea of the procedure is to separate the sources of variability into a vertical (elevation) component and a horizontal (spatial) component (Garen and Marks, 2001; Susong et al., 1999).

E. Laps Rate IDW (LIDW) and Laps Rate Kriging (LKRI)

From the Laps Rate Method, the temperature data at the stations are transformed applying a constant trend $dT dh^{-1}$ (about $-0.007 K m^{-1}$). Data are reduced to sea level values. The new data are then spatially interpolated by IDW or Kriging and are then reprojected at the elevation of the grid points by using the same laps rate $dT dh^{-1}$.

$$LAPS_i = T_i + dT/dh \cdot (0 - H_i)$$

$$LIDW_{(x,y)} = IDW_{(x,y)}^{LAPS} + dT/dh \cdot DHM_{(x,y)} \tag{3.4-18}$$

or $LKRI_{(x,y)} = KRI_{(x,y)}^{LAPS} + dT/dh \cdot DHM_{(x,y)}$

To adopt these interpolation methods, it is imperative to know the northing and easting (y and x co-ordinates) and the elevation (H_i) of all available meteorological stations. A reliable digital elevation model (DHM) of the investigated domain is also essential.

3.5.1 Meteorological zones

The spatially interpolated meteorological information required for driving PREVAH is averaged for so called meteorological sub-units.

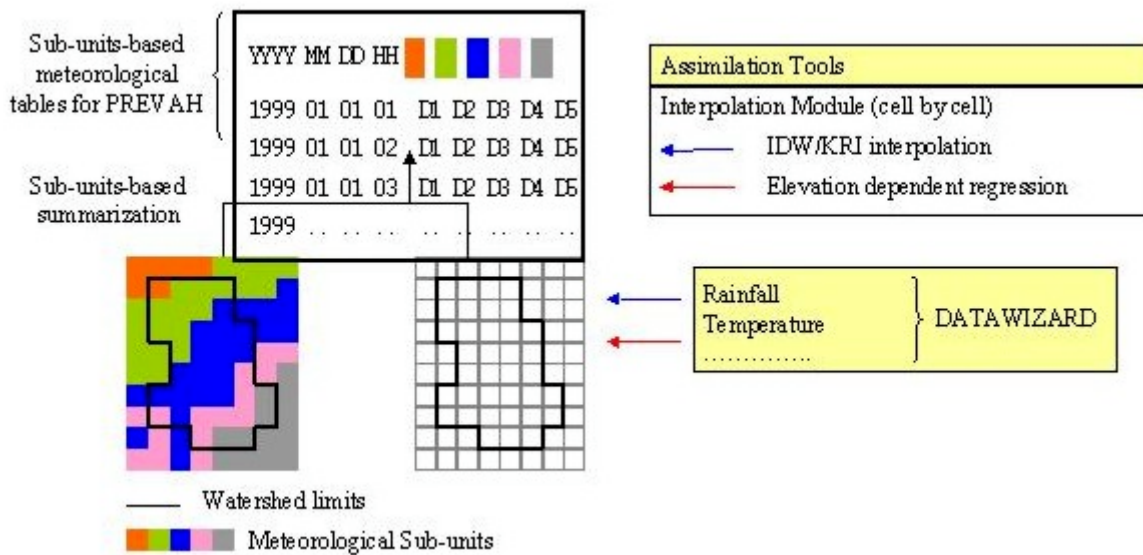


Figure 3.5-1: Assimilation of meteorological information for PREVAH using the interpolation module dtidw.exe.

Output tables for PREVAH:

Figure 3.5-1 shows the concept of averaging the interpolated meteorological fields for so called *meteorological sub-units*. Meteorological sub-units can be defined through WINHRU (see separate documentation).

A table is written for each year and variable.

We recommend the following rules for the definition of meteorological zones:

Watershed Area	First GRID	Second GRID
< 100 km ²	Elevation Zones	None
100 km ² < 300 km ²	1 st Order Streams	Elevation Zones
300 km ² < 1000 km ²	2 nd Order Streams	Elevation Zones
≥ 3000 km ²	4 th Order Streams	Elevation Zones

The meteorological file for PREVAH is formatted as follows:

Meteorological file for PREVAH																				
YYYY	MM	DD	HH	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	0
2000	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	2	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.21	0.22	0.23	0.24	0.17
2000	1	1	3	0.02	0.03	0.05	0.07	0.08	0.10	0.12	0.14	0.16	0.17	0.19	0.21	0.23	0.25	0.26	0.28	0.14
2000	1	1	4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2000	1	1	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	1	20	0.08	0.08	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.15
2000	1	1	21	0.29	0.28	0.27	0.27	0.26	0.24	0.22	0.21	0.20	0.18	0.17	0.16	0.15	0.13	0.11	0.11	0.21
2000	1	1	22	0.49	0.49	0.51	0.52	0.51	0.50	0.50	0.49	0.49	0.49	0.49	0.49	0.50	0.49	0.48	0.49	0.50
2000	1	1	23	0.14	0.17	0.22	0.26	0.31	0.35	0.40	0.44	0.49	0.53	0.58	0.62	0.67	0.71	0.76	0.79	0.46
2000	1	1	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1	2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

First header: Title

Second header: YYYY_MM_DD HH followed by the ID of the meteorological sub-unit found in the defined GRID. The last ID ("0") is the average for the entire catchment.

Third header: YYYY_MM_DD HH followed by the relative portion of each meteorological zone.

Precipitation correction and adjustment

After interpolation of the meteorological variables, PREVAH offers a gauge error correction and water balance adjustment for the precipitation data.

Firstly, a gauge error correction may be applied to the interpolated precipitation data. It is calculated for snow and rain separately, using the interpolated wind speed:

$$\begin{aligned}
 PR_{korr} &= PR_{akt} \cdot [1 + 0.07 \cdot \ln(v_W + 1)] \\
 PS_{korr} &= PS_{akt} \cdot [1 + 0.20 \cdot \ln(v_W + 1)]
 \end{aligned}
 \tag{3.5-1}$$

with PR_{akt} , PS_{akt} gauged amount of snow or rain [mm h⁻¹]
 PR_{korr} , PS_{korr} corrected amount of snow or rain [mm h⁻¹]
 v_W wind speed [m s⁻¹]

Regional differences in the gauging conditions are considered with the help of wind speed and the distinction of the fluid and solid phase of precipitation. Therefore, further spatial differentiation of the correction is not necessary. Figure 3.5-2 shows the correction factors calculated with Equation 3.5-1 and compares it to the approach of Schulla and Jasper (2000) which is used in WaSiM. While Schulla and Jasper also use wind speed, the approach presented here has the advantage that it does not produce unreasonably high correction factors for high wind speeds.

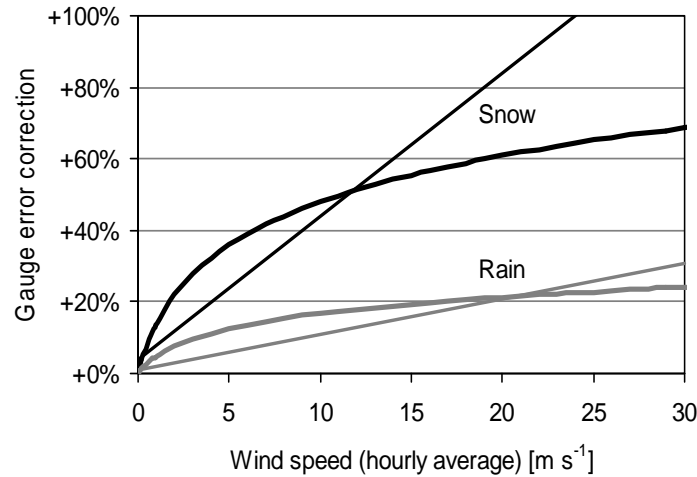


Figure 3.5-2: Wind-dependent gauge error correction for rain and snow as introduced in PREVAH (thick line) compared to correction by Schulla and Jasper (2000) (thin line).

In addition to the gauge error correction, PREVAH also implements a water balance adjustment which can be tuned with the help of two free model parameters (Gurtz et al., 1997a; Pos, 2001):

$$\begin{aligned} P_{Rain} &= P \cdot (1 - p_{Snow}) \cdot (1 + PKOR) \\ P_{Snow} &= P \cdot p_{Snow} \cdot (1 + SNOKOR) \end{aligned} \quad (3.5-2)$$

P is the precipitation value obtained from a meteorological tower or provided by the interpolation module of the PREVAH modelling system. P_{Rain} is the adjusted rainfall, P_{Snow} is the adjusted snowfall, p_{Snow} is the snow fraction. $PKOR$ and $SNOKOR$ are two catchment specific tunable parameters for rainfall and snowfall, respectively. Both parameters have to be determined during the calibration period. This allows for the minimisation of the differences between observed and computed runoff rates and compensates for errors in the measurement, assimilation, representativeness and interpolation of precipitation data (Sevruk, 1986). The parameters also indirectly compensate for errors in the estimation of evapotranspiration and snow evaporation. $PKOR$ and $SNOKOR$ can also be provided as monthly values (Gurtz et al., 2003).

3.5.2 Topography dependent adjustment of radiation and temperature

Calculation of sun co-ordinates, sunset and sunrise, radiation correction

The impacts of topography on radiation and air temperature are considered using the scheme after Oke (1987) (Figure 3.5-3).

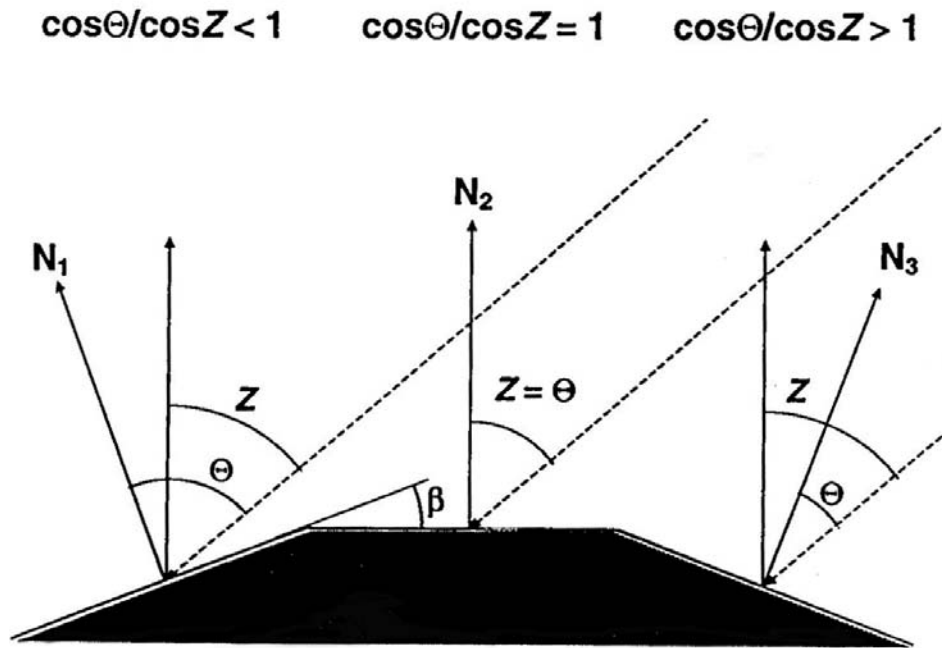


Figure 3.5-3: Schematic representation of topography dependent adjustment of radiation and temperature.

The symbols:

- ϕ geographical latitude (positive north, negative south)
- δ declination of the sun (angle between sun and equatorial plane of the earth)
- Z zenith angle (angle between direction of the sun and local zenith)
- h_s hour angle
- Ω_s azimuth angle (angle between projection of the direction to the sun and north)
- t_J Julian day (1st of January = 1, 31st of December = 365)
- t true local sun time (from average sun time corrected using: Jan: -3.2, Feb: -13.6, Mar: -2.6, Apr: -4.2, May: +2.8, Jun: +2.5, Jul: -3.5, Aug: -6.3, Sep: -0.3, Oct: +10.0, Nov: +16.4, Dec: +11.3 min)
- Θ_s incidence angle between the normal to the local slope and the direction of the sun
- β_i local slope angle
- $\hat{\beta}$ height of the sun above the horizon (as an angle)
- \hat{Q} azimuth angle of the local slope (aspect, clockwise from north, i.e. 0 to 359)

The equations for calculating zenith and azimuth angles are given by:

$$\cos Z = \sin \phi \sin \delta + \cos \phi \cos \delta \cosh_s = \sin \beta_i \quad (3.5-3)$$

$$\cos \Omega_s = (\sin \delta \cos \phi - \cos \delta \sin \phi \cosh_s) / \sin Z \quad (3.5-4)$$

$$\delta = -23.4 \cdot \cos[360(t_J + 10)/365] \quad (3.5-5)$$

$$h_s = 15(12 - t) [^\circ] \quad (3.5-6)$$

$$\text{with } \begin{array}{ll} \Omega_s = \arccos(\cos \Omega) & (t < 12, h_s > 0) \\ \Omega_s = 360^\circ - \arccos(\cos \Omega) & (t > 12, h_s < 0) \\ \Omega_s = 180^\circ & (t = 12, h_s = 0) \end{array}$$

The relations for calculating sunrise and sunset for use within the evaporation routine are given by:

$$\cos h_s = \frac{\sin \phi \sin \delta}{\cos \phi \cos \delta} \rightarrow h_{sr} = \frac{12}{\pi} \cdot \arccos(\cos h_s) = \frac{12}{\pi} \cdot h_s \text{ and } h_{ss} = 24 - h_{sr} \quad (3.5-7)$$

with h_{ss} time of sunset [h]
 h_{sr} time of sunrise [h]

The incoming clear sky direct short-wave radiation I_{max} on a plain perpendicular to the direction of the sun is estimated using an approach for the atmospheric extinction given by Oke (1987):

$$I_{max} = I_{tof} \cdot \psi_a^{\frac{p/p_0}{\cos Z}} \quad [\text{W m}^{-2}] \quad (3.5-8)$$

with I_{tof} incoming short-wave radiation at the top of atmosphere [W m^{-2}]
(solar constant $\approx 1368 \text{ W m}^{-2}$)
 p air pressure at the place of interest [hPa]
 p_0 air pressure at sea level ($\approx 1013 \text{ hPa}$)
 ψ_a transmissivity of the atmosphere [-]

A horizontal plane will then have a normal irradiation I_{norm} given by:

$$I_{norm} = I_{max} \cdot \cos Z \quad (3.5-9)$$

This type of irradiation estimation is also used in the evaporation module if no sunshine duration data is available.

The angle between the direction to the sun and the normal to a given grid cell (the incidence angle $\hat{\theta}$) and, hence, the correction factor for the direct irradiation is given by:

$$\cos \hat{\theta} = \cos \beta_t \cdot \cos Z + \sin \beta_t \cdot \sin Z \cdot \cos(\Omega_s - \hat{\Omega}) \quad (3.5-10)$$

For a horizontal plane, the correction is then given by:

$$I_{korr} = I_{norm} \cdot \frac{\cos \hat{\theta}}{\cos Z} \quad (3.5-11)$$

This correction factor can only be applied with the following restrictions:

- The sun has to be over the horizon
- The elevation angle of the sun should be greater than 12° , since smaller angles result in the optical density of the atmosphere decreasing too quickly (exponent in Equation 3.5-8); if the sun is less than 12° above the horizon, the correction factor is limited to ± 5
- The considered grid cell must not be in the shadow of another cell and $\hat{\theta} < 90^\circ$ must apply
- The relative sunshine duration has to exceed 0.1, otherwise only diffuse radiation is assumed which will not be corrected

If the model time-step is too large for a reasonable radiation correction (e.g., when using daily time steps), the time step is subdivided into sub-steps. Then, a radiation correction is carried out for each of these sub-steps. The effective correction factor for an entire time interval (time step) is then found as the weighted average of all sub-time-step correction factors. The weights for each sub-step are calculated as the respective normal irradiation divided by the sum of the normal irradiation of all sub-steps within the interval.

$$f_d = \frac{\sum_{i=1}^n \frac{\cos \hat{\theta}_i}{\cos Z_i} I_{norm,i}}{\sum_{i=1}^n I_{norm,i}} \quad (3.5-12)$$

with f_d average correction factor for a day [-]
 i sub-time-step index $1 \dots n$

The correction of the interpolated global radiation itself (as opposed to the calculation of the correction factor) is completed within the evaporation calculation scheme by:

$$RG_{eff} = RG \cdot \left(1 + (1 - cr_0) \cdot SSD \cdot \left[\frac{\cos \hat{\theta}}{\cos Z} - 1 \right] \right) \quad (3.5-13)$$

with RG_{eff} effective (corrected) global radiation [Wh m^{-2}]
 cr_0 empirical factor for consideration of diffuse short-wave radiation (for the Thur-basin around 0.23, see Schulla, 1997)
 SSD relative sunshine duration (interpolated, without (!) impacts of topographic shadowing)

Besides the correction of radiation, the azimuth angle Ω_s and the zenith angle Z are used for the analysis of shadowing of cells by other cells.

Modification of temperature

Using the radiation correction term of Equation 3.5-13, it is also possible to modify the air temperature. The parameters needed for this purpose are sunshine duration and an empirical parameter c_t :

$$\begin{aligned} T_{corr} &= T_{meas} + c_t \cdot SSD \cdot \ln \frac{\cos \hat{\theta}}{\cos Z} & \text{if} & \quad 0.2 \leq \cos \hat{\theta} \cdot (\cos Z)^{-1} \leq 5.0 \\ T_{corr} &= T_{meas} + c_t \cdot SSD \cdot 1.609 & \text{if} & \quad \cos \hat{\theta} \cdot (\cos Z)^{-1} > 5.0 \\ T_{corr} &= T_{meas} - c_t \cdot SSD \cdot 1.609 & \text{if} & \quad \cos \hat{\theta} \cdot (\cos Z)^{-1} < 0.2 \end{aligned} \quad (3.5-14)$$

Using sunshine duration accounts for the radiation correction factor being valid for clear sky conditions only. On the other hand, differences between cells with varying aspect will become smaller with higher cloudiness (i.e. shorter sunshine duration). If the sky is fully clouded, no temperature modification is completed. The value of c_t should be calibrated or taken from well-established temperature measurements on plots with varying aspect. Usually, c_t should be less than 5 K.

4. Theoretical basis of PREVAH

4.1 General notes on modelling hydrological processes and systems

A model is a simplified representation of a real system, the corresponding simulation is a, more or less, accurate representation of a number of processes which run in a model. A model can be characterised as follows:

- Representation characteristics: Models as a representation of a natural system can show different grades of adaptation to this system, depending on the stage of system research and the necessity and possibility of a complete representation.
- Shortening and simplification characteristics: Models only include the parts of a natural system which are relevant to the solution of a given problem. Therefore, the model structure is strongly influenced by the goal of the modelling.
- Subject characteristics: The representations of processes are only valid for a defined subject and are limited to certain operations during a given time period.

To model a river stream system, the following hydrological processes need to be represented with more or less accuracy, depending on the goal of the model:

Atmosphere:

- Correct spatial and temporal estimation of the actual precipitation and other meteorological input variables
- Acquisition of input data necessary to calculate evapotranspiration
- Separation of precipitation into rain and snow
- Correct estimation of snowmelt and icemelt

Land surface: The interception storage, which is provided by the vegetation, needs to be modelled as the first influencing factor. The fraction of precipitation which exceeds this storage reaches the soil surface. Depending on the characteristic catchment area and the moisture-state of the area, this fraction can be assigned to:

- Direct infiltration into the soil
- More or less delayed runoff to the stream network
- Temporary storage on the land surface (swale storage)
- Delayed infiltration into the soil
- Evaporation from the land surface

Ventilated soil zone: The part of the precipitation that infiltrates directly or is delayed to the soil can:

- Flow directly below the soil surface (through the top soil layer) to a river channel (direct or quick interflow)
- Be delayed through the top soil layer to a river channel (delayed interflow)
- Be stored for a shorter or longer time in the ventilated soil zone
- Percolate in the groundwater zone (following gravity)
- Be taken out from the soil through evapotranspiration

Groundwater zone: The water which reaches the groundwater zone can:

- Runoff more or less delayed to the stream network (baseflow)
- Be stored for a longer time in the groundwater zone
- Return to the ventilated soil zone through capillary rise
- Percolate to deep, inactive soil zones
- Be transpired through plants, which feed on groundwater
- Be extracted by humans for various purposes

Stream network: The land surface runoff including glacier runoff, direct or delayed interflow, runoff from groundwater and precipitation that falls directly on the water surface flows through the river bed to the runoff profile of the catchment, whereby the water is temporally stored in the river bed, depending on the river bed characteristics and water level. Through this, the temporal distribution of the runoff as well as the hydrograph is changed.

Additionally, the following can be considered in a model:

- Regulated and non-regulated storage systems
- Dam influences
- Spacious irrigation and drainage
- External in- and outflow to ground and surface water
- Influence of karsts
- Runoff lags due to the utilisation of water

4.2 Interception

4.2.1 Definitions

Interception of precipitation, often called canopy storage in forested environments, plays an important role in calculating water balances (hydrology) and energy budgets (boundary layer climatology). With leaves and woody structures, vegetation modifies the intensity and distribution of precipitation falling through. Interception is technically defined as the plant canopy capturing precipitation and subsequently returning it to the atmosphere through evaporation or sublimation and is the most obvious effect plants have on falling precipitation (Figure 4.2-1). Interception is usually determined by subtracting throughfall from total precipitation input (Gash et al., 1980).

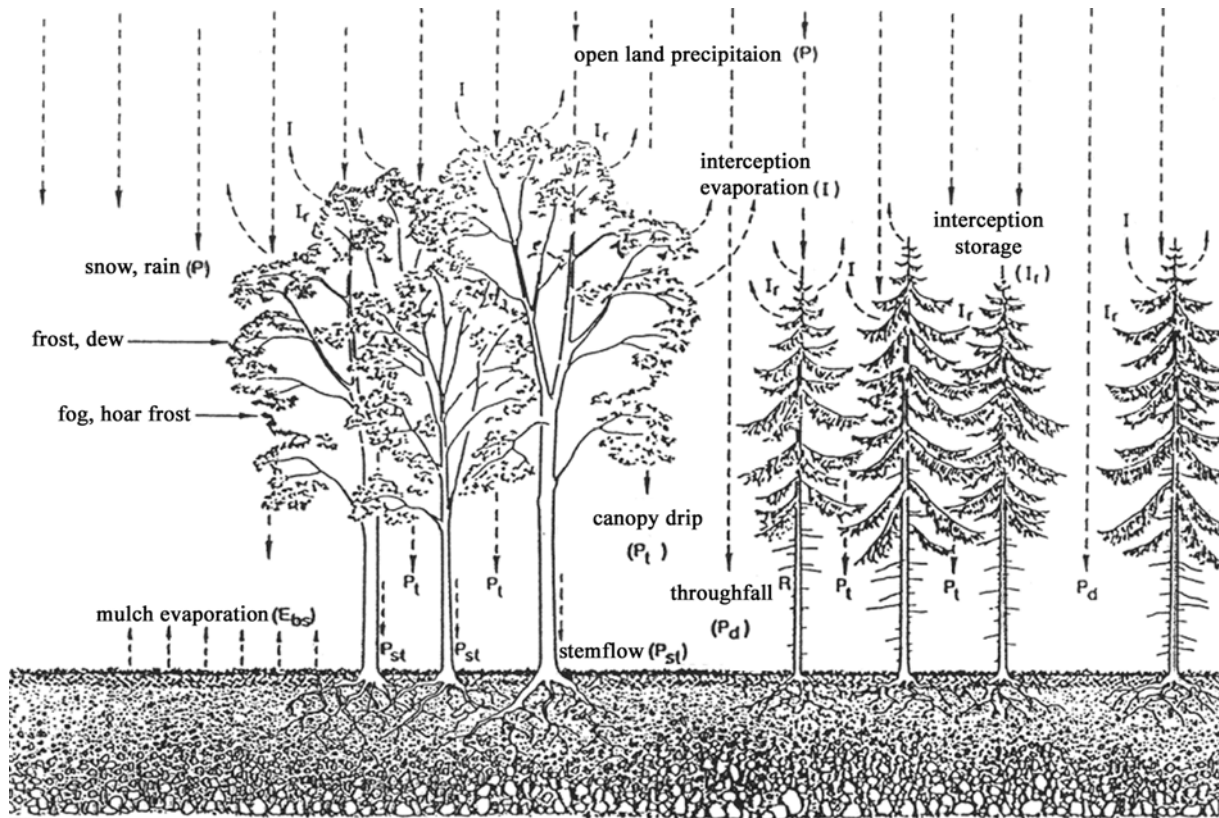


Figure 4.2-1: Schematic of interception for vegetation covered land surface.

The balanced equation from Figure 4.2-1 is

$$P_b = P_d + P_t + P_{St} = P - EI - \Delta SI \text{ [mm]} \quad (4.2-1)$$

where P_d is the throughfall, P_t the canopy drip, P_{St} the stemflow, P the open land precipitation, EI the interception evaporation and ΔSI the interception storage change. Vegetation can intercept up to 50 % of the rain that falls on its leaves. The leaves of deciduous trees commonly intercept 20 to 30 % of the falling rain. Water dripping off the leaves to the ground surface is technically called leaf or canopy drip.

4.2.2 PREVAH's interception module

The interception model implemented in PREVAH considers variations in interception storage capacity as a function of the vegetation type. Evaporation of intercepted water occurs from vegetated surfaces at the potential rate as long as the reservoir contains sufficient humidity. The surface depression storage capacity of rocky soils and urban areas is also defined for the calculation of direct evaporation.

To conceptualise the process of canopy interception, a simple bucket approach is used. A maximal interception storage capacity SI_{MAX} [mm] is assigned to each class of vegetation and may be set to vary monthly (Gurtz et al., 1997a). The filling of the interception storage SI [mm] is computed as proposed by Menzel (1997) using the actual storage content SI_A :

$$SI(t) = SI_A(t - \Delta t) + (SI_{MAX} - SI_A(t - \Delta t)) \cdot (1 - e^{-cPI(t)}) \text{ [mm]} \quad (4.2-2a)$$

$$c = SI_{MAX}^{-1} \text{ [mm}^{-1}] \quad (4.2-2b)$$

where t is the computation time, ΔT is the calculation time step and PI is the intensity of precipitation [mm] for the current time step. The consumption or emptying of SI occurs through interception evaporation:

$$SI_E = SI(t) - EI_{\Delta t} \quad (4.2-3)$$

The interception evaporation EI depends on the interception storage filling state SI , potential interception evaporation intensity ETP_{SI} and degree of vegetation coverage VBG . During the time period ΔT , it is calculated in the following way:

$$\begin{aligned} EI_{\Delta T} &= ETP_{SI} \cdot \Delta T \cdot VBG && \text{if } (ETP_{SI} \cdot \Delta T \cdot VBG) \leq SI(t) \\ EI_{\Delta T} &= SI && \text{if } (ETP_{SI} \cdot \Delta T \cdot VBG) > SI(t) \\ EI_{\Delta T} &= 0 && \text{if } SI(t) = 0 \end{aligned} \quad (4.2-4)$$

using: SI_A = interception storage at the beginning of the time interval [mm]
 SI_E = interception storage at the end of the time interval [mm]
 SI_{max} = interception storage capacity [mm]
 PI = precipitation intensity during the time interval [mm h^{-1}]
 ΔT = time interval [h]
 VBG = vegetation cover grade ($0 \leq VBG \leq 1$)
 ETP_{SI} = potential interception evaporation [mm h^{-1}]. It is assumed that ETP_{SI} is equal to the calculated potential evapotranspiration ETP .

4.3 Snow and glacier melt

4.3.1 Snow accumulation

The process of snow accumulation and distribution, which involves a variety of meteorological and topographical interactions in a basin during the winter accumulation period, is much more complex than a rain-only situation, since temperature and elevation play a prominent role in determining whether precipitation falls as rain or snow.

In the middle latitudes, precipitation usually falls as a result of the colloidal instability of a mixed water-ice cloud at temperatures below 0°C . Winter precipitation begins as snow crystals in subfreezing portions of clouds. As the snowflakes fall through the atmosphere, they later melt into raindrops when falling through warmer air at lower elevations. The melting-level air temperature for snowflakes falling through the atmosphere varies from 0 to 4°C , but it is usually about 1 – 2°C . On the Earth's surface, accordingly, snow falls at elevations above the melting level temperature, while rain falls at elevations below the melting level temperature.

For modelling, the separation between snow and rain is realised as follows: the type of precipitation is estimated for each grid cell using the interpolated air temperature in the given time step. If the interpolated air temperature at 2 meters height T_a [$^\circ\text{C}$] is lower than a calibrated threshold temperature T_{GR} , the phase of precipitation is solid. Otherwise, the phase of precipitation is liquid. A transition parameter (T_{TRANS}) defines the air temperature range where the phase of precipitation is considered a mixture of rain and snow. The snow fraction (p_{snow}) is given by (cf. Figure 4.3-1):

$$p_{Snow} = \frac{T_{R/S} + T_{trans} - T}{2 \cdot T_{trans}} \text{ for } (T_{R/S} - T_{trans}) < T < (T_{R/S} + T_{trans}) \quad (4.3-1)$$

with p_{snow} fraction of snow to the total precipitation (0..1)
 T air temperature [$^\circ\text{C}$]
 $T_{R/S}$ temperature at which 50 % of precipitation is falling as snow [$^\circ\text{C}$]
 T_{trans} half of the temperature-transition range from snow to rain [$^\circ\text{C}$]

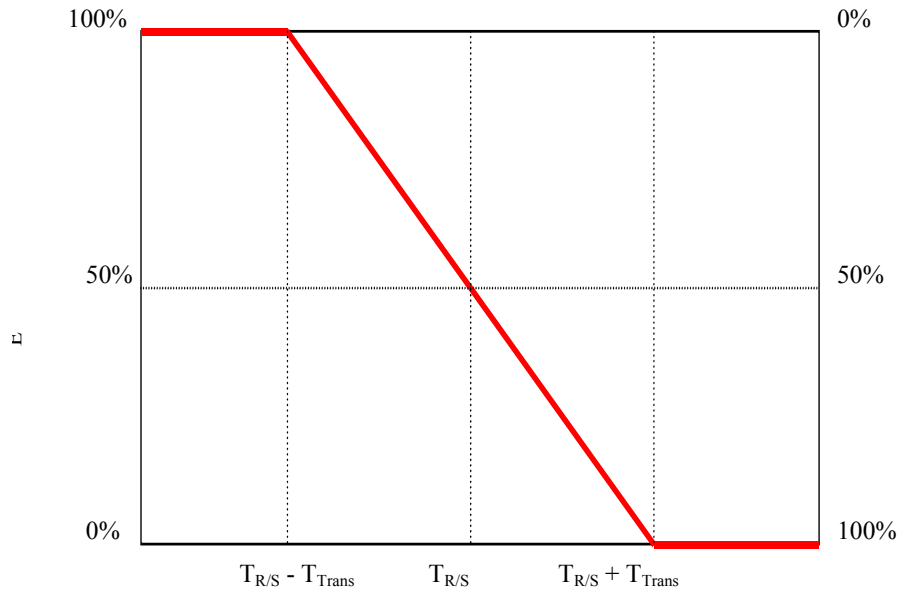


Figure 4.3-1: Separation of precipitation into snow and/or rain depending on temperature.

4.3.2 Snow melt

For the calculation of processes of snow melt, different approaches of different complexity can be used in the PREVAH model.

The Positive Degree-Day Index (PDDI): This classical temperature-index method (Hock, 2003) requires only the availability of interpolated temperature data. If T is below a threshold temperature for snowmelt (T_0), then the melt rate (M) is zero. If T exceeds T_0 , then the melt rate is calculated. The temperature dependent melt factor (c_0) can be defined by a sinus shaped function of the threshold values between the annual maximum (set for June 21st) and minimum values (December 21st). In this differentiation, the seasonal variation of the solar radiation is taken into account (Braun, 1985).

$$M = c_0 \cdot (T - T_0) \cdot \frac{\Delta t}{24} \text{ for } T > T_0, \text{ else } M = 0 \quad (4.3-2)$$

with M melting rate [$\text{mm } \Delta t^{-1}$]
 c_0 temperature dependent melt factor [$\text{mm } ^\circ\text{C}^{-1} \text{ d}^{-1}$]
 T air temperature, using modification after Equation (4.3-1) [$^\circ\text{C}$]
 T_0 temperature at the beginning of snowmelt [$^\circ\text{C}$]
 Δt time step [h]

The temperature-wind-index-approach additionally takes a wind dependent melt factor and the wind speed into account:

$$M = (c_1 + c_2 \cdot u) \cdot (T - T_0) \cdot \frac{\Delta t}{24} \text{ for } T > T_{0,m}, \text{ else } M = 0 \quad (4.3-3)$$

with M melt rate [$\text{mm } \text{DT}^{-1}$]
 c_1 temperature dependent melt factor [$\text{mm } ^\circ\text{C}^{-1} \text{ d}^{-1}$]
 c_2 wind dependent melt factor [$\text{mm } (^\circ\text{C m s}^{-1} \text{ d}^{-1})^{-1}$]
 u wind speed [m s^{-1}]
 T air temperature, using modifications after Equation (4.3-1)
 T_0 threshold temperature at the beginning of snow melt [$^\circ\text{C}$]
 Δt time step [h]

The Combination approach (COMB): Anderson (1973) extended the PDDI method to introduce a combination of radiation melt for dry periods and advection melt for wet days. Radiation melt occurs when the melt is dominated by radiation energy. This occurs when the precipitation is less than the threshold intensity. In this case, snowmelt is calculated using Equation (4.3-2). Advection melt occurs when rainfall exceeds the threshold intensity. In this case, a simple empirical parameterisation of the energy balance, Equations (4.3-4 and 4.3-5), is applied for the computation of snowmelt (Braun, 1985). The total snowmelt M is the sum of the melt rates given by long wave radiation (M_R), sensible heat flux (M_S), latent heat flux (M_L) and precipitation (M_P). Melt is calculated only at air temperatures above the threshold temperature T_0 . For time steps with precipitation ($P \geq 2 \text{ mm d}^{-1}$), melt is composed of radiation melt, melt from sensible heat, melt from latent heat, and melt from energy import from precipitation:

$$M = (M_R + M_S + M_E + M_P) \cdot \frac{\Delta t}{24} \quad (4.3-4)$$

with M_R radiation melt [mm]
 M_S melt by sensible heat [mm]
 M_E melt by latent heat [mm]
 M_P melt by import of energy by precipitation [mm]
 Δt time step [h]

The melt fractions in Equation (4.3-4) are parameterised by:

$$\begin{aligned} M_R &= 1.2 \cdot T \\ M_S &= (c_1 + c_2 \cdot u) \cdot (T - T_0) \\ M_E &= (c_1 + c_2 \cdot u) \cdot (e_s - 6.11) / \gamma \\ M_P &= 0.0125 \cdot P \cdot T \end{aligned} \quad (4.3-5)$$

with T air temperature [$^{\circ}\text{C}$]
 T_0 threshold temperature for melt [$^{\circ}\text{C}$]
 c_1 temperature dependent melt factor [$\text{mm } (^{\circ}\text{C d})^{-1}$]
 c_2 wind dependent melt factor [$\text{mm } (^{\circ}\text{C m s}^{-1} \text{ d})^{-1}$]
 u wind speed [m s^{-1}]
 γ psychrometric constant [hPa K^{-1}]
 e_s saturation vapour pressure at air temperature T [hPa]
 (extended approach after Braun, 1985: observed vapour pressure e)
 P precipitation [mm]

Storage and refreezing of liquid water in snow cover

The water equivalent of snow cover SSO is subdivided into a snow and water fraction. A coefficient CWL is used to control the maximum capacity of water storage as a fraction of the total storage (usually around 10 % of the water equivalent). The effective melt is the amount of water exceeding the water holding capacity, where rain and melt are superposed prior to this calculation. The capillary forces of snow cover can hold and store fluid water against gravity. This occurs if rain falls onto snow and infiltrates, or in the case of a positive radiation balance and positive heat flux, which causes melting in the snow cover. The maximal water storage capacity of snow is described by:

$$SLIQ_{\max} = CWL \cdot SSO \quad (4.3-6)$$

using: $SLIQ_{\max}$ maximum amount of fluid water which can be held against gravity [mm]
 CWL water storage ability [as a decimal, e.g. 0.1]
 SSO snow cover [mm water equivalent]

As long as the water storage capacity of snow is not reached, the melting water and rain, respectively, are restrained by the snow cover.

If the storage for the liquid fraction is not emptied at the beginning of a time step, it is required to calculate a refreezing M_{neg} in cases of temperatures below T_0 .

$$M_{neg} = c_{rfr} \cdot RMF \cdot (T - T_0) \cdot \frac{\Delta t}{24} \quad (4.3-7)$$

with M_{neg} „negative melt“ (refreezing water) [mm]
 c_{rfr} coefficient for refreezing [-]
 RMF seasonally dependent radiation melt coefficient [mm (°C d)⁻¹]
 T air temperature modified by Equation (4.3-1) [°C]
 T_0 threshold temperature for the beginning of snow melt [°C]
 Δt time step [h]

After calculating the negative melt, the storages of liquid (S_l) and solid (S_s) fractions on the water equivalent are balanced. The refrozen amount of liquid water is added to the solid fraction and subtracted from the liquid fraction (limited by the amount of water in the liquid fraction storage).

There is the possibility to use a simplified energy balance model for snow melt calculation, which was developed by Strasser et al. (2002) and referred to as ESCIMO. The one-layer snow model ESCIMO (Energy-Balance Snow Cover GIS-Integrated Model) was developed for the hydrological simulation of the Weser catchment in Northern Germany (Strasser and Mauser, 2001). It is designed as a physically-based model for the hourly simulation of the energy balance, water equivalent and melt rate of snow cover. The principle and most influential terms of the energy balance are the short and longwave radiation, and sensible and latent heat fluxes. The energy conducted by solid or liquid precipitation and a constant soil heat flux are also taken into account for the energy balance computation, even if their contribution is negligible. The snow albedo is modelled using a function considering the age and surface temperature of the snow pack (Rohrer, 1994a and 1994b). For each time step, the following scheme is adopted (Abbott et al., 1986a and 1986b): calculation of the energy balance; decision whether the precipitation is solid or liquid; estimation of the water mass and energy budget based on the hypothesis of zero snowmelt at the current time step; comparison of the total available energy of the mass sustained as snow to the total available mass at 273.16 K; calculation of the snowmelt produced by the available excess energy; and a subsequent update of the mass and energy budgets. The number of free parameters is limited to the three. These control the simulation of albedo and are the maximal albedo (ALB_{MAX}) and the parameters determining the ageing of the albedo (A_{POS} for positive and A_{NEG} for negative snow temperature). The mathematical representations of the simulated physical processes as used in ESCIMO are described in Strasser et al. (2002).

4.3.3 Glacier melt and runoff

By storing water seasonally during winter and for up to thousands of years, glaciers regulate streamflow by augmenting inputs when precipitation is low, thereby masking the variability of precipitation inputs and prolonging the melt season into summer.

Because it forms from the metamorphosis of snow, the behaviour of glacier ice deviates from other forms of ice. Melt results from influxes of solar radiation, sensible heat of air and rain, latent heat of condensation (dew and frost) and heat conducted from supraglacial debris (enhanced melt up to a threshold depth of debris; thick deposits insulate the ice).

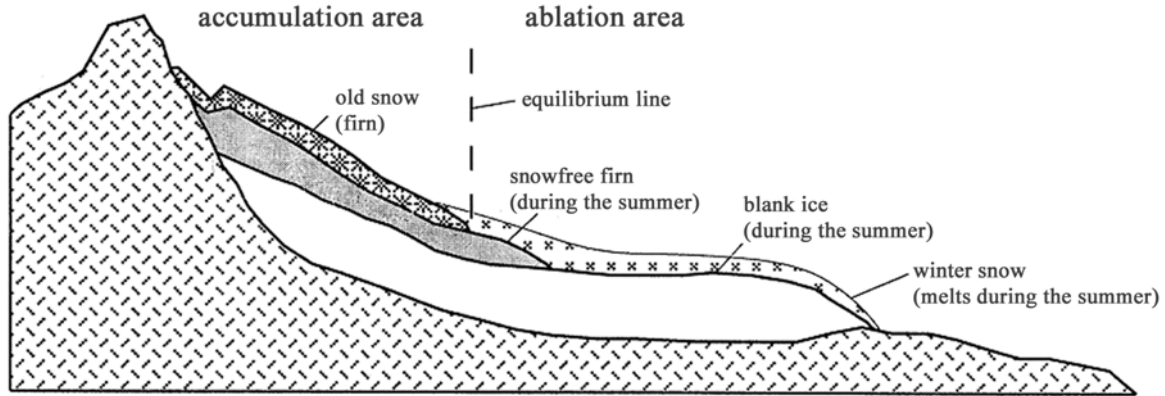


Figure 4.3-2: Longitudinal section of a glacier.

Melt of firn and ice

There are two methods for calculating glacier melt: a classical temperature index method and an extended temperature index method after Hock (1998) which includes information on the global radiation during each time step on each grid cell to modify the melt. The melt after the classical temperature index approach is calculated by:

$$M = \begin{cases} \frac{1}{n} DDF_{snow/firn/ice} \cdot (T - T_0) & : T > T_0 \\ 0 & : T \leq T_0 \end{cases} \quad (4.3-8)$$

with M melt [mm DT⁻¹]
 n number of time steps per day [d⁻¹]
 DDF 3 degree-day-factors for snow, firn and ice, respectively [mm °C⁻¹ d⁻¹]
 T air temperature in a standard elevation of 2 m above land surface [°C]
 T_0 threshold temperature for melt

The melt is calculated for snow, firn and ice separately using specific parameters. If a glacier cell is covered with snow, the melt calculation is completed using the parameters DDF_{snow} and no firn or ice melt is calculated. If the cell is not covered by snow, then the melt calculation is completed using the parameters according to the cell code: DDF_{ice} for ice cells (code 1) or DDF_{firn} for firn cells (code 2). Typically, the relationship $DDF_{ice} > DDF_{firn} > DDF_{snow}$ holds. All three parameters are constant in space and time for the entire model run. The parameter values are ranging from 2 to 10 mm °C⁻¹ day⁻¹.

Using the extended melt approach from Hock (1998), the melt of snow, firn, and ice is calculated by:

$$M = \begin{cases} \left(\frac{1}{n} MF + \alpha_{snow/firn/ice} \cdot I_0 \right) \cdot (T - T_0) & : T > T_0 \\ 0 & : T \leq T_0 \end{cases} \quad (4.3-9)$$

with M melt [mm DT⁻¹]
 n number of time steps per day [d⁻¹]
 MF melt factor with identical values for snow, firn and ice (around 2 mm °C⁻¹ d⁻¹)
 α empirical coefficients for snow and firn (identical, approx. 0.002) and for ice (around 0.001) [mm Wh⁻¹ m² °C⁻¹ day⁻¹]
 I_0 potential direct incoming short-wave radiation (visible incoming sun radiation) for each HRU (depends on aspect and slope angle, time and season, but not on cloudiness) [Wh m⁻²]
 T air temperature in a standard elevation of 2 m above ground surface [°C]
 T_0 threshold temperature for melt

The correction of the melt factor is completed using the relationship between the observed global radiation at a meteorological station and the theoretical potential global radiation at the same location. This relationship represents the effects of cloudiness multiplied by the potential radiation I_0 on the actual cell. The latter meas-

ure represents the local real global radiation. Since the model uses global radiation interpolated from non-shaded stations, and since it already performs a radiation correction considering local topography, the term $I_0 G_S I_S^{-1}$ is replaced internally by the interpolated global radiation. The actual correction is performed in the evaporation module. However, for using this melt model approach, it is necessary to enable the radiation correction and to use Penman-Monteith, Turc/Ivanov or Wendling evaporation for corrected radiation. Further, it is recommended not to use net radiation instead of global radiation. If no radiation correction is performed, no variations in the melt pattern will be recognisable since only the interpolated radiation is used for scaling the melt. The model stops its execution if no radiation is found during the initialisation.

The parameters α_{ice} , α_{firm} , and α_{snow} are becoming smaller in this order and range between 10^{-4} and $5 \cdot 10^{-3} \text{ mm Wh}^{-1} \text{ m}^2 \text{ }^\circ\text{C}^{-1} \text{ d}^{-1}$. The radiation is given in $[\text{Wh m}^2]$, scaling the small α -values to the order of reasonable degree day factors. Since the product of α and interpolated global radiation is added to the melt factor MF , the latter is smaller than the degree day factors in a classical temperature index approach. MF has a value of around $2 \text{ mm }^\circ\text{C}^{-1} \text{ d}^{-1}$.

If a glaciated HRU is coded as ice, but is covered with snow, the current melting is calculated using the parameters for snow. Only in cases of snow free ice area is the melt calculated using the ice parameters.

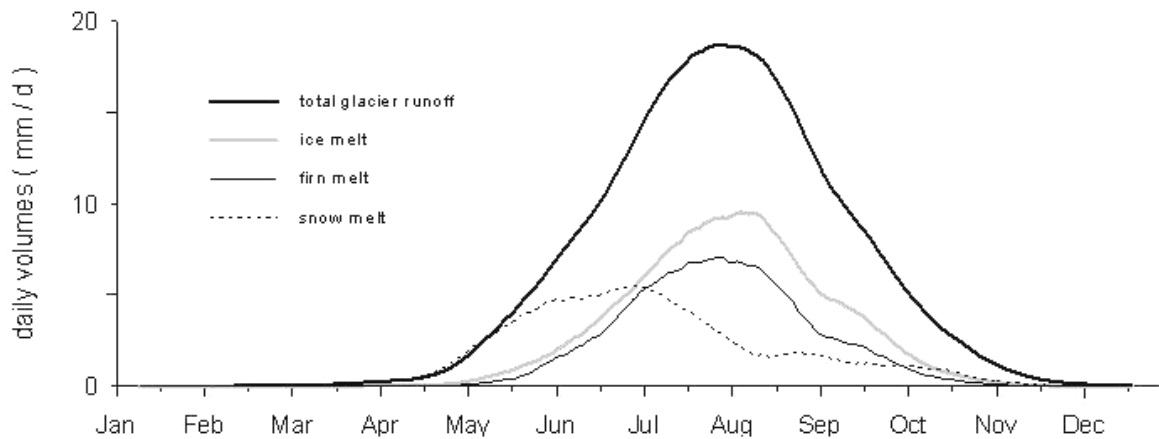


Figure 4.3-3: 21 day moving average of melt components from 1981 to 2000 in the Rhone catchment.

Routing of the different melt components through the glacier

For glaciated sub-basins, there are three melt components calculated following Equations (4.3-8) and (4.3-9), respectively. These components are then delayed and routed to the sub-basin outlet using a set of parallel single linear reservoirs in combination with a translation movement using individual storage and translation times:

- Ice (ablation zone): very short storage and translation times (in the model, k_{ice} of 1 to 10 hours), output is added to the fast runoff component Q0
- Snow on ice (ablation zone): longer storage time (k_{snow} of 10 to 100 h), translation time of about 2 h, output is added to the delayed runoff component Q1
- Firn and snow on firn (accumulation zone): long storage and translation times, (k_{firm} of around 100 to 1000 h) melt water is added to baseflow storage input (i.e. SLZ)

Rainfall falling on the three glacier sections described is treated as melt water and directly enters the respective storages.

For model calibration, it is important to initialise the three parallel reservoirs with matching initial values. If the calibration begins when the total glacier is frozen, e.g. in January, then only the firn reservoir must be initialised with a small initial outflow, the other two reservoirs may be initialised with zero.

The total runoff from the glacier sub-basins is handled in the discharge routing module as the runoff of any other sub-basin.

4.4 Water in the soil-plant-atmosphere system

4.4.1 Characterisation of soil water

The mass and energy exchange between soil, vegetation and atmosphere significantly determines the charge and consumption of the water storage of an area. A positive DS (reserve) develops if $P > (ET + R)$, a negative DS (consumption) when $P < (ET + R)$. This exchange occurs mainly in the vertical direction, as most of the precipitation is returned to the atmosphere through evapotranspiration, whereby the soil-moisture-zone is the dominant turnover space. This is also shown with the help of the soil column in Figure 4.4-1 where the components and sub-processes of the water cycle in the land phase can be observed. As this is only a section of a catchment area, input and output to the subsystem have to be considered additionally to achieve a closed water balance. Only for the case of negligible horizontal flows, can the water balance be calculated alone from the vertical flows.

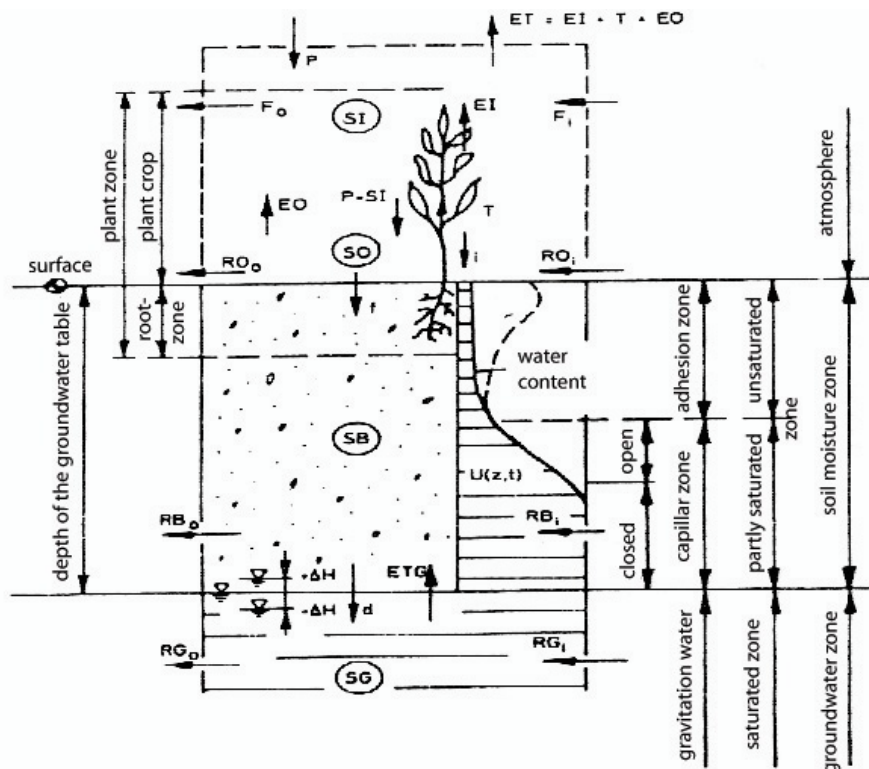


Figure 4.4-1: Schematic representation of the soil-plant-atmosphere system.

The soil-water-budget is determined through three processes: (1) infiltration of water through the surface with the generation of soil moisture, (2) unsaturated water flow through the ventilated soil zone and (3) groundwater flow through saturated granular soil or bedrock. The soil pores in the ventilated and moistened zone may also contain air beneath water. At the groundwater surface, atmospheric pressure is registered, beneath the groundwater layer, pressure rises linearly. Above the groundwater surface, capillary forces may saturate a porous medium to a certain extent. Higher in the soil column, the soil is only temporally saturated after the infiltration of precipitation.

As the hollow space between the soil grains can take up liquid and/or gaseous matter, the soil can store or pass on water. The rate of the storage and conductance ability depends on the volume and size distribution of the hollow spaces, and is thus determined from the grain size and their distribution.

The pore volume (porosity) is defined as:

$$n = \frac{\text{pore space volume}}{\text{total volume}} \quad (4.4-1)$$

n can be found in the range of 0.25 to 0.75, depending on the soil texture.

The water or moisture content of a soil is defined as:

$$\Theta = \frac{\text{water volume}}{\text{total volume}} \quad (4.4-2)$$

From the degree of saturation $s = \Theta / n$, we can draw conclusions on the temporal development of the water content.

The field capacity and wither point are characteristic values of the water fixation. The field capacity FC represents the amount of water a soil can hold against gravity without influence of the evapotranspiration. It is determined after a longer precipitation period, after the gravity water has largely pertered out.

If the water content falls under a certain value, most plants wither irreversibly. This is called the permanent wilting point WP .

The absorption and capillary water in the range between FC and WP can be used from the plants. Therefore the plant usable or plant available field capacity is defined:

$$AFC = FC - WP. \quad (4.4-3)$$

Table 4.4-1: Classification of the plant available field capacity AFC .

AFC-steps	storage capacity [mm]	volume %
very good	> 100	24
good	60 – 100	16
moderate	45 – 60	11
low	30 – 45	8
very low	15 – 30	4.5
extremely low	< 15	1.5
rocky, urban area	0	0

It depends on the vegetation which part of the precipitation reaches the soil surface and which part is held back by interception. Vegetation and soil characteristics are influenced by the infiltration of precipitated water to the soil.

Table 4.4-2: Recommendation for the soil-model-parameters in dependency of the soil type (after Haberlandt, 1989): Porosity n , field capacity FC , wilting point WP .

soil type		n Vol.-%	FC Vol.-%	WP Vol.-%
sand	S	28 – 35	8 – 15	1 – 7
sand, clayey	Sl	30 – 40	10 – 16	2 – 5
clayey sand	IS	32 – 42	13 – 24	5 – 8
sandy clay	sL	33 – 45	22 – 30	8 – 13
clayey silt	IU	43 – 45	28 – 35	8 – 14
clay	L	35 – 50	20 – 35	12 – 19
silty clay	UL	43 – 46	32 – 43	14 – 20
silt	U	40 – 52	28 – 35	18 – 22
sandy potters's clay	sT	42 – 55	32 – 40	16 – 24
silty potter's clay	uT	49 – 60	37 – 46	18 – 24
potter's clay	T	50 – 65	40 – 55	25 – 35

The plant available soil moisture storage is depleted by evapotranspiration. It is assumed that the maximal content of the soil moisture storage corresponds to the maximum plant available soil moisture SFC_{MAX} [mm]. Such a water content is available for transpiration. The parameterisation of SFC_{MAX} requires the availability to estimate the specific plant AFC [Vol%] and the knowledge of the soil depth T_B [m]. SFC_{MAX} is then parameterised for each vegetated hydrological response unit according to the following equation:

$$SFC_{MAX} = AFC \cdot T_B \cdot 10.0 \quad (4.4-4)$$

Additionally, it is assumed that the soil water is only available up to a depth close to the rooting depth T_{WU} [m]. The rooting depth varies seasonally and according to the land use. To account for capillary rise, an additional depth of 15 cm is included in the parameterisation of the effective soil depth, which is relevant for the parameterisation of the effective SFC_{EFF} :

$$SFC_{EFF} = AFC \cdot (T_{WU} + 0.15) \cdot 10.0 \quad (4.4-5)$$

It may happen that soils are less deep than the roots. In this case, the available field capacity is limited by $SNFC_{MAX}$. The actual maximal plant available soil moisture storage $SNFC$ is therefore defined as:

$$SFC = MIN[SNFC_{EFF}, SNFC_{MAX}] \quad (4.4-6)$$

where $SNFC_{EFF}$ is the effective plant available soil moisture storage.

SFC is parameterised separately for non vegetated surfaces. If no vegetation is present, then soils can be depleted by direct soil evaporation up to a depth of 25 cm:

$$SFC = AFC \cdot 0.25 \cdot 10.0 \quad (4.4-7)$$

Urban areas are an exception to this rule, where values of SFC ranging between 4 and 5 mm are assumed.

4.4.2 Potential evapotranspiration

Plants need water to build up substance and as a dissolver-, transport-, welling- and cooling-resource. Through transpiration, the water vapour transfer to the atmosphere, a steady transport of plant available water from the roots to the leaves is assured. The leaves are specially adapted to the regulation of the gas exchange. The transpiration suction of the leaves is the pushing force of the water transport through the plants. It depends on the suction power gradient between the soil and atmosphere. Therefore, the evapotranspiration is an important factor for the water and energy balance of a land surface.

Definitions

Evapotranspiration is defined as the sum of all processes by which water in the liquid or solid phase at or near the earth's land surface becomes atmospheric water vapour. Evapotranspiration is a combined process of both evaporation from soil and plant surfaces as well as transpiration through plant canopies. Evapotranspiration is responsible for the occurrence of more than 50% of the energy flux from a land surface to the atmosphere, which shows the importance of this variable.

Evaporation occurs from uncovered surfaces (soil-, snow- or ice-evaporation), the precipitation which is restrained in the plant canopy (intercepted evaporation) and from free water surfaces (water evaporation). Evaporation can be defined as the process by which liquid water is converted into a gaseous state. Evaporation may only occur when water is available. It is also required that the humidity of the atmosphere is below the humidity of the evaporating surface (at 100% relative humidity, there is no evaporation). The evaporation process requires large amounts of energy. For example, the evaporation of one gram of water at a temperature of 0° C requires 600 calories of heat energy.

Transpiration is the physiological regulated loss of water vapour to the atmosphere through the stomata of plants and can be regarded as evaporation from the plant's vascular system. The water is absorbed by the roots, rises by capillary action to stomatal cavities in the leaves where it finally evaporates and is diffused through stomata (Greek "stomatos": mouth). Under dry, windy and/or hot and sunny conditions, transpiration may exceed the rate at which water can be supplied from the soil. By closing the stomates, plants prevent water loss, but also restrict access to atmospheric CO₂ for photosynthesis.

The standard rates are defined in the following ways:

- *Potential evaporation* in [mm] is defined as the amount of water which evaporates from an idealised, extensive free water surface under given atmospheric circumstances.
- A reference value for the *potential plant evapotranspiration* in [mm] is defined as the evapotranspiration that occurs from an idealised grassy surface with a vegetation height of 12 cm, an albedo of 0.23 and a surface resistance of 69 s m⁻¹. The latter is a measure for the ability of the atmosphere to remove water from the plant surface through processes of evaporation and transpiration, assuming unlimited water supply and no advection (wind).

The evapotranspiration joins the environmental compartments of air, water, soil and vegetation in multiple ways (cf. Figure 4.4-2)

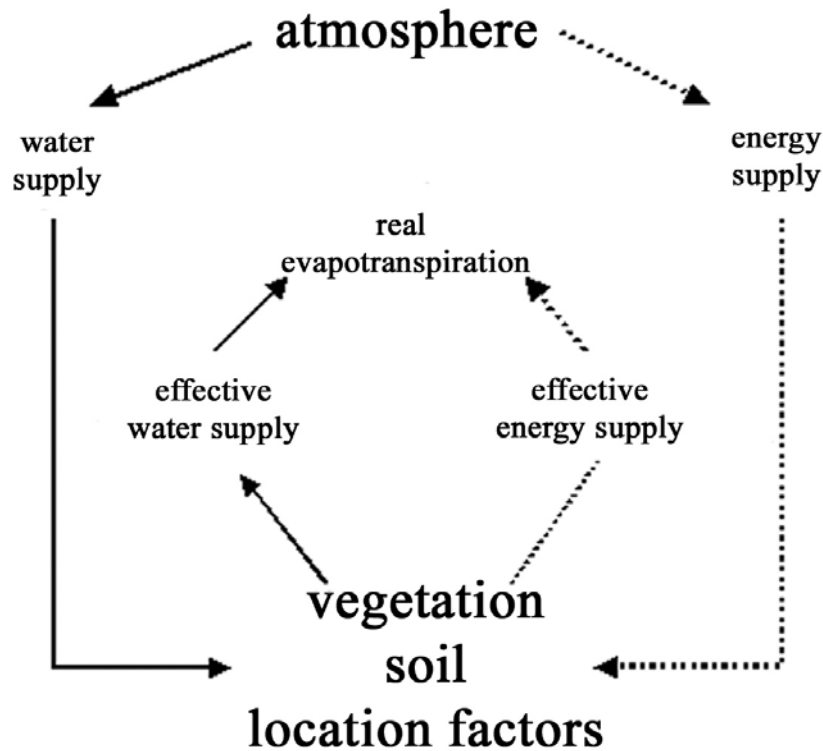


Figure 4.4-2: The evapotranspiration in the complex system atmosphere-plant-soil.

Potential evapotranspiration after Penman (1948) and Penman-Monteith (1975, 1981)

The most widely adopted scheme for the estimation of evapotranspiration in distributed hydrological models relies on the Penman (1948) and Penman-Monteith equation (Monteith, 1975; Menzel, 1997; DVWK, 1996; Gurtz et al., 1997a; Schulla and Jasper, 2000).

The Penman (1948) equation is referred to as

$$ETP = \frac{UFK}{\rho_w L} \frac{\Delta \cdot R_N + \gamma + a}{\Delta + \gamma} \tag{4.4-8}$$

using

$$E_a = 0.263 (0.5 + 0.537 u) (e_s - e) \frac{L}{86400} \tag{4.4-9}$$

and the Penman-Monteith (1975, 1981) equation is as follows:

$$ETP = \frac{UFK}{\rho_w L} \frac{\Delta \cdot (R_N - G) + \frac{\rho c_p (e_s - e)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a} \right)} \tag{4.4-10}$$

- where
- ETP potential evapotranspiration [mm d^{-1}]
 - E_a aerodynamic term [W m^{-2}], ventilation
 - ρ density of dry air [kg m^{-3}]
 - ρ_w density of water $\cong 1000$ [kg m^{-3}]
 - γ psychrometric constant [hPa K^{-1}]
 - c_p specific heat of dry air at constant pressure [$\text{J kg}^{-1} \text{K}^{-1}$]
 - e actual water vapour pressure [hPa]
 - e_s saturated vapour pressure at actual temperature [hPa]
 - Δ first derivative of the saturated vapour pressure curve (around temperature T) [hPa K^{-1}]
 - R_N net radiation [W m^{-2}]

G	ground heat flux [W m^{-2}]
L	latent evaporation heat [$\text{J kg}^{-1} \text{K}^{-1}$]
r_a	aerodynamic diffusion resistance [s m^{-1}]
r_s	stomata diffusion resistance, surface resistance [s m^{-1}]
u	wind speed 2 m above ground [m s^{-1}]
UFK	86'400'000 (conversion from m s^{-1} to mm d^{-1})

The latent evaporation heat is a temperature dependent term

$$L = 2501 - 2.37 T \text{ [kJ kg}^{-1}\text{] using } T = \text{air temperature } [^{\circ}\text{C}] \quad (4.4-11)$$

The saturated vapour pressure e_s can be calculated with the Magnus-equation

$$e_s = 6.11 \exp\left(\frac{17.3 T}{237.3 + T}\right) \text{ [hPa]} \quad (4.4-12)$$

The actual water vapour pressure e is calculated from the relative humidity U with

$$e = U \cdot e_s \text{ [hPa]} \quad (4.4-13)$$

Δ is the first derivative of the saturated vapour pressure curve around air temperature T (Magnus-equation).

$$s = \frac{\partial e_s}{\partial T} = \frac{4098 e_s}{(237.3 + T)^2} \text{ [hPa K}^{-1}\text{]} \quad (4.4-14)$$

The term γ is called psychrometric constant and is a function of the air pressure and air temperature.

$$\gamma = \frac{p \cdot c_p}{m \cdot L} = 0.016286 \frac{p}{L} \text{ [hPa K}^{-1}\text{]} \quad (4.4-15)$$

c_p = specific heat of dry air at constant pressure = 1000 [$\text{J kg}^{-1} \text{K}^{-1}$]

m = ratio of the molar masses water vapour to dry air = 0.622 [-]

The air pressure p can be expressed with the barometric height equation.

$$p = 1013 e^{-\frac{H}{7991+29.337T}} \text{ [hPa]} \text{ using } H = \text{height above sea level [m]} \quad (4.4-16)$$

The air density is estimated as a function of temperature:

$$\rho = 0.349 \frac{p}{275 + T} \text{ [km m}^{-3}\text{]} \quad (4.4-17)$$

The ground heat flux G can be expressed as a fraction of the net radiation (R_N):

$$G = C_R \cdot R_n \text{ [W m}^{-2}\text{]} \quad (4.4-18)$$

C_R = ground factor ≈ 0.3 for urban areas, rocky areas and water
 ≈ 0.2 for grassy surfaces
 $\approx (0.3 - 0.03 LAI)$ for vegetation covered surfaces

LAI = leaf area index

The net radiation is derived from the balanced short-wave (R_{sw}) and long-wave (R_{lw}) radiation:

$$R_n = R_{sw} + R_{lw} \text{ [W m}^{-2}\text{]} \quad (4.4-19)$$

The balanced short-wave radiation is determined in the following way:

$$R_{sw} = RG (1 - \alpha) \text{ [W m}^{-2}\text{]} \quad (4.4-20)$$

with α = albedo [-] and RG = global radiation [W m^{-2}]

To determine the balanced long-wave radiation, SSD which is the ratio of the measured sunshine duration n to the maximum possible sunshine duration N is needed:

$$SSD = \frac{\text{sunshine duration}}{\text{max. possible sunshine duration}} = \frac{n}{N} \text{ [h h}^{-1}\text{]} \quad (4.4-21)$$

Following this, f is derived as a factor which considers the reverberation from clouds:

$$f = f(SSD) = (c_0 + (1 - c_0) \cdot SSD) \text{ using } c_0 = 0.23 \text{ for the Thur River catchment} \quad (4.4-22)$$

and ε is the net emission of the considered surface:

$$\varepsilon = (a_e + b_e \sqrt{e}) , \quad a_e = 0.48 , \quad b_e = -0.065 \quad (4.4-23)$$

Giving the balanced long-wave radiation:

$$Rlw = -f(SSD) \varepsilon D(275 + T)^4 \text{ [W m}^{-2}\text{]} \quad (4.4-24)$$

where σ is the Stefan-Boltzmann constant ($5.68 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$).

The aerodynamic diffusion resistance r_a is:

$$r_a = \frac{4.72 \cdot \left(\ln \frac{z}{z_0} \right)^2}{1 + 0.54u} \text{ [s m}^{-1}\text{]} \quad (4.4-25)$$

using z height above ground where the wind speed is measured [m]
 z_0 aerodynamic roughness-length as a parameter of every form of land use
 ($z_0 \approx 0.125 \cdot (h - d)$ [m])
 u wind speed 2 m above ground [m s^{-1}]
 h height of vegetation [m]
 d height displacement = 0.6 h

The surface resistance r_s is calculated for the daytime as:

$$\frac{1}{r_{sT}} = \frac{(1 - A)}{r_{sc}} + \frac{A}{r_{ss}} \quad (4.4-26)$$

using r_{sT} minimal surface resistance in daytime [s m^{-1}]
 r_{sc} minimal surface resistance of the plants with full water supply and dense cover [s m^{-1}]
 r_{ss} surface resistance for uncovered ground ($\approx 150 \text{ s m}^{-1}$) [s m^{-1}]
 $1 - A$ factor to characterise the evaporating vegetation cover
 $A = f^{LAI}$ using $f \approx 0.7$

At night, the following equation applies:

$$\frac{1}{r_{sN}} = \frac{LAI}{2500} + \frac{A}{r_{ss}} \quad (4.4-27)$$

using r_{sN} minimal surface resistance at night [s m^{-1}]

The terms z_0 and LAI (additionally, the degree of vegetation cover and radix depth to calculate the utilisation of the soil moisture) show a vegetation specific annual fluctuation.

The averaged surface resistance r_s throughout a day:

$$\frac{1}{r_s} = \frac{T_L}{24r_{sT}} + \left(1 - \frac{T_L}{24} \right) \frac{1}{r_{sN}} \quad (4.4-28)$$

using T_L day length [h]

Potential evapotranspiration after Wendling (1975):

The estimation of potential evapotranspiration (ETP) after Wendling (1975) (see also DVWK, 1996) is applicable only when using a time step of one day or longer. The potential evapotranspiration is then given by:

$$ETP = (RG(1.1 - \alpha) + 93 \cdot f_k) \frac{T + 22}{150(T + 123)} [\text{mm d}^{-1}] \quad (4.4-29)$$

using RG	global radiation in [$\text{J cm}^{-2} \text{d}^{-1}$], transformed from [W m^{-2}] using the multiplier 8.64
α	albedo (0 to 1) [-]
f_k	empirical correction value which takes into account the parameters that cannot be collected using the radiation and temperature (coastal 0.6, lowland 1, assessed empirical value for northern Switzerland, compared to Penman-Monteith evapotranspiration: 0.5) [-]
T	daily mean value of air temperature [$^{\circ}\text{C}$]

Potential evapotranspiration after Hamon (1961) (from Federer and Lash, 1983)

$$ETP = 0.1651 \cdot f_i \cdot h_d / 12 \cdot \frac{216.7 \cdot e_s}{T + 273.3} [\text{mm d}^{-1}] \quad (4.4-30)$$

using f_i	empirical factor, varies monthly (Table 4.4-2)
h_d	day length [h]
e	saturated vapour pressure at temperature T [hPa]
T	air temperature [$^{\circ}\text{C}$]

Table 4.4-2: Monthly correction factor f_i for Hamon-evapotranspiration (valid for northern Switzerland).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
f_i	0.5	0.6	0.8	1.1	1.2	1.3	1.2	1.1	1.0	0.9	0.7	0.5

Potential evapotranspiration after Turc/Ivanov:

The Turc (1961) scheme (DVWK, 1996) is applied in France and in arid/semi-arid regions when air temperature exceeds 5°C . For temperatures below 5°C , the scheme after Ivanov (see DVWK, 1996) is used. Both schemes are applicable only using a time step of one day or more.

Turc scheme, for $T \geq 5^{\circ}\text{C}$

$$ETP = 0.0031 (RG + 209.4) \frac{T}{T + 15} ETPF_{mon} [\text{mm d}^{-1}] \quad (4.4-30)$$

Ivanov scheme, for $T < 5^{\circ}\text{C}$

$$ETP = f_k \cdot 0.00006 (T + 25)^2 (100 - RH) [\text{mm d}^{-1}] \quad (4.4-31)$$

using RG	global radiation in [$\text{J cm}^{-2} \text{d}^{-1}$], calculated from [W m^{-2}] using the multiplier 8.64
$ETPF_{mon}$	empirical factor varies monthly (see Table 4.4-3)
f_k	empirical correction value, cf. Wendling (1975)
T	daily mean value of air temperature [$^{\circ}\text{C}$]
RH	relative humidity [%]

Table 4.4-3: Empirical coefficient $ETPF_{mon}$ for ETP_{TURC} (valid for central Europe).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$ETPF_{mon}$	0.7	0.85	0.95	1.05	1.25	1.15	1.05	0.95	0.9	0.8	0.75	0.7

In the PREVAH model, the potential evapotranspiration is calculated as daily averaged values in mm d^{-1} . In case of using a computation time step of 1 hour, the daily values are distributed to the hours of the day between the time of sunrise and sunset. The disaggregation of daily evapotranspiration to the different day hours is carried out depending on the cloudiness for cloudy sky (relative sunshine duration smaller than 0.7) and for clear sky using the distribution functions from the following schematic (Figure 4.4-3).

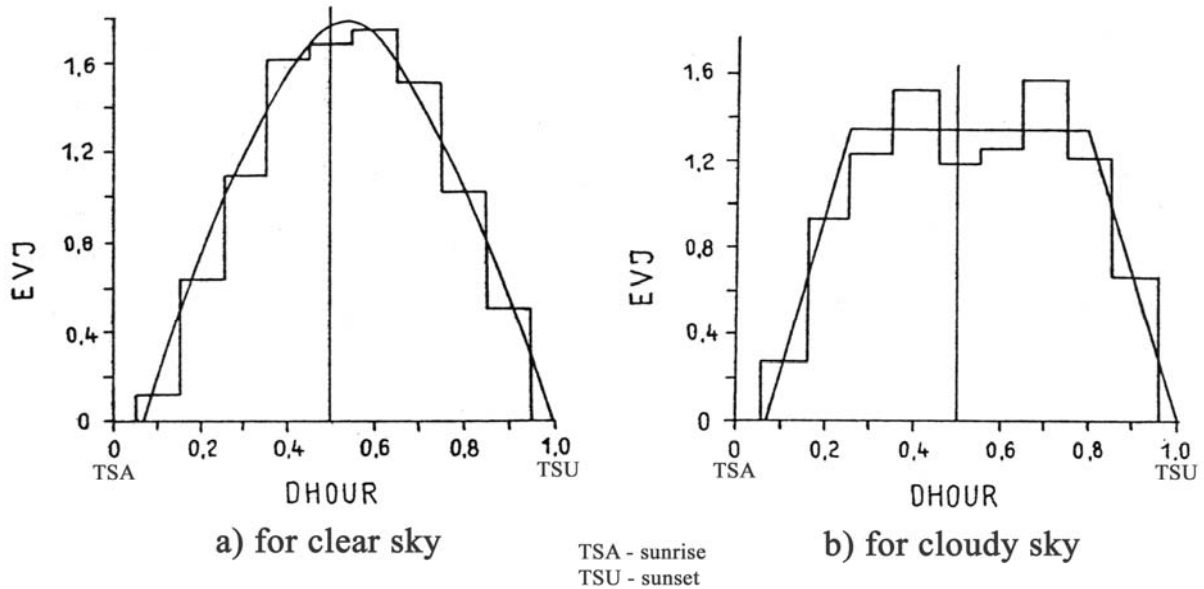


Figure 4.4-3: Mean distribution function of the evapotranspiration during a day.

In the appendix, the equations optionally used in PREVAH to calculate the short and long wave radiation are supplied.

4.4.3 Real evapotranspiration

The real evapotranspiration ETR from the soil surface and soil itself is controlled by different factors (Figure 4.4-4): meteorological conditions and the resulting energy supply; water supply at the surface and in the ventilated soil zone; height of the groundwater table; and further location-specific factors (morphology, geology, soil type, cropping, vegetation type and succession).

The direct evaporation from a land surface or the soil is an unproductive process. With sufficient moisture, it is only determined by meteorological conditions. Transpiration through the stomata is a plant physiological process. It is the base of nutrient supply and biomass production, and is therefore called productive evaporation. Plants have the possibility to reduce the transpiration in case of water shortages by closing their stomata. Water for transpiration is supplied through a network of roots of varying length, whose size and position changes with the growth of the plant and moisture supply. For this reason, the distance of the water transport between the soil and roots is significantly shorter in comparison to the evaporation. Further, the available soil space for water supply becomes larger. Beside the transpiration demand, it is the water transport ability which regulates the transpiration rate. Again, the water transport ability depends on the development stage of a plant. Therefore, the transpiration process is a very important part of the highly non linear soil-plant-atmosphere system.

For uncovered soil, only evaporation occurs. For covered soil, the fraction of transpiration rises with increasing vegetation density. Lastly, for a closed vegetation cover, the fraction of evaporation is extremely small.

The modelling of the evapotranspiration always needs to be regarded in close relation to the modelling of soil moisture. It strongly depends on the spatial and temporal process scales considered and the temporal and spatial differentiation of the model input data available.

In practice, the ETR is generally calculated on the basis of ETP and then adjusted to actual moisture, soil and vegetation conditions at the location of focus.

During dry periods, evapotranspiration is reduced constantly. This is tantamount to an increase in the suction power and, therefore, the binding intensity of the soil water and soil resistance. Real evapotranspiration may drop substantially under the potential evapotranspiration. This process can be described with the extraction- or reduction-function $r(\Theta)$:

$$ETR = r(\Theta) \cdot ETP \quad (4.4-32)$$

As the function $r(\Theta)$ theoretically can not be differentiated, the chosen function type differs from model to model. To simplify the complicated functions, a stepwise linear characteristic is commonly used.

For covered soil, rb applies:

$$\begin{aligned} rb(\Theta) &= 1 && \text{for } \Theta_0 \leq \Theta \leq \Theta_S \\ rb(\Theta) &= (\Theta - \Theta_{WP}) / (\Theta_0 - \Theta_{WP}) && \text{for } \Theta_{WP} \leq \Theta < \Theta_0 \\ rb(\Theta) &= 0 && \text{for } \Theta < \Theta_{WP} \\ \Theta_0 &= cu \cdot \Theta_{FC} && cu = 0.4 \text{ to } 0.8 \text{ (parameter)} \end{aligned} \quad (4.4-33)$$

Uncovered soil is characterised by ru :

$$\begin{aligned} ru(\Theta) &= 1 && \text{for } \Theta_{FC} \leq \Theta \leq \Theta_S \\ ru(\Theta) &= (\Theta - \Theta_{WP}) / (\Theta_{FC} - \Theta_{WP}) && \text{for } \Theta_{WP} \leq \Theta < \Theta_{FC} \\ ru(\Theta) &= 0 && \text{for } \Theta < \Theta_{WP} \end{aligned} \quad (4.4-34)$$

Θ is the volumetric soil moisture content, Θ_S , Θ_{FC} , Θ_{WP} are the values of Θ at saturation, field capacity and wilting point, respectively.

If the fraction of the plant-covered soil is defined with the vegetation-covering-grade VBG ($0 \leq VBG \leq 1$), $ETR(b+u)$ of partly covered soil can be estimated as:

$$ETR(b+u) = ETP [(rb(\Theta) \cdot VBG) + (ru(\Theta) \cdot (1 - VBG))] \quad (4.4-35)$$

If potential evapotranspiration is calculated with the Penman-Monteith equation, ETR can be estimated either directly over the moisture dependent reduction function or the resistance analogy method, where the stomatal resistance is adjusted depending on the particular soil moisture (for $\Theta \leq \Theta_0$).

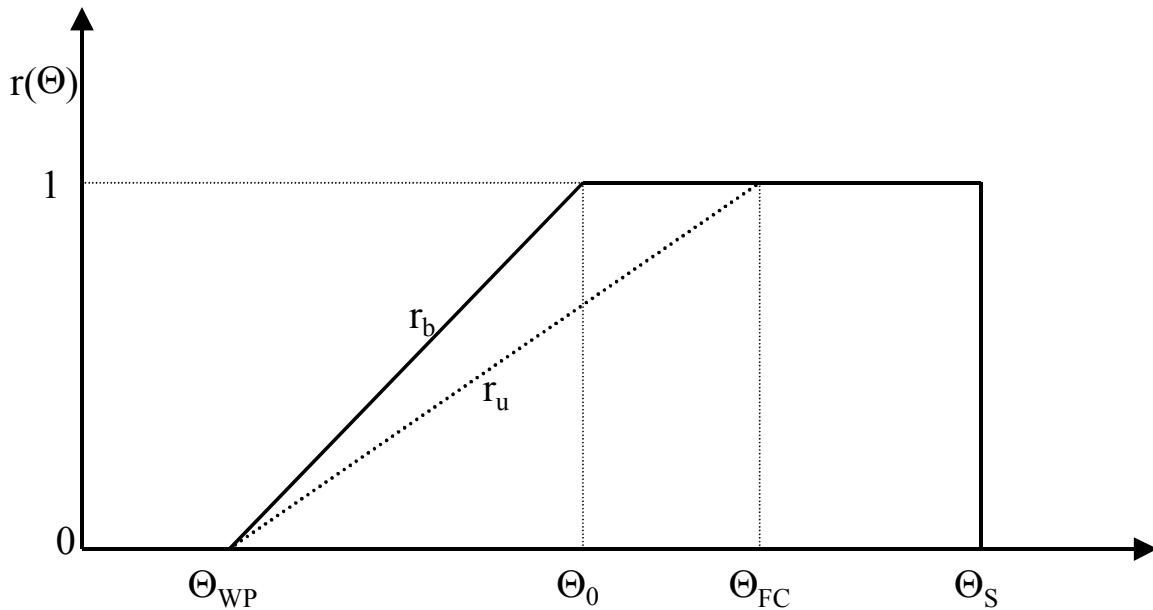


Figure 4.4-4: Schematic for the estimation of real evapotranspiration depending on soil moisture Θ .

4.5 Runoff generation, runoff components and runoff concentration

4.5.1 Generation of soil moisture, land surface runoff, interflow and percolation

The runoff (R or Q) is defined as the water volume per time unit ($[m^3 s^{-1}]$ or $[l s^{-1}]$) that leaves a catchment through a surface runoff profile (e.g. river profile) and possibly also through subsurface ways. This water originates from the catchment area which, in turn, is limited by the watersheds. Surface and subsurface catchment areas are distinguished. The surface catchment area is defined by natural watersheds like mountain ridges, its area corresponds to the horizontal projection of the area which is enclosed by the watersheds. The subsurface catchment area is affected by the geological conditions. The characteristics of the geological layers, and geological faults, cleavages or vugs, may influence water flow such that inflows or outflows are virtually impossible to determine.

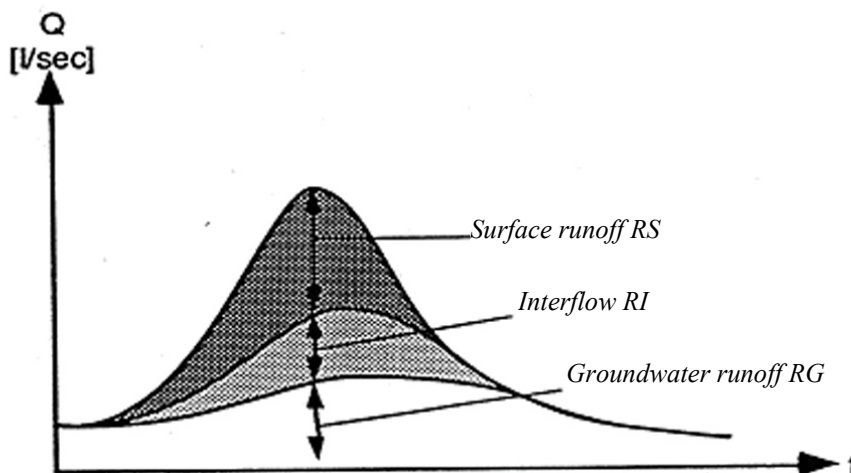


Figure 4.5-1: Composition of a runoff hydrograph from the surface runoff RS , the interflow RI and the groundwater runoff (baseflow) RG .

The runoff hydrograph consists of different runoff components generated in different parts of the catchment at the land surface, in the unsaturated soil zone and in the saturated groundwater zone using different runoff generation sub-models. The flowing of the generated runoff to the outlet profile of the catchment at the land surface, through the soil and in the river network occurs with different velocities and is described by runoff concentration sub-models. The runoff generation and concentration modules can be coupled similarly as in the PREVAH model.

Equations of the runoff-generation module used in PREVAH

Here, we present the equations for the water flows within the runoff generation module of PREVAH (see Chapter 2). The water flows are computed for each HRU at each time step dt [h] as represented schematically in Figure 2-2. Table 4.5-1 summarises the variables and parameters of the soil and runoff generation modules.

Table 4.5-1: Main variables and parameters of the soil and runoff-generation modules.

Name	Unit	Definition
State Variables		
SNFC	[mm]	Maximum plant available soil moisture storage
SSM	[mm]	Plant available soil moisture storage
DSUZ	[mm h ⁻¹]	Inflow into the runoff generation module
SUZ	[mm]	Upper storage reservoir
PERC	[mm h ⁻¹]	Deep percolation rate
RS	[mm h ⁻¹]	Surface runoff
RI	[mm h ⁻¹]	Interflow
SG1	[mm]	Fast response groundwater reservoir
SG2	[mm]	1 st order slow response groundwater reservoir
SG3	[mm]	2 nd order slow response groundwater reservoir
GR1	[mm h ⁻¹]	Recharge of SG1
GR2	[mm h ⁻¹]	Recharge of SG2
GR3	[mm h ⁻¹]	Recharge of SG3
RG1	[mm h ⁻¹]	Fast response groundwater runoff component
RG2	[mm h ⁻¹]	Delayed groundwater runoff component
R _{TOT}	[mm h ⁻¹]	Total runoff
Tuneable parameters		
BETA	[-]	Soil moisture recharge parameter
SGR	[mm]	Threshold content of SUZ for generation of surface runoff
SG1 _{MAX}	[mm]	Maximum content of the fast response groundwater reservoir SG1
K0	[h]	Storage time for surface runoff
K1	[h]	Storage time for interflow
K2	[h]	Storage time for quick response baseflow
K3	[h]	Storage time for delayed baseflow
PERC _{MAX}	[mm dt ⁻¹]	Maximal deep percolation rate

The inflow $DSUZ$ into the storages of the runoff generation module is relative to SFC :

$$DSUZ(t) = P_b(t) \cdot \left(\frac{SSM(t-1)}{SNFC} \right)^{BETA} \quad (4.5-1)$$

BETA is a dimensionless non-linearity parameter that controls the redistribution of the available water amount for runoff generation P_b [mm h⁻¹] between the plant available soil moisture storage reservoir (*SSM*) and upper storage reservoir *SUZ*.

The *SUZ* reservoir temporarily stores water amounts that can either drain by gravitation in the groundwater storages *SLZ*, or generate surface runoff and interflow. *SUZ* contains the water available for land surface runoff generation and the fraction of the soil moisture content which exceeds the field capacity and contributes to runoff generation (Figure 4.5-2) and percolation. The soil moisture recharge (*SMR*) is the difference between P_b and *DSUZ*. *SMR* increases with increasing *BETA* (Uhlenbrook, 1999).

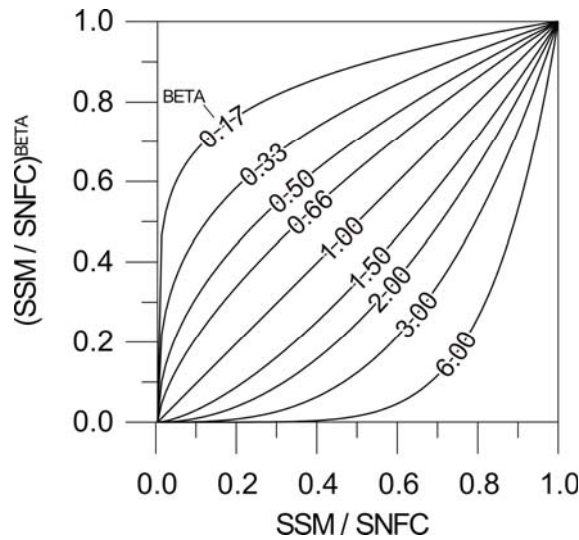


Figure 4.5-2: Relation of storage inflow (abscissa) to storage outflow (ordinate) depending on the parameter *BETA*.

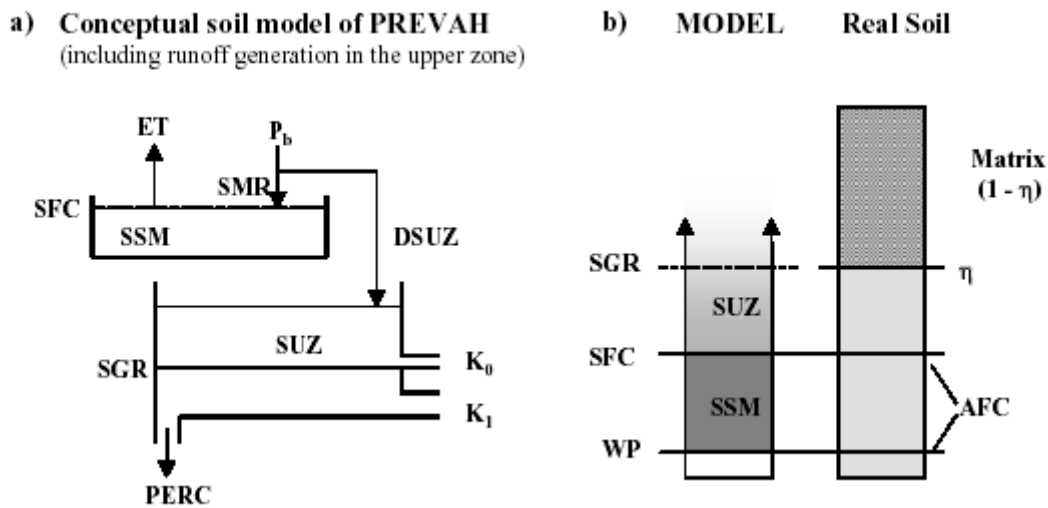


Figure 4.5-3: Conceptualisation of the soil model in PREVAH (left) and schematic conceptualisation of the real soil and its parameterisation in the hydrological model (right).

As a first step, the storage reservoir *SUZ* is incremented by *DSUZ*:

$$SUZ_1(t) = SUZ_{(t-1)} + DSUZ(t) \cdot dt \tag{4.5-2}$$

SUZ is emptied by deep percolation $PERC$ into the reservoirs of the saturated zone $SG1$, $SG2$, $SG3$, by surface runoff RS and interflow RI :

$$SUZ_2(t) = SUZ_1(t) - PERC(t) \cdot dt \quad (4.5-3)$$

$$\text{with } PERC(t) = \min \left[\left(SUZ_1(t) \cdot dt^{-1} \right), PERC_{MAX} \right] \quad (4.5-4)$$

The percolation rate $PERC$ is a tuneable parameter. $PERC$ (Eq. 4.5-4) is limited by the content of SUZ obtained from Equation 4.5-2. The generation of surface runoff RS (Eq. 4.5-5) and interflow RI (Eq. 4.5-5) depends on the content of the linear reservoir SUZ , as obtained from Equation 4.5-2:

$$\begin{aligned} RS(t) &= (SUZ_2(t) - SGR) \cdot (1 - e^{-dt/K0}) \cdot dt^{-1} & \text{if } SUZ_2(t) > SGR \\ RS(t) &= 0 & \text{if } SUZ_2(t) \leq SGR \\ RI(t) &= SUZ_2(t) \cdot (1 - e^{-dt/K1}) \cdot dt^{-1} & \text{if } SUZ_2(t) > 0 \\ RI(t) &= 0 & \text{if } SUZ_2(t) = 0 \end{aligned} \quad (4.5-5)$$

where SGR is a model parameter defining a threshold content of SUZ [mm] that must be exceeded to allow for surface runoff generation. The two storage times $K0$ and $K1$ [h] are tuned through model calibration and adopted as catchment specific parameters to govern the generation of surface runoff and interflow, respectively.

The content of SUZ at the end of the time-step is:

$$SUZ(t) = SUZ_2(t) - (RI(t) + RS(t)) \cdot dt \quad (4.5-6)$$

4.5.2 Groundwater storage and generation of baseflow

The principle of parallel connection of single linear storages is used in PREVAH to compute the base runoff. It is implemented in the sub-model SLOWCOMP from Schwarze et al. (1999). The groundwater storage is divided into a quick-leaking storage $SG1$ and a slow-leaking storage $SG2$. The capacity of $SG1$ for the fast groundwater components is limited through a given maximal storage charge $SG1_{MAX}$. Further, the free storage volume of $SG1$ can only be filled as fast as it would leak when fully charged; the corresponding storage time is CGH . Subsequently, $SG2$ only receives the fraction of percolation which is not absorbed by $SG1$.

Additionally, a smaller, even slower leaking storage $SG3$ is usually added to $SG2$ in parallel. The mean storage time $K3$ is assigned as $9 \cdot K2$, the input consumes $1/9$ of the input to $SG2$. The total content of the groundwater storages (also called SLZ , for "storage lower zone") is the sum of the three partial storages $SG1$, $SG2$ and $SG3$. Total base runoff is combined from the outflow of the three partial storages.

The storage times for $SG1$ (CGH) and $SG2$ ($K2$) are parameters which need to be estimated empirically for the particular catchment. This may be achieved through an analysis of the runoff hydrographs (Schwarze et al. 1999). $K3$ (for $SG3$) is derived from $K2$, and therefore does not need to be estimated.

The recharge rates $GR1$, $GR2$ and $GR3$ of the groundwater storage reservoirs $SG1$, $SG2$ and $SG3$ are determined as a function of the deep percolation rate $PERC$. The computation of the water flows within the groundwater storages and the corresponding runoff components follows the method developed in the sub-model SLOWCOMP by Schwarze et al. (1999):

$$\begin{aligned} \text{if } SG1(t) \geq SG1_{MAX} & \quad GR1(t) = 0 \\ & \quad GR2(t) = PERC(t) \cdot 8/9 \\ & \quad GR3(t) = PERC(t) \cdot 1/9 \end{aligned} \quad (4.5-7)$$

$$\begin{aligned} \text{if } SG1(t) < SG1_{MAX} & \quad GR1 = \min(PERC(t), GR1_{MAX}(t)) \\ & \quad GR2 = (PERC(t) - GR1) \cdot 8/9 \\ & \quad GR3(t) = (PERC(t) - GR1) \cdot 1/9 \end{aligned} \quad (4.5-8)$$

$$\text{with } GR1_{MAX}(t) = \left[\frac{(SG1_{MAX} - SG1(t))}{K2_H} \right] \quad (4.5-9)$$

where $SG1_{MAX}$ is a threshold factor which restricts the content of the quick response groundwater reservoir $SG1$. $SG1_{MAX}$ is not exceeded during the time step dt .

Equations 4.5-10 to 4.5-12 describe the computation of the change in storage for the three groundwater reservoirs during dt .

$$SG1(t) = SG1(t-1) \cdot e^{-dt/K2} + \left[(1 - e^{-dt/K2}) \cdot GR1(t) \cdot K2 \right] \quad (4.5-10)$$

$$SG2(t) = SG2(t-1) \cdot e^{-dt/K3} + \left[(1 - e^{-dt/K3}) \cdot GR2(t) \cdot K3 \right] \quad (4.5-11)$$

$$SG3(t) = SG3(t-1) \cdot e^{-dt/K4} + \left[(1 - e^{-dt/K4}) \cdot GR3(t) \cdot K4 \right] \quad (4.5-12)$$

The generation of the groundwater runoff components is governed by the tuneable storage times $K2$ and $K3$:

$$RG1(t) = \frac{SG1(t)}{K2} \quad (4.5-13)$$

$$RG2(t) = \frac{SG2(t)}{K3} + \frac{SG3(t)}{K4} \quad (4.5-14)$$

$$\text{with } K4 = K3 \cdot 1/9 \quad (4.5-15)$$

$K2$ and $K3$ are the storage times [h] governing the generation of a quick response ($RG1$) and delayed ($RG2$) groundwater runoff, respectively. The additional reservoir $SG3$ also generates a delayed groundwater component ($RG3$), whose storage time $K4$ is parameterised as a function of $K3$ (Equation 4.5-15). The storage times of the groundwater runoff components can be either tuned through model calibration or determined by an analysis of the hydrograph's recession curve (Schwarze et al., 1999).

The total runoff generation R_{TOT} in time step dt is determined by adding all components generated in the upper storage reservoir and groundwater reservoirs:

$$R_{TOT}(t) = RS(t) + RI(t) + RG1(t) + RG2(t) \quad (4.5-16)$$

R_{TOT} is assumed to be instantaneously routed to the catchment outlet.

4.5.3 Runoff concentration

Runoff routing and estimation of the total runoff

When elaborating a model concept, simulation of storage and translation processes in the catchment area and stream system is approached with simple mathematical models. The model parameters are estimated such that the processes in the natural system are approximated as accurately as possible. A commonly used concept to represent storage effects is the so-called single linear storage (SLS; Figure 4.5-4) which can be combined with a translation element.

$$S = k \cdot q \quad \text{or} \quad q = (1/k) \cdot S \quad (4.5-17)$$

using:

S = storage

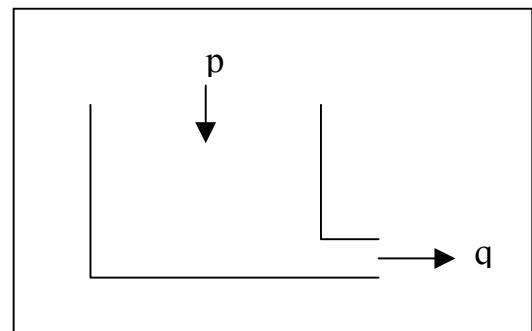
q = outflow

k = storage constant as the residence time

p = inflow

If the storage change as shown in Equation 4.5-18

$$p - q = dS / dt \quad (4.5-18)$$



is inserted in Equation 4.5-17, the differential equation for the SLS is achieved:

$$p = q + k \cdot (dq / dt) \quad (4.5-19)$$

The corresponding solution is:

$$q(t) = q(t_0) \cdot \exp(-(t-t_0)/k) + p(\tau) \cdot (1/k) \cdot \exp(-(t-t_0)/k) \cdot d(\tau) \quad (4.5-20)$$

using: $q(t_0)$ = storage outflow at time t_0
 $q(t)$ = storage outflow at time t

The first term takes into account the idle process during periods without inflow ($p=0$), whereas the second term describes the outflow $q(t)$ which results from the system input p and corresponds to the convolution integral

$$q(t) = p(\tau) \cdot h(t - \tau) d(\tau).$$

From this, we get the pulse response from the SLS:

$$h(t) = (1/k) \cdot \exp(-t/k) \quad (4.5-21)$$

This means that the storage experiencing a pulsed input will drain according to an e-function.

Assuming a rectangular input pulse with $0 \leq t \leq \Delta t$ results in a rising outflow hydrograph:

$$q(t) = p(t) \cdot (1 - \exp(-t/k)) \quad (4.5-22)$$

The recession of the hydrograph is calculated using the idle term for $t > \Delta t$ and $q_{\Delta t}$ as outflow at the end of the rectangular pulse:

$$q(t) = q_{\Delta t} \cdot \exp(-(t - \Delta t)/k) \quad (4.5-23)$$

The parameter k (storage constant of the *SLS*) corresponds to the residence time of the water in the *SLS*. If the *SLS* is applied to calculate the runoff concentration of effective precipitation to direct runoff in a flood event, k may be estimated as half of the time between the end of the precipitation and the end of the flood event (concentration time T_C).

Linear translation element (LTE)

The single linear storage does not take into account translation processes in the considered hydrological system. The outflow always begins at the same time as the initiating inflow, which is unlikely to happen in reality. Therefore, a completion with the linear translation element is required. It forwards every input without any modification. The inflow $p(t)$ to a translation element, which is passed through with a translation time T , is used to calculate the outflow:

$$q(t) = p(t-T) \quad (4.5-24)$$

Regarding the runoff concentration of a catchment or the characteristics of river runoff, both storage and translation processes are involved. In general, these processes are simulated more accurately with a combined model (storage and translation). The system parameter T for a pure translation system is interpreted from the time displacement of specific points on the in- and outflow hydrographs.

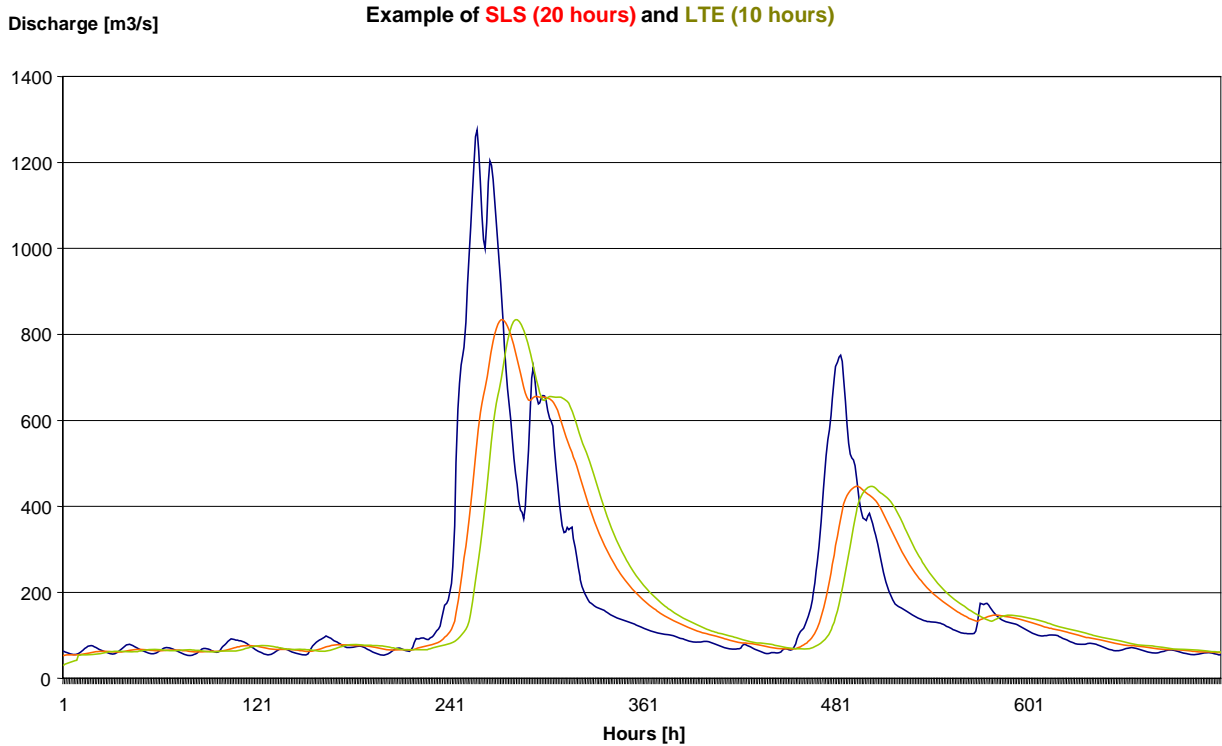


Figure 4.5-4: Example of a single linear storage (SLS) and a Linear translation element (LTE).

SLS and LTE may be also adopted in order to approximate the retention of lakes (Figure 4.5-5).

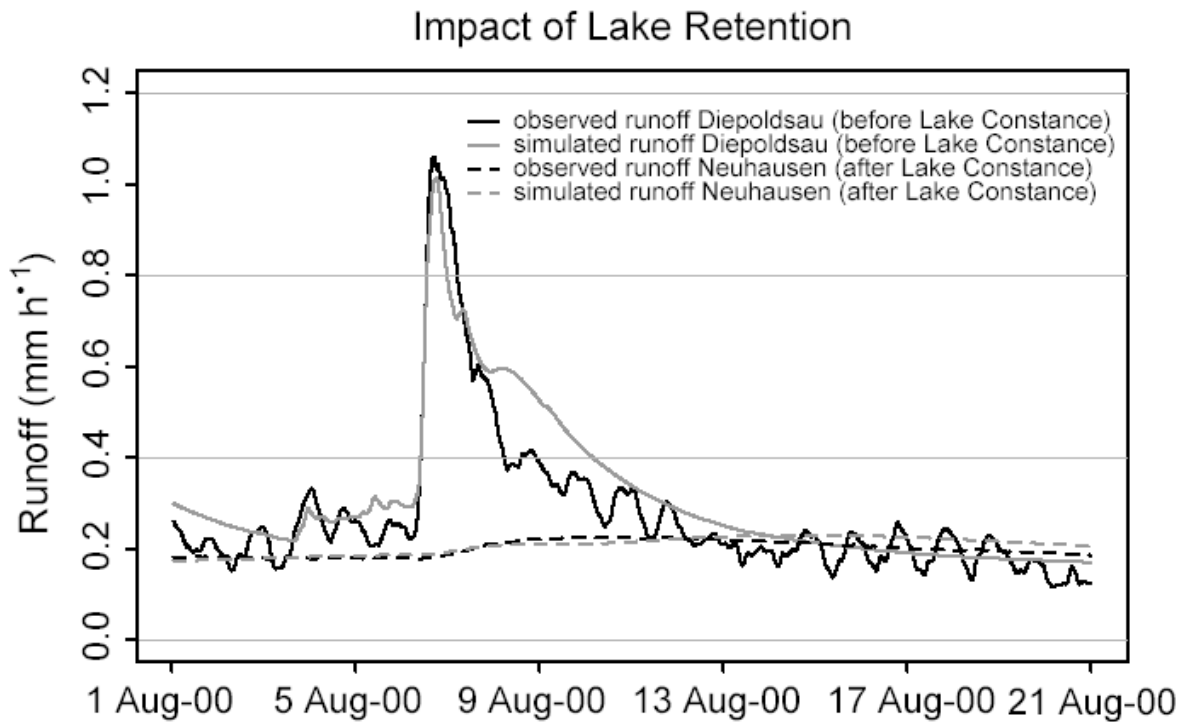


Figure 4.5-5: Impact of Lake Constance retention on the August 2000 flood-peak, illustrated by the simulated and observed discharges at the gauges Diepoldsau and Neuhausen (Verbunt et al., 2006).

Flood routing in the river bed system

Regarding the wave flow phases, we have to answer the question of how the different flood waves from the catchment areas are combined the moment they reach the main river (forecast of flood water). The development of these waves in an open stream system is, in general, in an unsteady state, a flow process which is changing gradually. This process can be described on the basis of the "Saint-Venant-Equation" which is composed of the dynamic base equation and continuity equation. As there is no known analytic solution for this equation, different simplified approaches were developed, e.g. the diffusion-wave-model and kinematic-wave-model.

As an alternative to these hydraulic models, which require a demanding calculating capacity to obtain a numerical solution, hydrologists developed simpler mathematical terms. These models, which show a robust behaviour, are called hydrological or conceptual models. They are based on the following equation, which is valid for an extended river section:

$$Q_z - Q_a = \frac{dS}{dt} \quad (4.5-25)$$

using: S storage capacity of the river section

Q_z inflow to river section

Q_a outflow from river section

The dynamic equation is substituted through a more or less empirical dependency between S and Q_z and/or Q_a . One of these model concepts is the Muskingum-Model after McCarthy (1938)

$$S = K[g \cdot Q_z + (1 - g) \cdot Q_a] \quad (4.5-26)$$

using an accumulation constant K and a dimensionless weighting factor g with values from 0 to 1

Another flood routing model concept is the Kalinin-Miljukov-Model, (Kalinin and Miljukov, 1957) consisting of a cascade of n linear storages using

$$S = K \cdot Q_a \quad (4.5-27)$$

In PREVAH, this term is integrated for the calculation of flood routing in the river bed by the Storage-Translation-Model, consisting of a SLS coupled with a pure translation element.

5. Assimilation and use of hydrological data

5.1 Model requirements

The most important hydrological data are time series of observed discharges at river gauges. These data are required in order to calibrate the model and estimate model efficiency. The format is identical to the format for meteorological station data, except the second row which does not contain the altitude but the catchment area of a gauging station. This is important if the discharges (in $[m^3 s^{-1}]$) are converted into specific discharges (in $[mm \Delta t^{-1}]$), as latter is the unit required by the model.

5.2 Computation of model efficiency

To calibrate and validate a model, the calculated (y_i) and observed (x_i) values are compared assess the simulation and modelling quality, respectively. Beside the visual control of the graphical diagram, quality and error criteria should be used to obtain a more objective rating of the differences between the simulated and observed values. For the use of mathematical parameter optimisation, such objective quality criteria are essential since the parameter optimisation tries to maximise and minimise the particular quality criteria, respectively. The choice of a quality criteria and the corresponding timeframe needs to be completed carefully and in a sophisticated way, depending on the conceptual formulation.

The runoff is the most commonly used term to compare processes in hydrological modelling. However, there can also be other terms used such as evapotranspiration, soil moisture or fill level of storage to obtain a quality assessment of a simulation. It has to be considered that the quality of a simulation depends on the regarded temporal resolution.

The objective statistical coefficients that were used to evaluate the simulated variables S with respect to the observed variables O are:

Empirical coefficient of correlation R_{os} :

This quality criterion is used in analogy to the correlation coefficient of the linear regression. As the required linearity is mostly not fulfilled, and the simulated runoff is not a random variable, the term "correlation coefficient" should be substituted with "sum of the deviation products" or at least used with apostrophes. It has to be recognised that the range of the variant calculation only varies between -1 and +1 and, therefore, changes in the simulation are more difficult to discover than with other quality criteria. We have the possibility to compare different catchment areas.

$$R_{os} = \frac{\sum_{i=1}^N (S_i - \bar{S})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^N (S_i - \bar{S})^2 \sum_{i=1}^N (O_i - \bar{O})^2}} \quad (5.2-1)$$

with \bar{O} and \bar{S} the mean of the observations O_i and simulated S_i values, respectively and N the number of observations. R_{os} tends to unity the more the simulated values have similar dynamics with respect to the observations.

Root mean square error RMSE:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (S_i - O_i)^2}{N}} \quad (5.2-2)$$

$RMSE$ allows for the quantification of the magnitude of the deviation of the simulated from the observed values.

Mean absolute deviation MAD:

$$MAD = \frac{\sum_{i=1}^N |S_i - O_i|}{N} \quad (5.2-3)$$

MAD must be minimised in the calibration phase to obtain a better quantitative agreement for the simulated variable with respect to the observation.

Efficiency score E_2 (Legates and McCabe, 1999; Nash and Sutcliffe, 1970):

$$E_2 = 1 - \frac{\sum_{i=1}^n |O_i - S_i|^2}{\sum_{i=1}^n \left| O_i - \left[\frac{1}{n} \sum_{i=1}^n O_i \right] \right|^2} \quad (5.2-4)$$

E_2 quantifies the relative improvement of the model compared to the mean of the observations. An efficiency below zero indicates that average daily measured stream flow would have been as good a predictor as the modelled stream flow. A perfect model prediction has a score equal to one. Any positive value corresponds to an improvement. E_2 tends towards unity when S_i tends towards O_i . Further, the logarithmic formulation of E_2 (Schulla, 1997; Hock, 1999) is considered:

$$E_2^{\log} = 1 - \frac{\sum_{i=1}^n |\ln(O_i) - \ln(S_i)|^2}{\sum_{i=1}^n \left| \ln(O_i) - \left[\frac{1}{n} \sum_{i=1}^n \ln(O_i) \right] \right|^2} \quad (5.2-5)$$

The logarithmic efficiency score E_2^{\log} gives valuable indications on the model performance in the case of discharge simulations during low-flow periods in winter (Gurtz et al., 2001). The range of both E_2 and E_2^{\log} is $[-\infty, 1]$. The logarithmic form should possibly be used in addition to the linear variant.

5.3 Computation of flood statistics

Three peak-specific efficiency scores are computed by the PREVAH sub-module FLOODSTAT. They follow the recommendations of Lamb (1999) and allow in-depth analysis of the peak simulation ability of the PREVAH model parameter set in use (see Viviroli, 2007 for details). The efficiency scores are defined as follows:

Sum of time- and size-weighted peak errors (Lamb, 1999)

$$P - QT = \sum_{i=1}^m \sqrt{\left[\frac{(P_i - p_i)}{p^*} \right]^2 + \left[\frac{(T_i - t_i)}{t^*} \right]^2} \quad (5.3-1)$$

with $P_i = i^{\text{th}}$ observed peak, $p_i = i^{\text{th}}$ simulated peak, $p^* =$ difference between largest and smallest observed peak, $T_i =$ time of i^{th} observed peak, $t_i =$ time of i^{th} simulated peak, $t^* =$ time steps between occurrence of first and last observed peak and $m =$ number of extracted peaks in the peak flow record (usually three times the number of years considered, see FLOODSTAT OPTIONS in the WINPREVAH documentation for details). A $P-QT$ score of 0 means complete correspondence of observed and simulated peaks; with rising score the deviations in timing and size of the peaks increase. $P-QT$ is a relative score with no upper limit, and since the score is scaled relative to p^* and t^* , its meaning is specific and can not be compared between different peak flow records.

Sum of absolute errors SAE in peak flow record (Lamb, 1999)

$$P - SAE = \sum_{i=1}^m |P_i - p_i| \quad (5.3-2)$$

Sum of weighted absolute errors WAE in entire runoff record

$$WAE = \sum_{i=1}^n Q_i^a |Q_i - q_i| \quad (5.3-3)$$

with Q_i = observed runoff, q_i = simulated runoff, a = exponent (1.5 is recommended) and n = total number of runoff records.

Additionally, three further statistical scores are computed:

NSE: Efficiency score following Nash and Sutcliffe (1970) (see Section 5.2)

SPM_R: Spearman rank-correlation coefficient (see e.g. Bahrenberg et al., 1990) between observed and simulated peaks in the peak flow record.

$$SPM_R = 1 - \frac{\sum_{i=1}^m |R_i - r_i|}{m(m^2 - 1)} \quad (5.3-4)$$

With R_i = rank of i^{th} observed peak, p_i = rank of i^{th} simulated peak and m = number of extracted peaks. It is assumed that there are no peaks of exactly identical magnitude. This coefficient may be used to assess the ability of the current parameter set to reproduce the magnitude order of flood peaks.

SPM_P: Significance level of *SPM_R*. Example: In a two-sided test with an α error limit of 5%, a value below 0.975 means that there is no significant correlation between observed and simulated peaks. Note that normal distribution is assumed which applies only to record sets of 30 or more samples.

Please note that it is difficult to obtain high standard efficiencies and peak record efficiencies with the same set of PREVAH parameters. Depending on the accuracy desired by the user and the application goal, it may be necessary to use different parameter sets for the ideal representation of normal and extreme flow periods, respectively. However, a parameter set for simulating peak flows should achieve at least acceptable standard efficiencies (performance over the whole simulation period focusing on non-extreme runoff), since simulation results are more trustworthy when PREVAH is able to capture basic hydrological characteristics of the catchment in consideration (Viviroli, 2007).

6. Model calibration

6.1 Introduction

As a standard procedure for model calibration and validation, the available data sets for hydrological simulations in a catchment are divided into two non-overlapping periods. If the global time series is longer than five years, at least three years are used as the calibration period. The first year of the simulation period should be used as an initialisation period and then excluded from the evaluation. This decision is based on the uncertainty of the values for the snow water equivalent and different water storages at initialisation. This restriction is less important in regions where snow accumulation plays a marginal role in the runoff generation process.

The remaining period is used for verification of the model quality without further adjustments of the tuneable parameters. The analysis of the hydrological behaviour of the catchment generally includes the entire available time series. The quality of the model simulation can be assessed by using different observed variables. The comparison of different outputs of a model run with selected observed variables allows a multiple-response verification of the model's capabilities. Hydrometeorological observations available for model evaluation include:

- Discharge observations
- Soil moisture time series
- Observed fluctuations of the groundwater level
- Lysimeter data (evapotranspiration, percolation, storage changes)
- Records of snow height and snow water equivalent
- Snow patterns derived by satellite observations
- Latent heat flux values observed by eddy correlation and computed using the Bowen ratio method

6.2 Trial and error calibration

If calibration of PREVAH is completed manually, the output is compared with observed values and evaluated by means of objective statistical criteria. A graphical comparison between observation and simulation is made in the calibration phase for a subjective assessment of the simulation quality. This allows an expertise-based assessment of the model's free parameters. As a further index of the model quality, the quantitative difference between computed and measured data is taken into account and analysed (e.g. between computed and observed average yearly discharge). The most sensitive catchment specific tuneable parameters to be calibrated are:

- Adjustment factors for precipitation (snow and rain)
- Parameters of the snowmelt module
- Parameters of the glacial melt module
- Non-linearity exponent controlling the soil moisture recharge
- Threshold storage parameter for the generation of surface runoff
- Maximal storage available for fast baseflow (Schwarze et al., 1999)
- Storage times which govern the process of runoff generation (surface runoff, interflow, delayed and fast baseflow)
- Percolation rate

6.3 Automatic calibration

6.3.1 Procedure and set-up

To perform the automatic model calibration, observed runoff data for the catchment in the defined simulation period are required. The general idea behind an automatic calibration is to allow the calibration module to find the best settings for the selected tuneable parameters with help of a set of model runs which are evaluated by means of different objective functions. These functions are computed on the basis of the determined efficiency and volume error of the model simulations with PREVAH. The model parameters are calibrated pair-wise (two parameters at a time). The following procedure is applied for the automatic calibration of PREVAH:

- A set of so-called parameter pairs is defined. Maximum and minimum limits are set for each parameter. Thus, a parameter space is defined (see also the documentation of the tool VIEWOPTIM).
- The parameter space is subdivided into 9 sections, each of them covering $\frac{1}{9}$ of the area of the parameter space.
- The parameter combinations found at the 4 main intersections of the parameter space are used for running PREVAH.
- The objective scores are computed as defined in the next section, so that the calibration module can decide which of these 4 runs (and corresponding parameter configurations) was the most accurate.
- The parameter space is then reduced (white area), a new parameter space is centred on the best parameter configuration of the previous iteration. $\frac{5}{9}$ of the original parameter space area is discarded (grey area).
- The new parameter-space is then subdivided anew into 9 sections, and the procedure described above is repeated. This is continued until a pre-defined number of iterations is reached or until the improvement in model efficiency as compared to the last iteration remains under a defined threshold.

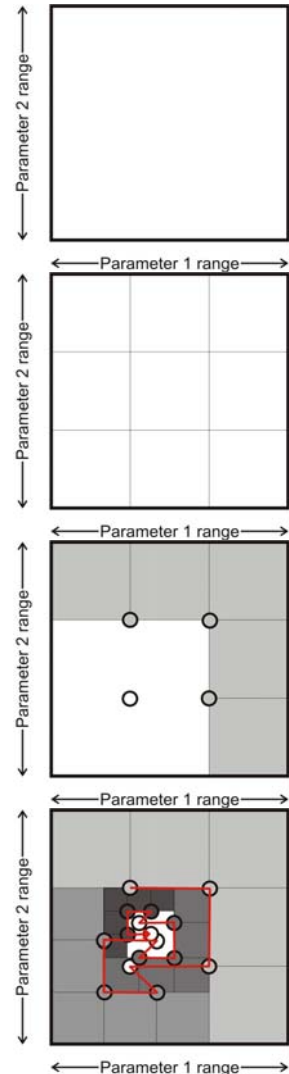


Table 6.3-1: Default parameter-pairs for automatic calibration of PREVAH for Swiss glaciated catchments. These default settings assume that the recommended snowmelt module "4. EMA with varying melt factor" is used.

PAIR	Parameter 1	Parameter 2
1	Rain correction [%]	Snow correction [%]
2	Threshold Temperature Rain-snow [°C]	Transition Temperature Rain-snow [°C]
3	Maximal degree day factor [mm d ⁻¹ K ⁻¹]	Minimal degree day factor [mm d ⁻¹ K ⁻¹]
4	Threshold Temperature Rain-snow [°C]	Threshold Temperature snowmelt [°C]
5	Exponent for soil moisture recharge [-]	Percolation [mm h ⁻¹]
6	Refreezing factor [mm d ⁻¹ K ⁻¹]	Rad. melt factor snow [mm h ⁻¹ K ⁻¹ W ⁻¹ m ²]
7	Threshold storage for surface runoff [mm]	Storage time for surface runoff [h]
8	Storage time for interflow [h]	Percolation [mm h ⁻¹]
9	Storage time for fast baseflow [h]	Maximum storage for fast baseflow [mm]
10	Storage time for delayed baseflow [h]	Percolation [mm h ⁻¹]
11	Temperature melt factor for ice [mm d ⁻¹ K ⁻¹]	Rad. melt factor ice [mm h ⁻¹ K ⁻¹ W ⁻¹ m ²]

Table 6.3-2: Recommended parameter-pairs for automatic calibration of PREVAH for large catchments with no glaciers and daily meteorological input. These default settings require that the snowmelt module "0. Positive degree day index (PDDI)" (see Section 4.5.1) is used.

PAIR	Parameter 1	Parameter 2
1	Rain correction [%]	Snow correction [%]
2	Threshold Temperature Rain-snow [°C]	Transition Temperature Rain-snow [°C]
3	Maximal degree day factor [mm d ⁻¹ K ⁻¹]	Minimal degree day factor [mm d ⁻¹ K ⁻¹]
4	Refreezing factor [mm d ⁻¹ K ⁻¹]	Threshold Temperature snowmelt [°C]
5	Exponent for soil moisture recharge [-]	Percolation [mm h ⁻¹]
6	Threshold storage for surface runoff [mm]	Storage time for surface runoff [h]
7	Storage time for interflow [h]	Percolation [mm h ⁻¹]
8	Storage time for fast baseflow [h]	Maximum storage for fast baseflow [mm]
9	Storage time for delayed baseflow [h]	Percolation [mm h ⁻¹]

The number of iterations can be defined by the user although 4 to 8 iterations for each parameter pair are recommended. If the calibration module does not register an improvement from the previous iteration step, further iterations are skipped and the calibration continues with the subsequent parameter pair. The set-up of the automatic calibration is controlled by WINPREVAH (see Part III of the PREVAH documentation).

6.3.2 The 3×3 objective scores

Three scores are computed to assign a total score to each model run and determine the best model run during automatic model calibration. Each score is computed on the basis of three objective functions which in turn can be weighted separately. Thus, a specific score and objective function can have larger or smaller influence on the total score.

Linear Score (ALIN)

The linear score analyses the quality of the model run with respect to the linear efficiency score E_2^{lin} (Nash and Sutcliffe, 1970; Legates and McCabe, 1999). Three weighted objective functions are defined to assess ALIN:

- The linear efficiency score during the calibration period.
The range of this score is between $-\infty$ and 1. The goal of the calibration should be to maximise this score. To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALIN_{PERIOD} = \begin{cases} 0 & \text{if } E_2^{lin} < E_{2_MIN}^{lin} \\ \frac{(E_2^{lin} - E_{2_MIN}^{lin})}{(E_{2_MAX}^{lin} - E_{2_MIN}^{lin})} & \text{if } E_{2_MIN}^{lin} \leq E_2^{lin} \leq E_{2_MAX}^{lin} \\ 1 & \text{if } E_2^{lin} > E_{2_MAX}^{lin} \end{cases} \quad (6.3-1)$$

The fuzzy function is governed by two parameters: the user-definable maximum and minimum values for E_2^{lin} . As a result, the score of a simulation with respect to the linear efficiency score during the entire calibration period is established ($ALIN_{PERIOD}$).

- The year-to-year standard deviation (STDEV) of the linear efficiency score during the calibration years. The range of this score is between 0 and ∞ . This score should allow that all the years in the calibration period have a similar linear efficiency score. The goal of the calibration should be to maximise this score (and thus minimise year-to-year standard deviation). To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALIN_{YY} = \begin{cases} 1 & \text{if } STDEV_{YY}(E_2^{lin}) < STDEV_{YY_MIN} \\ \left(1 - \frac{(STDEV_{YY}(E_2^{lin}) - STDEV_{YY_MIN})}{(STDEV_{YY_MAX} - STDEV_{YY_MIN})}\right) & \text{if } STDEV_{YY_MIN} \leq STDEV_{YY}(E_2^{lin}) \leq STDEV_{YY_MAX} \\ 0 & \text{if } STDEV_{YY}(E_2^{lin}) > STDEV_{YY_MAX} \end{cases} \quad (6.3-2)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of E_2^{lin} from year to year ($STDEV_{YY}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of linear efficiency score during the different years of the calibration period ($ALIN_{YY}$).

- The month-to-month standard deviation of the linear efficiency score during the calibration years. The range of this score is between 0 and ∞ . This score should allow that, during the calibration period, all the months have a similar linear efficiency score. The goal of the calibration should be to maximise this score (and thus minimise month-to-month standard deviation). To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALIN_{MM} = \begin{cases} 1 & \text{if } STDEV_{MM}(E_2^{lin}) < STDEV_{MM_MIN} \\ \left(1 - \frac{(STDEV_{MM}(E_2^{lin}) - STDEV_{MM_MIN})}{(STDEV_{MM_MAX} - STDEV_{MM_MIN})}\right) & \text{if } STDEV_{MM_MIN} \leq STDEV_{MM}(E_2^{lin}) \leq STDEV_{MM_MAX} \\ 0 & \text{if } STDEV_{MM}(E_2^{lin}) > STDEV_{MM_MAX} \end{cases} \quad (6.3-3)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of E_2^{lin} from month to month ($STDEV_{MM}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of linear efficiency score during the different months in the calibration period ($ALIN_{MM}$).

ALIN is then computed as follows:

$$ALIN = ALIN_{PERIOD} \cdot \frac{w_1^{lin}}{(w_1^{lin} + w_2^{lin} + w_3^{lin})} + ALIN_{YY} \cdot \frac{w_2^{lin}}{(w_1^{lin} + w_2^{lin} + w_3^{lin})} + ALIN_{MM} \cdot \frac{w_3^{lin}}{(w_1^{lin} + w_2^{lin} + w_3^{lin})} \quad (6.3-4)$$

with w_1^{lin} , w_2^{lin} , w_3^{lin} as the weight of the three fuzzy scores obtained through application of the previously defined fuzzy functions. All parameters and weights of the fuzzy function have to be assigned at the beginning of the simulation.

Logarithmic Score (ALOG)

The logarithmic score analyses the quality of the model run with respect to the logarithmic efficiency score E_2^{log} . Three weighted objective functions are defined to assess ALOG:

- The logarithmic efficiency score during the calibration period. The range of this score is between $-\infty$ and 1. The goal of the calibration should be to maximise this score. To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALOG_{PERIOD} = \begin{cases} 0 & \text{if } E_2^{log} < E_{2_MIN}^{log} \\ \frac{(E_2^{log} - E_{2_MIN}^{log})}{(E_{2_MAX}^{log} - E_{2_MIN}^{log})} & \text{if } E_{2_MIN}^{log} \leq E_2^{log} \leq E_{2_MAX}^{log} \\ 1 & \text{if } E_2^{log} > E_{2_MAX}^{log} \end{cases} \quad (6.3-5)$$

The fuzzy function is governed by two parameters: the maximum and minimum E_2^{log} . These two parameters have to be defined to establish the score of a simulation with respect to the logarithmic efficiency score during the calibration period ($ALOG_{PERIOD}$).

- The year-to-year standard deviation of the logarithmic efficiency score during the calibration years. The range of this score is between 0 and ∞ . This score should allow that all the years in the calibration period have a similar logarithmic efficiency score. The goal of the calibration should be to maximise this score (and thus minimise year-to-year standard deviation). To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALOG_{YY} = \begin{cases} 1 & \text{if } STDEV_{YY}(E_2^{log}) < STDEV_{YY_MIN} \\ \left(1 - \frac{(STDEV_{YY}(E_2^{log}) - STDEV_{YY_MIN})}{(STDEV_{YY_MAX} - STDEV_{YY_MIN})} \right) & \text{if } STDEV_{YY_MIN} \leq STDEV_{YY}(E_2^{log}) \leq STDEV_{YY_MAX} \\ 0 & \text{if } STDEV_{YY}(E_2^{log}) > STDEV_{YY_MAX} \end{cases} \quad (6.3-6)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of E_2^{log} from year to year ($STDEV_{YY}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of logarithmic efficiency score during the different years of the calibration period ($ALOG_{YY}$).

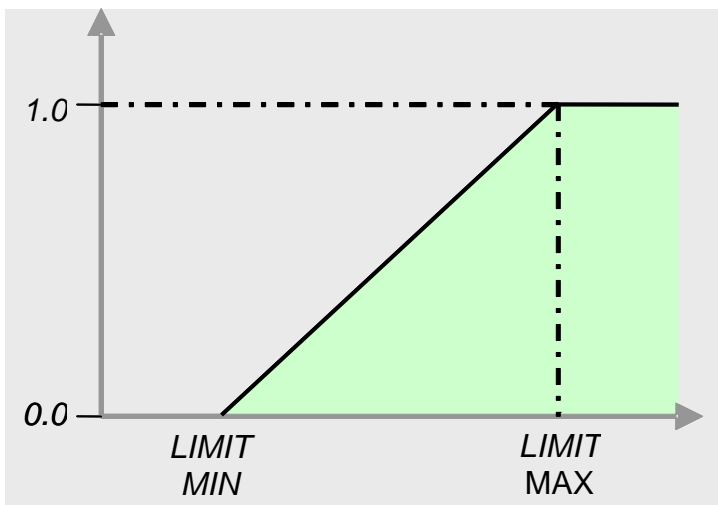


Figure 6.3-1: Minimum and maximum limits of the fuzzy functions needed to scale the objective functions to a range between 0 and 1.

- The month-to-month standard deviation of the logarithmic efficiency score during the calibration years. The range of this score is between 0 and ∞ . This score should allow that, during the calibration period, all the months have a similar logarithmic efficiency score. The goal of the calibration should be to maximise this score (and thus minimise month-to-month standard deviation) To reduce this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$ALOG_{MM} = \begin{cases} 1 & \text{if } STDEV_{MM}(E_2^{log}) < STDEV_{MM_MIN} \\ \left(1 - \frac{(STDEV_{MM}(E_2^{log}) - STDEV_{MM_MIN})}{(STDEV_{MM_MAX} - STDEV_{MM_MIN})} \right) & \text{if } STDEV_{MM_MIN} \leq STDEV_{MM}(E_2^{log}) \leq STDEV_{MM_MAX} \\ 0 & \text{if } STDEV_{MM}(E_2^{log}) > STDEV_{MM_MAX} \end{cases} \quad (6.3-7)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of E_2^{log} from month to month ($STDEV_{MM}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of logarithmic efficiency score during the different months in the calibration period ($ALOG_{MM}$).

$ALOG$ is then computed as follows:

$$ALOG = ALOG_{PERIOD} \cdot \frac{w_1^{log}}{(w_1^{log} + w_2^{log} + w_3^{log})} + ALOG_{YY} \cdot \frac{w_2^{log}}{(w_1^{log} + w_2^{log} + w_3^{log})} + ALOG_{MM} \cdot \frac{w_3^{log}}{(w_1^{log} + w_2^{log} + w_3^{log})} \quad (6.3-8)$$

with w_1^{log} , w_2^{log} , w_3^{log} as the weight of the three fuzzy scores obtained through application of the previously defined fuzzy functions. All the parameters and weights of the fuzzy function have to be assigned at the beginning of the simulation.

Volumetric Score (*AVOL*)

The Volumetric score analyses the quality of the model run with respect to the volumetric deviation in percent (*DV*) between observed and simulated runoff. *DV* is defined as follows:

$$DV = \left| \sum_{i=1}^n \frac{S_i}{O_i} - 1 \right| \quad (6.3-9)$$

S_i is the simulated runoff at the time step i , O_i is the observed runoff at time step i . n is the number of time steps. Three weighted objective functions are defined for *AVOL*:

- The volumetric score during the calibration period.
The range of this score is between 0 and ∞ . The goal of the calibration should be to minimise this score. To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$AVOL_{PERIOD} = \begin{cases} 1 & \text{if } DV < DV_{MIN} \\ \left(1 - \frac{(DV - DV_{MIN})}{(DV_{MAX} - DV_{MIN})} \right) & \text{if } DV_{MIN} \leq DV \leq DV_{MAX} \\ 0 & \text{if } DV > DV_{MAX} \end{cases} \quad (6.3-10)$$

The fuzzy function is governed by two parameters: the maximum and minimum *DV*. These two parameters have to be defined by the user to establish the score of a simulation with respect to the volumetric score during the full calibration period ($AVOL_{PERIOD}$).

- The year-to-year standard deviation of the volumetric score during the calibration years.
The range of this score is between 0 and ∞ . This score should allow that all the years in the calibration period have a similar volumetric score. The goal of the calibration should be to maximise this score (and thus minimise year-to-year standard deviation) To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$AVOL_{YY} = \begin{cases} 1 & \text{if } STDEV_{YY}(DV) < STDEV_{YY_MIN} \\ \left(1 - \frac{(STDEV_{YY}(DV) - STDEV_{YY_MIN})}{(STDEV_{YY_MAX} - STDEV_{YY_MIN})} \right) & \text{if } STDEV_{YY_MIN} \leq STDEV_{YY}(DV) \leq STDEV_{YY_MAX} \\ 0 & \text{if } STDEV_{YY}(DV) > STDEV_{YY_MAX} \end{cases} \quad (6.3-11)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of *DV* from year to year ($STDEV_{YY}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of volumetric score during the different years of the calibration period ($AVOL_{YY}$).

- The month-to-month standard deviation of the volumetric score during the calibration years.
The range of this score is between 0 and ∞ . This score should allow that, during the calibration period, all the months have a similar volumetric score. The goal of the calibration should be to maximise this score (and thus minimise month-to-month standard deviation). To scale this score to a range between 0 and 1, a simple fuzzy function is introduced:

$$AVOL_{MM} = \begin{cases} 1 & \text{if } STDEV_{MM}(DV) < STDEV_{MM_MIN} \\ \left(1 - \frac{(STDEV_{MM}(DV) - STDEV_{MM_MIN})}{(STDEV_{MM_MAX} - STDEV_{MM_MIN})} \right) & \text{if } STDEV_{MM_MIN} \leq STDEV_{MM}(DV) \leq STDEV_{MM_MAX} \\ 0 & \text{if } STDEV_{MM}(DV) > STDEV_{MM_MAX} \end{cases} \quad (6.3-12)$$

The fuzzy function is governed by two parameters: the maximum and minimum standard deviation of *DV* from month to month ($STDEV_{MM}$). These two parameters have to be defined by the user to establish the score of a simulation with respect to the variability of volumetric score during the different months in the calibration period ($AVOL_{MM}$).

AVOL is then computed as follows:

$$AVOL = AVOL_{PERIOD} \cdot \frac{w_1^{vol}}{(w_1^{vol} + w_2^{vol} + w_3^{vol})} + AVOL_{YY} \cdot \frac{w_2^{vol}}{(w_1^{vol} + w_2^{vol} + w_3^{vol})} + AVOL_{MM} \cdot \frac{w_3^{vol}}{(w_1^{vol} + w_2^{vol} + w_3^{vol})} \quad (6.3-13)$$

with w_1^{vol} , w_2^{vol} , w_3^{vol} as the weight of the three fuzzy scores obtained through application of the previously defined fuzzy functions. All the parameters and weights of the fuzzy function have to be assigned at the beginning of the simulation.

Table 6.3-3: Recommended settings for the nine objective functions used for the calibration of PREVAH.

#	Description	SCORE	WEIGHT	LIMIT _{MIN}	LIMIT _{MAX}	Function
1	Linear efficiency – full period	ALIN _{PERIOD}	6	0.25	0.95	E_2^{lin}
2	Linear efficiency – year-by-year	ALIN _{YY}	4	0.1	0.01	STDEV(E_2^{lin})
3	Linear efficiency – month-by-month	ALIN _{MM}	2	0.5	0.02	STDEV(E_2^{lin})
4	Logarithmic efficiency – full period	ALOG _{PERIOD}	3	0.25	0.95	E_2^{log}
5	Logarithmic efficiency – year-by-year	ALOG _{YY}	2	0.1	0.01	STDEV(E_2^{log})
6	Logarithmic efficiency – month-by-month	ALOG _{MM}	1	0.5	0.02	STDEV(E_2^{log})
7	Volume error – full period	AVOL _{PERIOD}	10	0.1	0.01	DV
8	Volume error – year-by-year	AVOL _{YY}	4	0.15	0.02	STDEV(DV)
9	Volume error – month-by-month	AVOL _{MM}	3	0.10	0.02	STDEV(DV)

The column SCORE in Table 6.3-3 defines the different functions (see Equations 6.3-1 to 6.3-16).

Table 6.3-3 indicates the recommended (and default) weights of each function for building the corresponding summary score and overall score, as well as the "worst case" (minimum) and "best case" (maximum) limits.

6.3.3 Overall score (ATOT)

The overall score is a weighted function of the three scores ALIN, ALOG and a VOL (cf. Figure 6.3-2):

$$ATOT = ALIN^{w^{lin}/w^{tot}} \cdot ALOG^{w^{log}/w^{tot}} \cdot AVOL^{w^{vol}/w^{tot}} \tag{6.3-14}$$

with $w^{lin} = w_1^{lin} + w_2^{lin} + w_3^{lin}$; $w^{log} = w_1^{log} + w_2^{log} + w_3^{log}$; $w^{vol} = w_1^{vol} + w_2^{vol} + w_3^{vol}$ (6.3-15)

and $w^{tot} = w^{lin} + w^{log} + w^{vol}$ (6.3-16)

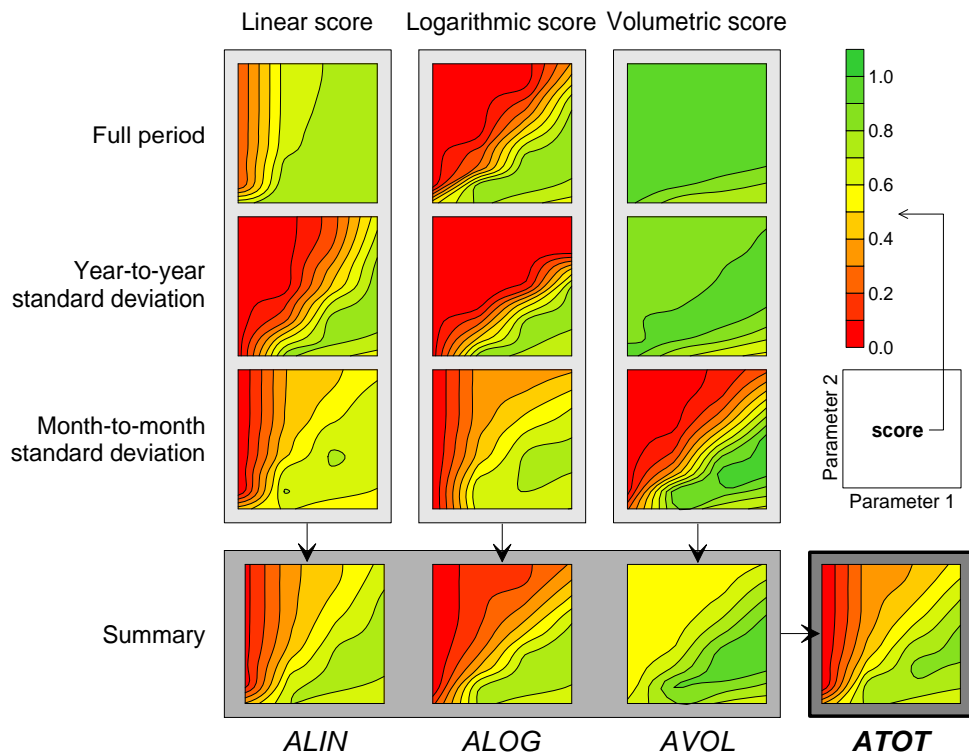


Figure 6.3-2: Composition of overall score from partial scores (Viviroli, 2007).

Figure 6.3-3 shows the course of these overall scores during a calibration process. PREVAH maintains a log of the corresponding values which is written to a file (see Part III, Chapter I: VIEWOPTIM).

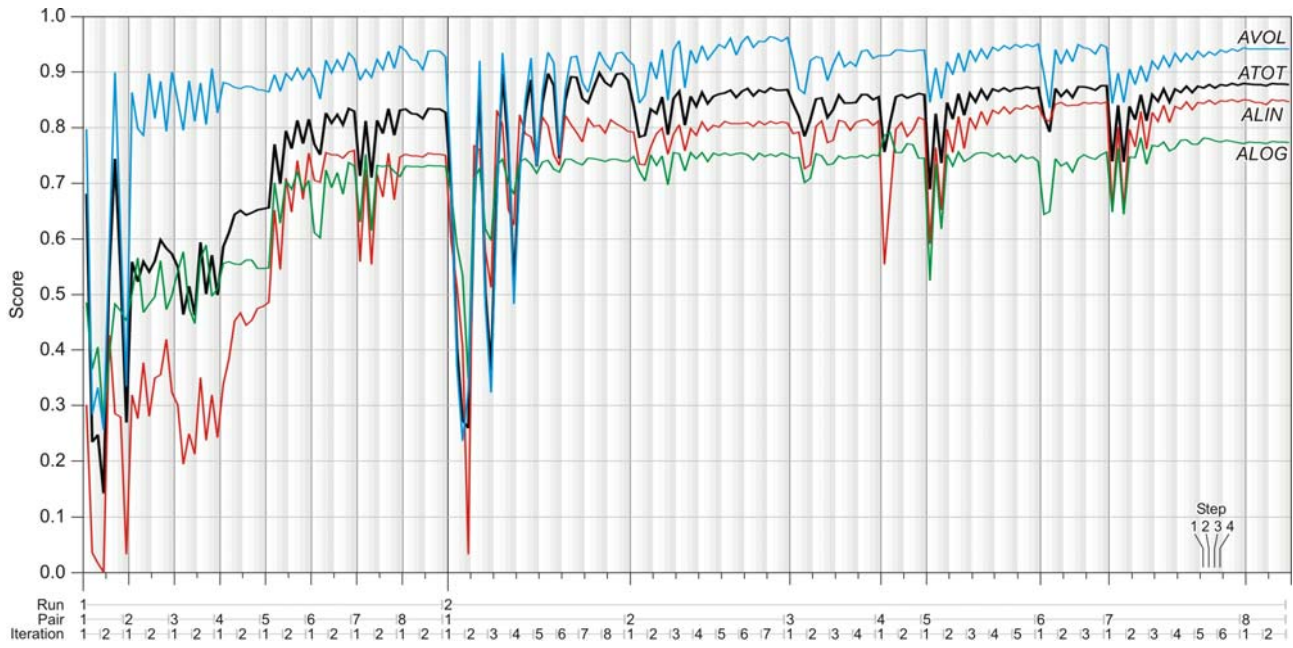


Figure 6.3-3: Full visualisation of the log file (*.log) of the calibration module of WINPREVAH. ALIN is the linear score, ALOG the logarithmic score, AVOL the volumetric score and ATOT the total score (Viviroli, 2007).

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Appendix

Radiation equations used in PREVAH

Short wave radiation R_{sw}

Default using observed and spatially interpolated global radiation (RG):

$$R_{sw} = (1 - \alpha) \cdot RG$$

where α is the albedo

Penman (1948):

$$R_{sw} = (1 - \alpha) \cdot G_0 \cdot (0.18 + 0.55 \cdot n/N)$$

where G_0 is the potential incoming clear sky direct radiation [W m^{-2}] and n/N is the relative sunshine duration

Penman (1956):

$$R_{sw} = (1 - \alpha) \cdot G_0 \cdot (0.20 + 0.48 \cdot n/N)$$

Golchert (1981):

$$R_{sw} = (1 - \alpha) \cdot G_0 \cdot (A_G + B_G \cdot n/N)$$

where A_G and B_G are dimensionless monthly varying constants after Golchert (1981)

Kasten und Czeplak (1980):

$$G_T = G_0 (1 - 0.7CN^3)$$

$$R_{sw} = (1 - \alpha) \cdot G_T \cdot (1 - 0.55 \cdot CN - 0.25 \cdot CN^4)$$

where G_T is the global radiation with cloud coverage [W m^{-2}] and CN is the cloud coverage ($1/8$ to $8/8$)

Morecs (1981):

$$\eta = 1$$

$$R_{sw} = (1 - \alpha) G_0 (\eta(A_M + B_M n/N) + C_M (1 - \eta))$$

where A_M , B_M and C_M are dimensionless constants after Morecs (1981); while B_M is monthly varying, A_M and C_M are constant over the year

Schulla (1997):

$$R_{sw} = (1 - \alpha) G_0 (0.23 + 1.77n/N) - 2.28(n/N)^2 + 1.28(n/N)^2$$

Long wave radiation R_{lw}

Penman (1948):

$$R_{lw} = -\sigma T_K^4 (0.56 - 0.09\sqrt{0.75e}) \cdot (0.1 + 0.9n/N)$$

where σ is the Stefan-Boltzmann constant and T_K is the air temperature in Kelvin

Penman (1956):

$$R_{lw} = -\sigma T_K^4 (0.47 - 0.0077\sqrt{0.75e}) (0.2 + 0.8n/N)$$

Angstroem (1918):

$$L_{DN0} = \sigma T_K^4 (0.79 - 0.174 * 10^{-0.055 * 0.75e})$$

where L_{DN0} is the reflectance of the atmosphere

Feussner(s.a.):

$$L_{DN0} = \sigma T_K^4 (1 - 10^{-0.424 * (0.75e_L)^{0.2}})$$

Kasten and Czeplak (1980):

$$L_{DN0} = \sigma T_K^6 A_{CZ} E_{PS0} - B_{CZ}$$

where A_{CZ} [-], B_{CZ} [$W m^{-2}$] and E_{PS0} [K^{-2}] are constants after Kasten and Czeplak (1980)

with sunshine duration:

$$Rlw = A_T (L_{DN0} - \sigma T_K^4) (0.2 + 0.8n / N)$$

where A_T is the reflectance coefficient of the surface for longwave radiation

with cloud amount:

$$Rlw = A_T (L_{DN0} (1 + 0.27CN^2) - \sigma T_K^4)$$

Brutsaert (1975):

$$Rlw = A_T \sigma T_K^4 (1.28(e / T_K)^{1/7} - 1) (0.2 + 0.8n / N)$$

Schulla (1997):

$$Rlw = \sigma T_K^4 (0.52 - 0.065\sqrt{e}) (0.23 + 0.77n / N)$$



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The Hydrological Modelling System PREVAH

Part III – User Manual

**Daniel Viviroli,
Joachim Gurtz,
and Massimiliano Zappa**

This document contains the user manual for the hydrological modelling system PREVAH. It is Part III of the extensive model documentation by Viviroli, Gurtz and Zappa (2007) and is complemented by Part I, which gives an overview of PREVAH, and Part II, the physical model description. Part IV is a sample project containing selected components of the modelling system.

<i>Publication Part</i>	Part I	Part II	Part III	Part IV
<i>Contents</i>	Overview and selected applications	Physical model description	User manual	Sample project and selected executables
<i>Availability</i>	Printed only	On-line only (pdf)	On-line only (pdf)	On-line only (zip)

The PREVAH modelling system is available for academic and research purposes exclusively. It must not be used commercially. Please read the "Terms of use" on page 3 of Part III.

Last change of this document: May 07, 2008

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Terms of use

The tools presented in this manual have been jointly developed by Daniel Viviroli (Institute of Geography, University of Berne) and Massimiliano Zappa (Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf) as an extension to the PREVAH model. Together with the model core, which was originally developed by Joachim Gurtz (Institute for Atmospheric and Climate Science, ETH Zürich), they represent a complete modelling system with various pre- and postprocessing tools (referred to as "Software" below).

The Software was developed in the Compaq Visual Fortran Environment, partly using freeware ActiveX components provided by the Compaq Array Viewer (both © 2001 Compaq Computer Corporation).

This Software is property of the authors. It is provided upon request to academics employed by educational institutions and for academic and research purposes exclusively. The authors do not make any warranty of any kind with respect to the suitability of the software for any particular use or its suitability for use under any specific conditions; and will not be liable for any claims, damages or liabilities which arise directly or indirectly from the use of the software, including claims for loss of profit. You must not use this Software commercially. This includes use of the software or any derivative of it for research with the final aim of developing products for sale or license to a third party.

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For the modelling system:

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Installation

Prior to the first use of several components of the hydrological modelling system PREVAH (i.e. WINGRID, WINHRU and HYDROGRAPH), the Array Viewer components (© 2001, Compaq Computer Corporation) have to be installed. The free, fully functional viewer component (declared "demo version") can be downloaded as installer package from Intel¹. Make sure your system supports the required OpenGL and ActiveX standards.

Alternatively, the batch program "install_viewer.bat" may be used; it is distributed with complete versions of the modelling system such as the release coming along with this publication. It comes with the necessary program libraries (AVIEW160.DLL, AVIS2D.OCX, AVISGRID.OCX and DFDLG100.DLL) which are registered after execution of the batch program.

A complete sample project, including selected components of the PREVAH modelling system described here, is available on-line.

¹ current hyperlink: <http://www.intel.com/cd/software/products/asmo-na/eng/compilers/226288.htm>

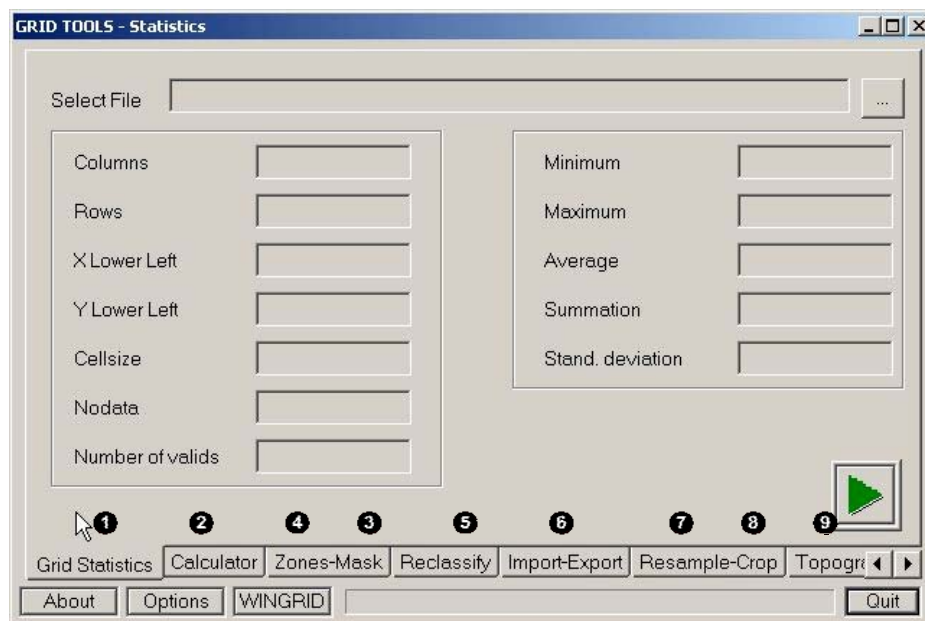
A GRIDMATH: Management of PREVAH-formatted binary grids

A.1 Introduction

The management of digital representations of spatially distributed physiogeographical information is an important requirement for the development, parameterisation and initialisation of GIS-based spatially distributed hydrological models. GRIDMATH is a tool allowing the management of spatial data stored in the grid format required for using the hydrological modelling system PREVAH.

The GRIDMATH tool allows different operations:

- ❶ Computation of statistical values of a grid
- ❷ Simple calculations between two grids or between a grid and a number
- ❸ Overlaying a grid mask to a grid
- ❹ Zonal statistics between two grids
- ❺ Reclassifying the content of a grid
- ❻ Importing grid from and exporting grid to other grid formats
- ❼ Reducing the resolution of a grid (resample) by different methods
- ❽ Reducing the size of a grid by cropping the borders
- ❾ Making the topographic analysis of a digital elevation model grid



Main dialog of GRIDMATH

A.2 Binary format

In the PREVAH modelling system, a binary grid format is used. In order to exchange grids between different computer platforms and with other software, e.g. with ESRI ArcInfo, an ASCII-format is required:

Rows 1 to 6: grid header (number of columns and rows, co-ordinates of the lower left corner, cell size, No-Data value)

The following rows represent the grid data from top left to bottom right:

ncols	7					
nrows	12					
xllcorner	680500					
yllcorner	222200					
cellsize	2000					
NoData_value	-9999					
-9999		-9999	-9999	-9999	-9999	-9999
-9999		-9999	-9999	-9999	-9999	-9999
-9999		-9999	586	559	595	601
584 -9999		-9999	-9999	-9999	-9999	-9999
-9999		449	-9999	-9999	454	511
-9999		561	529	509	498	487
521 523		523	534	-9999	-9999	-9999
-9999		-9999	-9999	-9999	-9999	-9999
-9999		-9999	-9999	-9999	-9999	345
567 453		456	478	789	576	482
123 -9999		1252	1211	876	564	825
-9999		-9999	234	1246	-9999	-9999

The PREVAH binary format is structured similarly to the ASCII-format. All values are stored in single precision (4 bytes in most computer systems, 6 to 7 digits precision). Records 1 to 6 correspond to the data of the ASCII-Format. Then 6 additional records describing the grid statistics follow:

Records 1 to 6: as in the ASCII-format

Records 7 to 12:

- Count of valid cells (without NoData-values)
- Minimum value of all valid grid cells
- Maximum value of all valid grid cells
- Sum of all valid grid cells
- Mean value of all valid grid cells
- Standard deviation of all valid grid cells

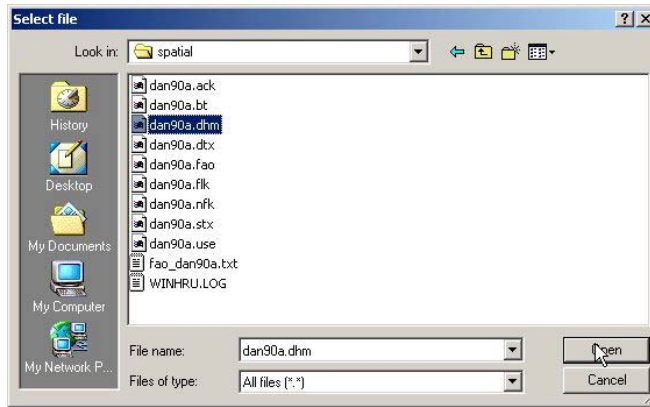
After this header, all cells of the grid are following in the same order as in the ASCII-format, i.e. from the top left cell to the lower right cell in a row by row order. GRIDMATH is able to convert the formats from one into another. ASCII-formats can be exchanged between different systems using e.g. ftp-programs with an automatic conversion of carriage returns/line feeds. To exchange binary data, they first have to be converted into ASCII-data, subsequently the exchange can be achieved and thereafter a re-converting on the target platform should be completed.

A.3 Usage

Basic commands:



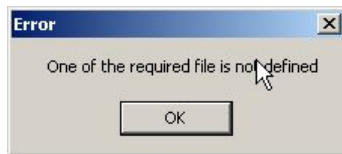
All the available operations require that files and directories are selected. This button launches the following dialog:



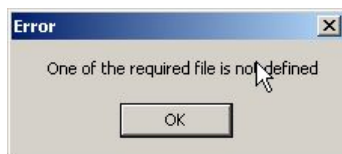
This dialog allows for the determination of the working directory, selection of the file to be analysed or typing of the name of an output file. It is also possible to use this dialog to create a directory, change the name of a file and delete a file.



This button starts the selected process (statistics, crop, resample, etc.). If a required file is not selected, an error box is displayed.



This button enables a dialog for the definition of the directory, where plug-ins are stored:



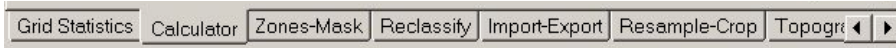
gridmath.exe requires two plug-ins: tanalys.exe (see Chapter 3.1.1., Part II of the PREVAH documentation) and wingrid.exe (see Chapter H). The initialisation file gridmath.ini stores this option. gridmath.ini is created in the same directory where gridmath.exe is stored.



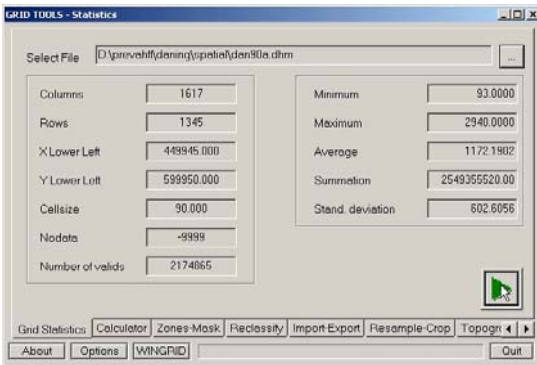
This button starts wingrid.exe (see separate documentation).

A.4 Operations

The name of the active operation, for example [GRID TOOLS – Masking and zonal statistics], is displayed in the title bar of the dialog. To change operation, select the appropriate tab at the bottom of the window.



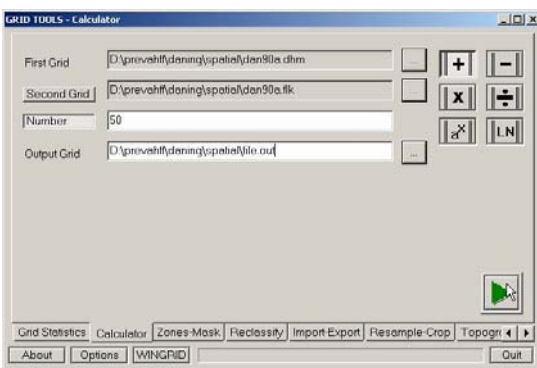
A.4.1 Grid Statistics



Usage: 1). Select grid. 2). Start process.

This operation displays the 12 headers of the selected binary file. This operation is very useful to determine if two files have the same dimensions (same number of columns and rows, co-ordinates, cell spacing and NoData value) and co-ordinate system.

A.4.2 Grid calculator

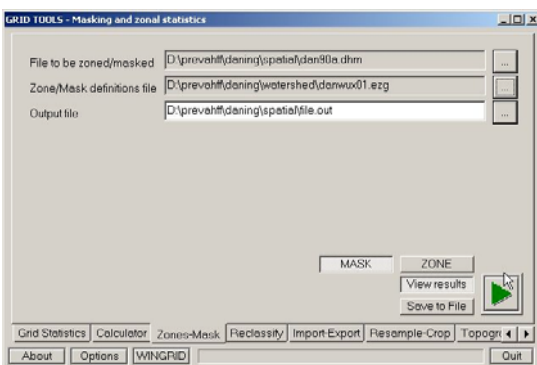


This operation allows for the completion of simple mathematical operations between two grids or between a grid and a number.

Usage: 1). Select first grid. 2). Select if you want to make a grid to grid (click [Second Grid]) or a grid to number (click [Number]) operation. 3). Select a mathematical operation. 4). Define an output grid. 5). Start process.

Notes: NoData cells are skipped. Division by '0' set values to NoData.

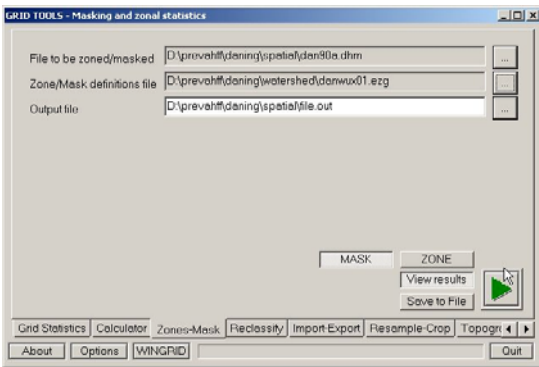
A.4.3 Changing the domain of a grid through a mask



This operation enables the change of the extent of the domain of a grid by selecting a second grid. All NoData values in the second grid are set as NoData in the first grid. This operation is very useful for cutting the perimeter of a watershed from full-extent grids.

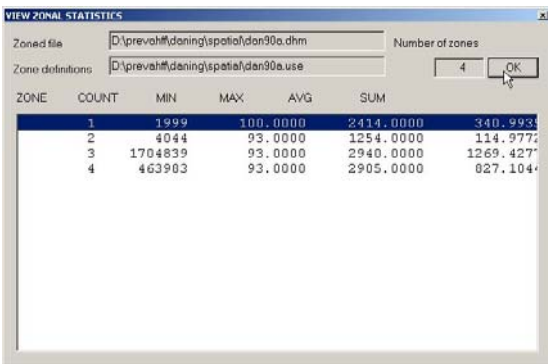
Usage: 1). Select first grid. 2). Select the mask grid. 3). Select the option [MASK]. 4). Define the name of an output grid. 5). Start process.

A.4.4 Zonal Statistics



This operation allows for the computation of zonal statistics between two grids

Usage: 1). Select first grid, whose statistics are required for each zone. 2). Select the grid containing the zones (which can be the same grid as the first grid). 3). Select the option [ZONE] and specify whether the results should be displayed in a dialog window (select or deselect [View results] button); if you wish to write the results to a file, click [Save to File]. 4). Define the name of a zonal statistics output file. 5). Start process.

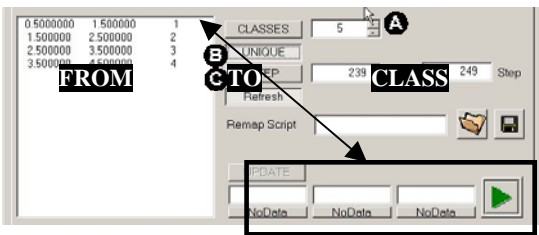


Both on the displayed dialog (here left) and in the output file (sample follows in the grey box) following statistical parameters are listed for each zone: Zone ID, Number of cells (COUNT); Minimum value (MIN); Maximum value (MAX); Average value (AVG); Summation (SUM).

Zonal statistics for D:\spatialch\CH\arhin\arhin.dhm
 Zone definitions D:\spatialch\CH\arhin\arhin.pus

1	57	530.4000	2402.3601	1626.2500	92696.2500
2	59	523.3200	1575.9200	842.0817	49682.8203
3	2078	1400.1600	2127.1599	1656.5428	3442296.0000
4	284	510.2000	796.4400	701.7695	199302.5469
5	1656	800.2400	1400.0000	1130.2294	1871659.8750
6	1	649.8400	649.8400	649.8400	649.8400
7	1591	503.5600	2138.6799	1149.6309	1829062.7500
8	787	567.8800	2335.2400	1874.3894	1475144.5000
14	278	2343.0000	3225.6399	2771.7542	770547.6250
15	3818	686.1600	3458.2400	2510.2693	9584208.0000
19	4	525.0800	577.0400	552.9200	2211.6799
22	2	998.7200	2050.4800	1524.6000	3049.2000
24	4744	829.2800	2750.8000	2107.9688	10000204.0000
25	623	1036.5200	2471.3999	1794.6443	1118063.3750
26	853	565.1200	2808.3201	2261.6719	1929206.1250
29	9	548.7600	611.6800	571.2000	5140.7998

A.4.5 Reclassify a grid



This operation allows for the reclassification of a grid. Different options are available.

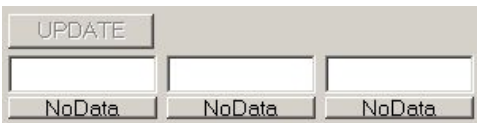
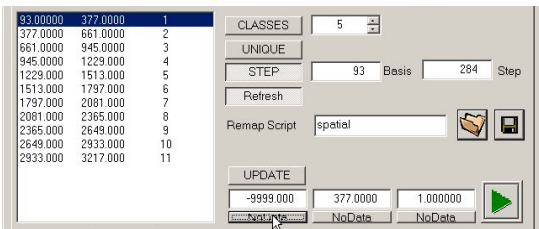
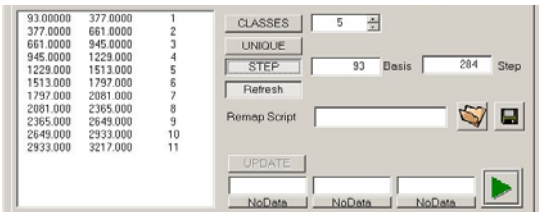
Basic Usage: 1). Select a grid. 2). Click [LOAD]. 3). Select the method ([CLASSES], [UNIQUE] or [STEP]). 4). Define the name of an output grid. 5). Start process.


Options:


A: Method CLASSES: Increase or decrease the number of classes (default 5 classes, equal interval) or type a number in the field to the right of the [CLASSES] button. After typing a number in the field click the [Refresh] button.

B: Method UNIQUE: No options. A class is defined for each integer number in the grid.

C: Method STEP: Change the basis of the step classification (default: Minimum in the selected grid) and dimension of the step (default: $1/11$ of the difference between maximum and minimum in the selected grid). After every change, click the [Refresh] button.

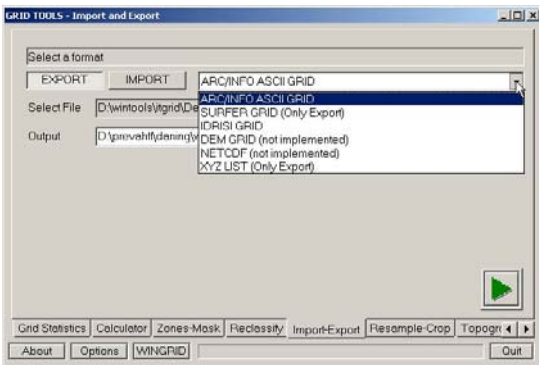


Save a Reclassify Script: A reclassify table can be saved into a script which can be used again later for similar tasks. Click  and provide a name for the script. The extension '.rms' will be added automatically to the script name.

Load a Reclassify Script: After loading the selected grid (see above), a saved reclassify table can be loaded. Click  and select the desired script (with the extension '.rms'). The script will be loaded into the list box of the dialog.

Change the range of the classes: 1). Mark one of the classes. 2). The range of the selected class is loaded in the three fields at the bottom part of the dialog. Type the new FROM/TO range and/or the new CLASS in the respective fields. If you want to set FROM/TO or CLASS to NoData, then click the corresponding button below the three fields. Click [UPDATE] to refresh the list box of the dialog.

A.4.6 Import-export tool



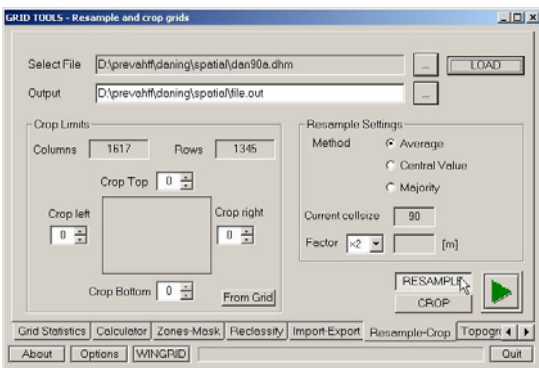
This operation allows the assimilation from and conversion to other grid formats.

Usage: 1). Select whether you want to [EXPORT] from or [IMPORT] to the PREVAH binary grid format. 2). Select non-PREVAH format. 3). Select source grid. 4). Define an output grid. 5). Start process.

Notes: Some of the declared formats are still not fully implemented.

To import from a grid with other formats is the first and most crucial step in using the PREVAH modelling system.

A.4.7 Resample tool



This operation allows for the reduction of the resolution of a grid after 3 methods.

Basic Usage: 1). Select the [RESAMPLE] operation. 2). Select a grid and click [LOAD]. 3). Define the name of an output grid. 4). Select the method (Average, Central Value or Majority). 5). Select a resample factor. 6). Start process.

After loading a grid the current cell size is displayed. The new cell size after resampling with the currently chosen factor is displayed in a second box.

Available methods (options):

Average: All the grid cells in the sample are averaged (best for physical values like elevation).

Central Value: The central cell of the cells sample is taken as representative random value for the full sample (suitable for spatially very variable categorical data like land cover classes).

Majority: The most frequent class in the sample is taken as a representative for the full sample (suitable for homogeneous categorical data like soil classes).

In the example shown, a grid with 9 columns an 9 rows is sampled by a factor of 3 (red lines in upper left grid) with the average method (upper right grid), the central value method (lower left grid, green box) and the majority method (lower right grid, red box). Some parameters controlling the analysis have to be specified (threshold values, constants, file names).

Original Grid

1	1	2	4	4	4	4	5	5
1	1	2	4	4	5	5	5	5
1	3	2	2	4	5	5	5	5
2	2	3	3	2	5	5	6	5
1	1	3	3	2	3	6	6	6
2	2	3	3	3	6	6	9	9
2	2	2	2	6	3	8	9	9
2	2	7	7	6	8	8	8	9
2	1	7	6	6	6	8	8	8

3x, Average

14/9	36/9	44/9
19/9	30/9	58/9
27/9	50/9	75/9

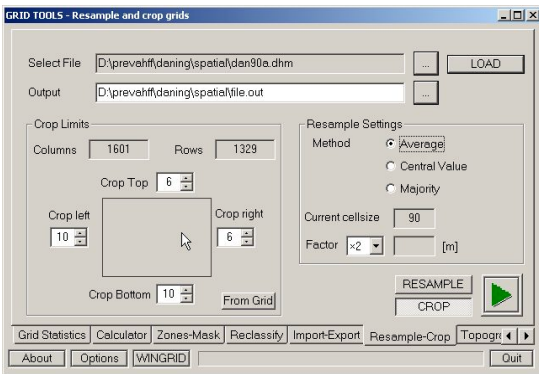
3x, Central Value

1	4	5
1	2	6
2	6	8

3x, Majority

1	4	5
2	3	6
2	6	8

A.4.8 Crop tool



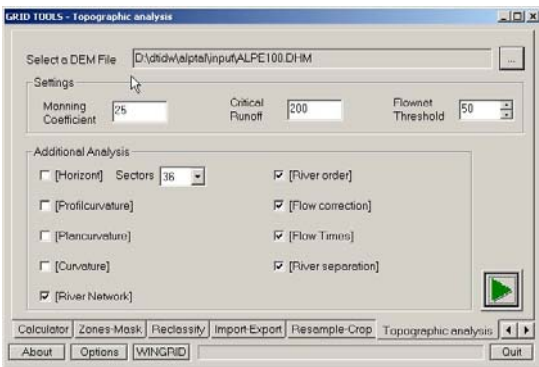
This operation enables the reduction of the domain of a grid.

Basic Usage: 1). Select the [CROP] operation. 2). Select a grid and click [LOAD]. 3). Define the name of an output grid. 4). Select the portion you want to crop. 5). Start process.

To cut undesired portions from a grid, you may specify the extent (in rows or columns) of the domain portion you would like to crop from left, top, right and bottom. Example:

Original Dimension of the Picture: 1617 columns × 1345 rows. Cropping 6 rows from top, 10 rows from bottom, 10 columns from left, and 6 columns from right. The final domain has only 1601 columns (1617-16) and 1329 rows (1345-16).

A.4.9 Topographical analysis



This operation makes a partial topographical analysis of a digital elevation model.

Basic Usage: 1). Select a digital elevation model (DEM) file. 2). Select the output options. 3). Start process.

GRIDMATH starts tanalys.exe and makes a partial topographical analysis. This operation is required to determine flow direction and flow accumulation.

Additional information on the topographical analysis is presented in Chapter 3.1.1, Part II of the PREVAH documentation. A list of the produced files with explanation of the extensions is provided in the Appendix.

B FAO-Soil: Processing soil grids from the FAO digital soil map of the world

B.1 Introduction

FAO-Soil is a tool allowing the parameterisation of soil properties grids from available information on the spatial distribution of FAO classes within the investigated domain. The FAO soil classes can be generated from the Digital Soil Map of the World (<http://www.fao.org/ag/agl/agll/dsmw.htm>), which is based on the FAO/UNESCO Soil Map of the World, original scale 1:5'000'000. The digital soil map of the world consists of the following map sheets: Africa, North America, Central America, Europe, Central and Northeast Asia, Far East, Southeast Asia, and Oceania. A set of ESRI ArcInfo (<http://www.esri.com>) coverages covering all the continental surfaces is provided upon request.

B.2 Data requirements

For the use of FAOSoil, the following binary grids are required:

- Digital Elevation Model (*.dhm)
- Land Use Map (*.use or *.pus)
- Grid with information on the FAO-Classes (*.fao)

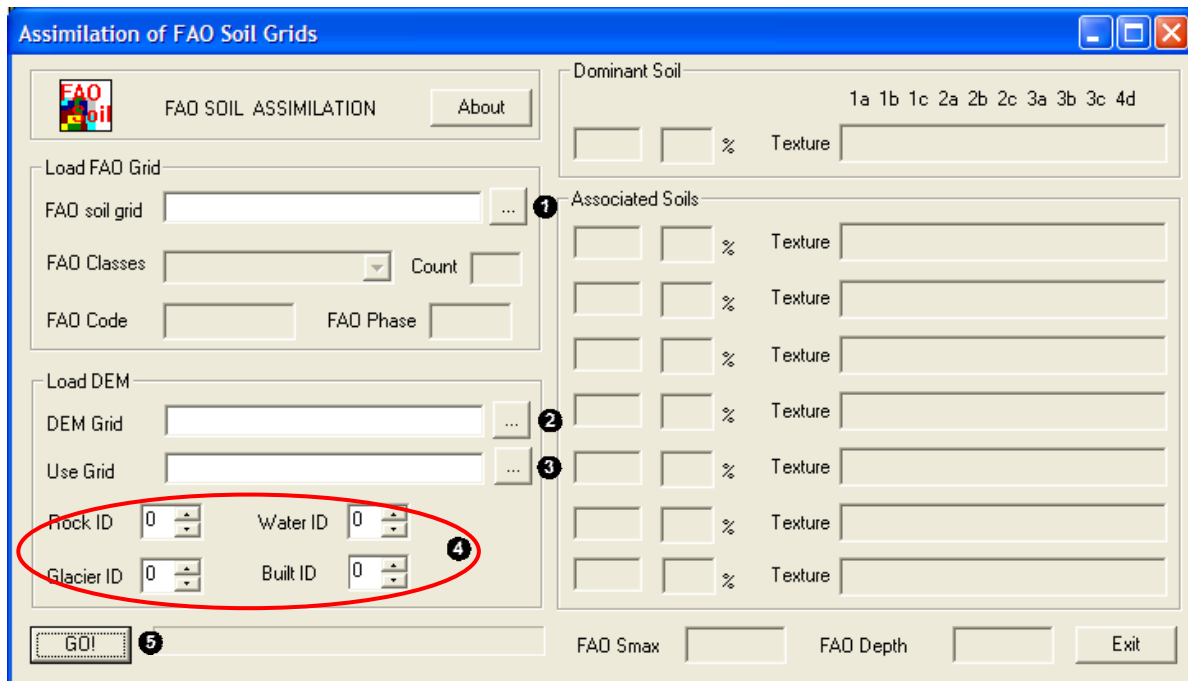
The FAO soil classes grid can be generated by using the provided ESRI ArcInfo coverages and commercial GIS and/or remote sensing software. To obtain the binary format required in the PREVAH modelling system the tool GRIDMATH has to be used (see separate documentation). It is imperative that all grids are in the same format (same number of columns and rows, same co-ordinates, cell spacing and NoData value).

Additionally, the following tables must be in the directory where FAOSoil is running:

- 'faoworld.dat'. Contains the Texture Identifier and portion of dominant and associate soils for all FAO soil classes
- 'faodepth.dat'. For each FAO soil a portion (in percent) for each of the five soil depth classes is given.
- 'faosmax.dat'. For each FAO soil a portion (in percent) for each of the seven soil moisture storage capacity classes is given.

These tables shouldn't be modified.

B.3 Usage



- ❶ Load an available grid with spatial distribution of FAO soil classes.
- ❷ Load an available grid of the digital elevation model (DEM).
- ❸ Load an available grid of the land use classes.
- ❹ Declare the ID of the land use classes Rock, Water, Glacier and Buildings in the land use grid.
- ❺ Click [GO!] and then look at the results in the right half of the dialog (compare with documentation and report file!). Exit.

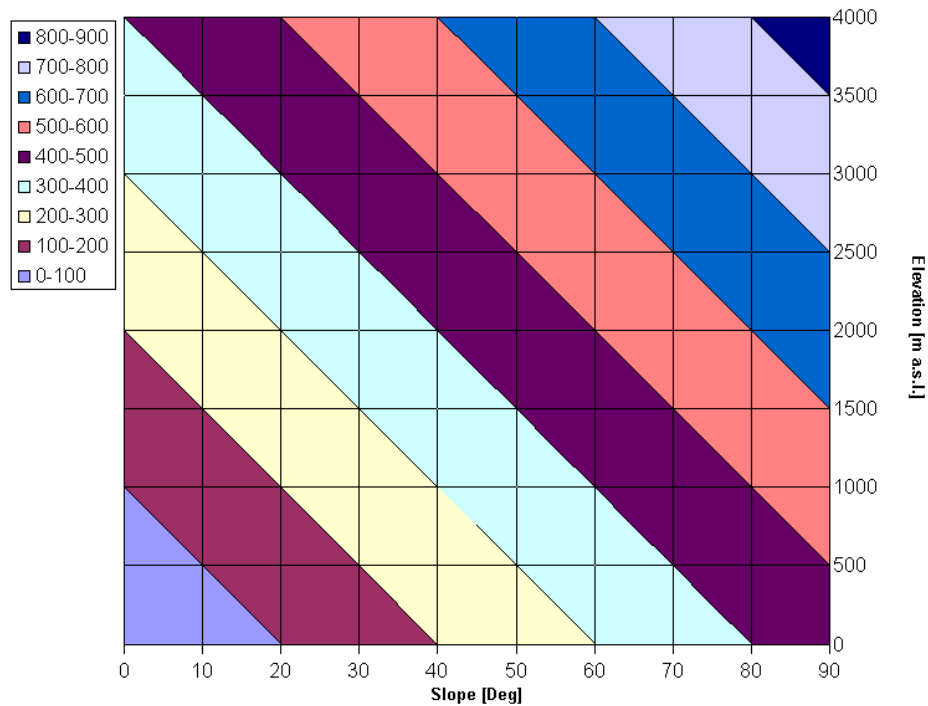
The resulting grids can then be evaluated with GRIDMATH and visualised with WINGRID.

B.4 Algorithm

For the spatial disaggregation of the soil properties according to the different portions of soil depth and available field capacity classes in the different FAO soil units, a simple index based on slope elevation and land use is adopted. The index is computed for each (x,y) grid cell in the investigated domain. It is assumed that the deepest soils and the soils with highest plant available field capacity are located in the lower altitudes and in the flat part of the domain. The disaggregation index is defined as:

$$SOIL_{(x,j)} = \frac{DHM_{(x,j)}}{10} + SLP_{(x,j)} \cdot 5 \quad (B1)$$

SOIL is the computed disaggregation index for a (x,y) grid cell. DHM is the elevation and SLP the slope for a (x,y) grid cell.



The above Figure shows the SOIL disaggregation index as a function of Elevation and Slope after Equation B1.

The disaggregation index is then normalised:

$$SOIL_{(x,j)}^{NORM} = 1 - \frac{(SOIL_{(x,j)}^{NORM} - SOIL_{MIN}^{NORM})}{(SOIL_{MAX}^{NORM} - SOIL_{MIN}^{NORM})} \quad (B2)$$

From Equation B2, it results that the (x,y) grid cells with a normalised soil disaggregation index close to 1 have the highest chance to show deep soils and high plant available field capacity.

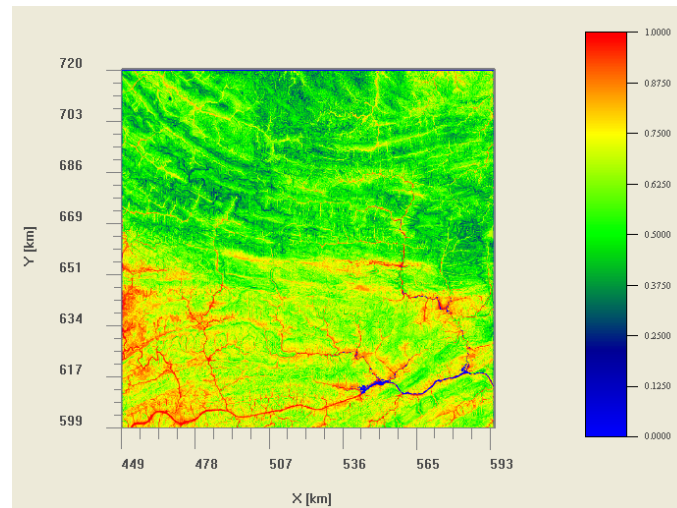
There are additional restrictions, which depend on the land use. Shallow soil should first be assigned to grid cells covered by water bodies, rocky areas, urban areas and glaciers. In case of the plant available field capacity the index for the land use "water bodies" is set per default to 1.

Default normalised disaggregation index for special land use categories

	Water bodies	Rocky areas	Urban Areas	Glaciers
Soil Depth	0.0	0.0	0.0	0.0
Field capacity	1.0	0.0	0.0	0.0

B.5 Results

- Grid of effective soil depth classes (*.bt).
- Grid of soil moisture storage capacity classes (*.nfk).
- Report file (fao*.txt).
- Grids of the two indices used for the downscaling of the soil classes (*.dtx and *.stx).



Normalised disaggregation index for the soil depth in the Daning catchment (China).

B.5.1 Effective soil depth derived from the soil map of the world

Soil depth is the vertical distance between the surface and parent material of a soil. Soil depth indicates the state of pedogenesis; its changes can indicate degradation and other transformation processes. Soil depth usually remains the same over very long periods of time. Sudden changes will most likely be the result of a change of the soil itself (erosion, soil removal or allocation).

To estimate effective soil depth, the following rules based on the soil unit's classification name, the soil phase(s) indicated for the dominant unit and the slope class. It takes into account the full composition of each mapping unit as given in the mapping unit composition file ('faoworld.dat'). Estimates for the % occurrence of each depth class are derived from a file called 'faodepth.dat'.

The following table indicates recommended parameterisation for soil depth in meters in the case of categorical data from the FAO "Digital Soil Map of the world" (FAO-UNESCO, 1988).

Classification of soil depth from the FAO soil map (FAO-UNESCO, 1988)

Category	Soil depth	Parameterisation [m]	Recommended [m]
5	Very Deep	1.5-3.0	2.00
4	Deep	1.00-1.5	1.25
3	Norm	0.5-1.0	0.75
2	Shallow	0.1-0.5	0.35
1	Very shallow	<0.10	0.10

B.5.2 Soil moisture storage capacity derived from the soil map of the world

Soil moisture storage capacity (also referred to as field capacity) is the water content of a soil at a defined time after its complete wetting and free drainage has become negligible. Soil moisture storage capacity is an important soil characteristic for two reasons: Firstly, together with the permanent wilting point, it defines the ability of a soil to satisfy the vegetation's water needs during periods without precipitation. Thus the plant-available filed capacity is defined as the amount of soil water that can be extracted by the plant, as the difference in soil moisture content between the field capacity and wilting point. It is expressed as millimetres of plant-available water within the root zone. Secondly, it describes a soil's effectiveness as a buffer in the vertical transfer of water after precipitation, thus determining a soil's water retention and purification properties.

In the context of defining ranges and values for important properties and qualities derived from the Soil Map of the World (FAO-UNESCO, 1988), this text describes a methodology to determine values for the soil moisture storage capacity to a depth of 100 cm or to an impermeable layer, which ever is shallower (SMAX).

It is recognised that the prediction of Smax is only a part of the solution to the more general problem of soil water available to plants (SWAP). Indeed, SMAX is determined in isolation of the prevailing climate and is, to a large extent, ignoring specific rooting habits of crops. Furthermore, some researchers have rejected the concept of the soil water availability as a static capacity in favour of a continuous variable in relation to atmospheric demand, root extension, water-table depth, rate of water movement to root surfaces etc.

SMAX classes proposed for the interpretation of the Soil Map of the World.

Symbol	EAV range	Smax_range	Class_name
1	Not_applicable	Not_applicable	W(wetlands)
2	> 120 mm	> 200 mm	A
3	100–120 mm	150–200 mm	B
4	60–100 mm	100–150 mm	C
5	40–60 mm	60–100 mm	D
6	20–40 mm	20–60 mm	E
7	< 20 mm	< 20 mm	F

C WINHRU: Gather and process spatial information

C.1 Introduction

Spatial information is an indispensable basis for distributed hydrological modelling. WINHRU serves to produce the necessary raster-based grids and handles the creation of hydrological response units (HRUs). The spatial information gathered with WINHRU may also be of use for various other hydrological and geographical applications. The resulting grids may be interpreted visually (e.g. with WINGRID) or be analysed statistically in a standard GIS system after conversion into a suitable exchange format (use e.g. GRIDMATH).

C.2 Basic features of WINHRU

WINHRU has been developed to easily create all the spatial information needed for running PREVAH in a single step. Some features may be specifically adjusted for application within Switzerland. However, this does not restrict the use of WINHRU for any other geographic domain. WINHRU is able to:

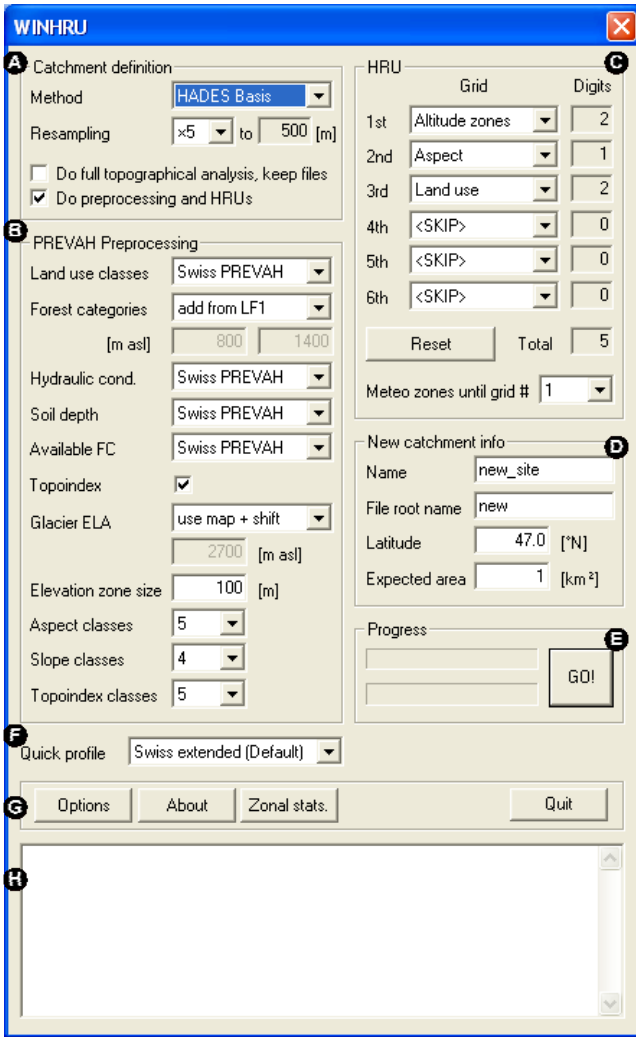
- Define hydrological catchments in various ways, e.g. based on a digital elevation model
- Perform a detailed topographical analysis
- Derive hydrological response units based on user-specified criteria
- Create tables and input files suitable for the PREVAH modelling system

Together with WINMET, all the tables necessary for running PREVAH can be created.

If you are not using the standard WINHRU paths and filenames, you will have to adjust these settings in the Options dialog (see page 27).

C.3 Start-up

Start winhru.exe by double-clicking the icon linked to the winhru.exe executable or by clicking the appropriate button in LAUNCHER.

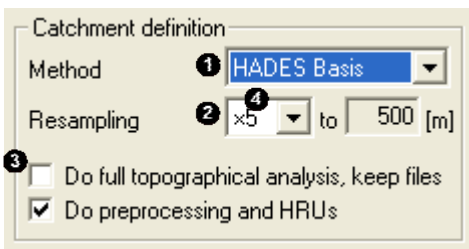


After start-up, the main dialog window of WINHRU is displayed. It consists of the following sections:

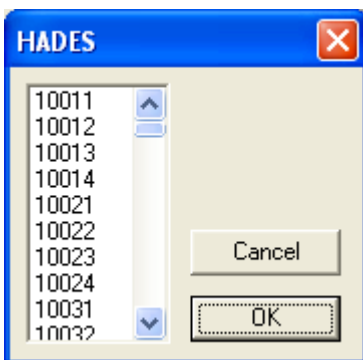
- A Catchment definition settings
- B PREVAH preprocessing settings
- C HRU definition settings
- D PREVAH project settings
- E Progress bar and launch button
- F Quick profile selector
- G Program runtime buttons
- H Console output

A detailed description of these components follows below. Note that changes in the dialog serve to configure the behaviour of WINHRU and take effect only after launching the program with the [GO!] button (Progress section, E).

C.3.1 Catchment definition settings (A)



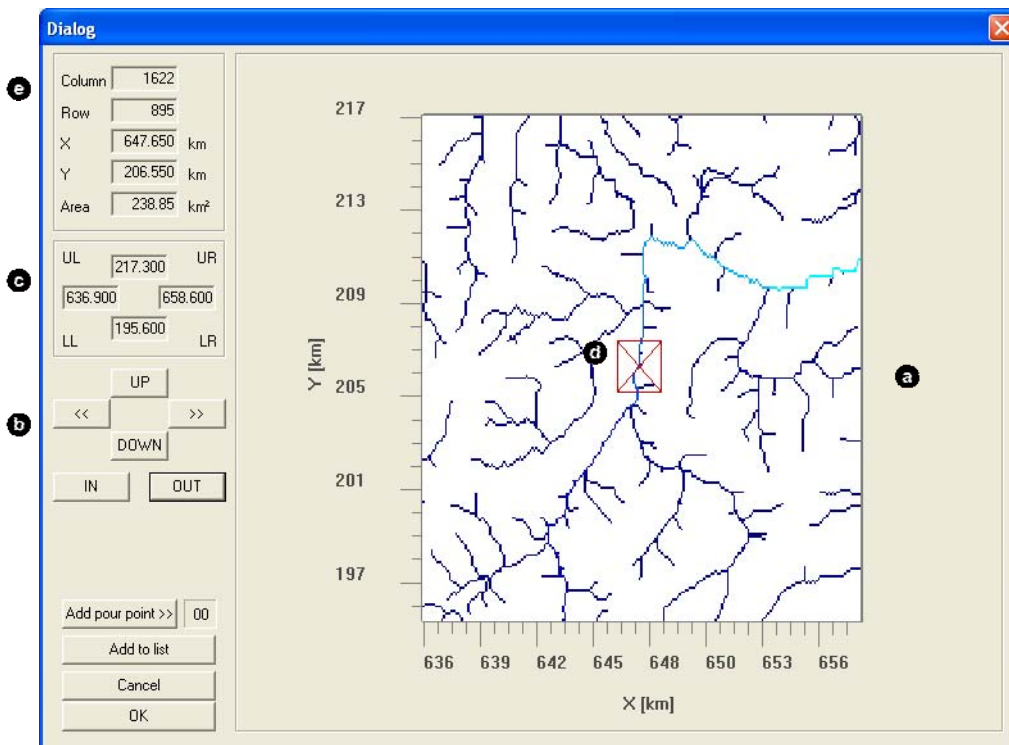
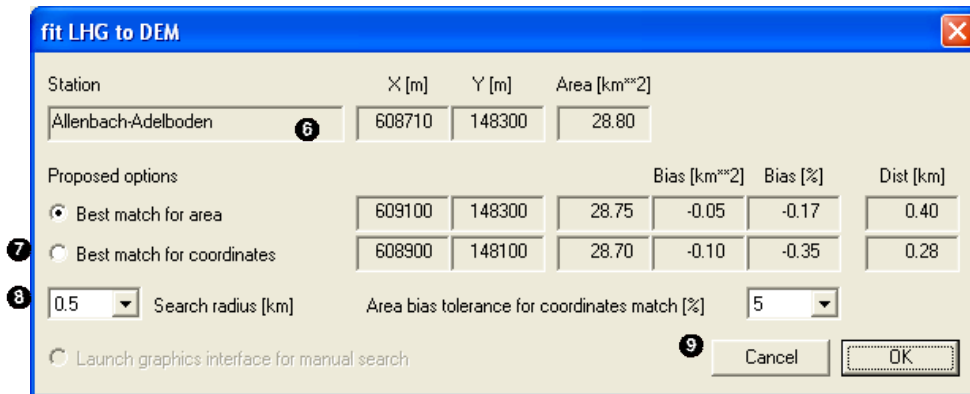
[Method] allows the selection of the manner of catchment definition (1). For the resulting catchment, a set of windowed grids is created from the source grids. Available methods are:



- HADES Basis: Definition based on small catchments as defined in the Hydrological Atlas of Switzerland ("Basisgebiete", see Breinlinger et al., 1992). After launching WINHRU, a dialog appears (4) where the desired catchments may be selected according to their 5-digit ID. Use <Ctrl> and <Shift> to select multiple basins. This option is applicable for Swiss catchments only.
- HADES Balance: Similar to HADES Basis, but applying to a 4-digit HADES water balance basins ID. This option is applicable for Swiss catchments only.
- LHG gauge site: Allows the selection of a specific gauge site. When WINHRU is launched, a dialog showing the available locations appears (5). [New...] and [Remove] may be used to add or delete stations from the record (see Options, page 27, for further details on file structure). Select the desired station and click [OK] to proceed. WINHRU derives the upstream



area of the selected location and subsequently displays a dialog showing location and basin area of the actual gauging station (6) as well as suggestions for defining the catchment based on the underlying digital elevation model (DEM) (7). Consider co-ordinates (X, Y), Area, Bias (km² and %) and distance (Dist) to decide upon a selection. Specify search radius (8) and tolerance for catchment area bias (9) to alter the suggestions. [OK] proceeds with the catchment definition; [Cancel] stops the catchment definition and returns to the main WINHRU dialog.



- Free pour point: Calls a dialog where the user may specify a basin outlet with the help of a graphical interface (a). Similarly to WINGRID, use the navigation buttons (b) to move and zoom the currently displayed domain; the limits are displayed in Swiss co-ordinates [km] (c). Click on the map or use the cursor keys to place the marker (d) on a point of choice in the flow accumulation map. Co-ordinates and basin area of the currently selected point are displayed in e. To launch the basin definition based on the selected pour point simply click [OK]. You may also add the currently selected point as an additional pour point for defining sub-catchments [Add pour point >>] or add it to the gauge site list [Add to list] for easier access in a subsequent catchment definition process (see Method, LHG gauge site, above). [Cancel] returns the user to the main WINHRU dialog without completing changes.

Due to the inaccuracies contained in any digital elevation model (DEM), flow accumulation and flow direction may not correspond with reality; this may lead to the determination of unsuitable basin areas and basin limits, especially in flat areas. There are two simple ways to avoid this problem: Either, use a different topographical analysis algorithm from a GIS-package to derive a new flow accumulation and flow direction grids; or edit the DEM directly (e.g. with WINGRID) and thereby correct obvious errors. The former option may be more suitable for some areas but fail to work in others. A more sophisticated approach is to apply a DEM Surface Reconditioning System such as AGREE (available at www.ce.utexas.edu/prof/maidment/GISHYDRO/ferdi/research/agree/agree.html).

- From grid file: A dialog opens where the user can load a PREVAH-formatted grid file which defines the catchment (values of 1 for grid cells inside of the catchment, NoData or 0 for all remaining cells); note that extent and resolution of this grid file must match these of the basic grid maps used (such as e.g. the digital elevation model). If necessary, use GRIDMATH (see Section A) to convert standard GIS formatted files (e.g. ASCII-type from ArcInfo) into the PREVAH format.

[Resampling] (2 in the WINRHU main dialog window) specifies the resampling factor which should be applied to the source grids (see Options in Section C.3.4). Factors 1, 2, 3, 4, 5, 10, 20 and 50 are available. The resulting grid resolution is displayed on the right-hand side of the list box. Simply select 1 as factor if no resampling is desired.

When [Do full topographical analysis and keep files] is checked (3), WINHRU derives a number of additional topographical maps which are not used by PREVAH but may be very useful for other hydrological interpretations. When unchecked, only the necessary topographical analysis is completed. The grids that are always created include aspect (*.exp), slope (*.slp), flow direction (*.fld), flow accumulation (*.acc) and basin area (*.ezg). Additional grids in full analysis are e.g. river network (*.lin) with associated river order (*.ord) and nomenclature (*.num), flow duration (*.fzt), flow depths (*.dep), flow widths (*.wit), sub-basins (*.e01, *.e02, ...) with associated pour points (*.m01, *.m02, ...) and flow time sums (*.zs1, *.zs2, ...) as well as a corrected digital elevation model (*.dhk) with sinks (*.sin) removed and associated corrected grids of flow direction (*.flk), flow accumulation (*.ack), river network order (*.ork) and river network nomenclature (*.nuk). The extended topographical analysis uses components from Schulla and Jasper (2000), which are partly described in Section 4.4.2, Part II of the PREVAH documentation.

C.3.2 PREVAH preprocessing (4)

In this dialog section, options for processing the windowed and resampled grids (see 4 in Section C.3.1) into PREVAH-suitable grids are specified.

1 [Land use classes]: Define the aggregation of land use information. Options are [keep actual classes] (this means that the PREVAH classes have already been assigned during a previous phase of the preprocessing of the land use grids), [Swiss PREVAH] (for application of PREVAH in Switzerland), [user defined] (to use previously stored default settings), [interactive] (a dialog is prompted to assign physically based values to categorical information) and [<Skip>] (do nothing).

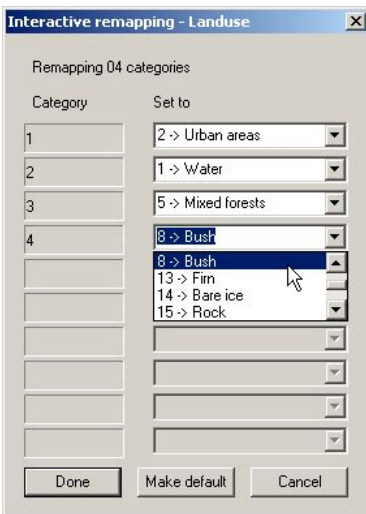
2 [Forest categories]: Define how the category "forest" from the land use map is split into deciduous and coniferous trees. [Add from LF1] uses the Swiss national forest statistics (WSL, 1988) to update the forest categories. [Define mixing zone] allows the specification of an altitude zone (edit boxes below) in which deciduous and coniferous trees are each assumed to represent a 50% share. Higher altitudes are assumed to be purely coniferous, lower altitudes are purely deciduous forest. This option assumes that all the

forested areas have been defined as mixed forest in the previous phase of the preprocessing of the land use grid or during the interactive reclassification of land use data. [Keep actual values] completes no updating. This means that the PREVAH classes for deciduous, mixed and coniferous forests have already been assigned during a previous phase of the preprocessing of the land use grid.

[Hydraulic conductivity] ③, [Soil depth] ④ and [Available field capacity] ⑤ specify the respective grid aggregation similarly to Land use classes.

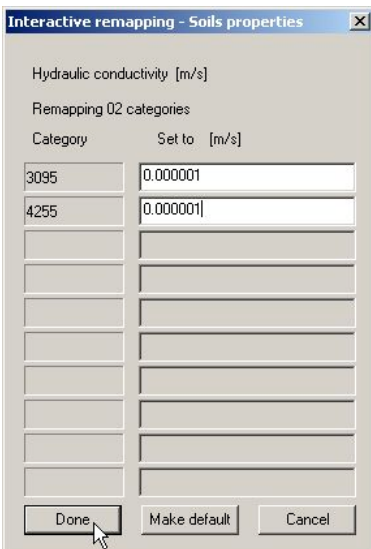
Interactive classification:

If you decide to interactively assign land use classes and/or physical parameterisations to the soil categories then, during the processing of WINHRU, the following dialogs are prompted:



1). Interactive remapping of land use into PREVAH land use categories. A full list can be found in Part II of the PREVAH documentation.

Activate [Make default] before clicking [Done] to set your choice as the default option. The file 'defpus.rm' is stored in the [Tools path] which may be defined through the Options dialog (see Section C.3.4).



2). Interactive remapping of hydraulic conductivity into physical values [m/s]. A list of recommended values from Swiss soil maps is provided in Part II of the PREVAH documentation. If you have no idea on the hydraulic conductivity, use the dummy value 0.000001.

Activate [Make default] before clicking [Done] to set your choice as the default option. The file 'defkms.rm' is stored in the [Tools path] which may be defined through the Options dialog (see Section C.3.4).

Category	Set to [m]
1	0.1
3	0.75
4	1.25

3). Interactive remapping of soil depth into physical values [m]. A list of recommended values from Swiss and FAO soil maps is provided in Part II of the PREVAH documentation.

Activate [Make default] before clicking [Done] to set your choice as the default option. The file 'defbtk.rm' is stored in the [Tools path] which may be defined through the Options dialog (see Section C.3.4).

Category	Set to [Vol%]
3	17.5
7	2.0

4). Interactive remapping of available field capacity into physical values [Vol%]. A list of recommended values from Swiss and FAO soil maps is provided in Part II of the PREVAH documentation.

Activate [Make default] before clicking [Done] to set your choice as the default option. The file 'defpfc.rm' is stored in the [Tools path] which may be defined through the Options dialog (see Section C.3.4).

If you saved your own defaults, you may choose the [user defined] option the next time you want to classify land use and soil properties.

⑥ [Topindex]: Defines whether topographic indices should be calculated. The definition of the topographic index is reported in Part II of the PREVAH documentation.

⑦ [Glacier ELA]: Allows the user to select a method for splitting glaciated areas into accumulation and ablation zones. [Use map] refers to the equilibrium line altitudes (ELAs) calculated for Switzerland by Maisch et al. 1999, which are then corrected for the individual site-specific expositions (see Viviroli, 2007). [Use map + shift] uses the same map, but with a shift of 25 m upwards in the ELAs (recommended). This is used in order to account for the glacier retreat since 1973, which is the reference year for the underlying glacier inventory. [User defined] allows using a specific ELA (entered in the edit box below). This is recommended if detailed regional knowledge on the area in scope is available.

Classification into elevation zones:

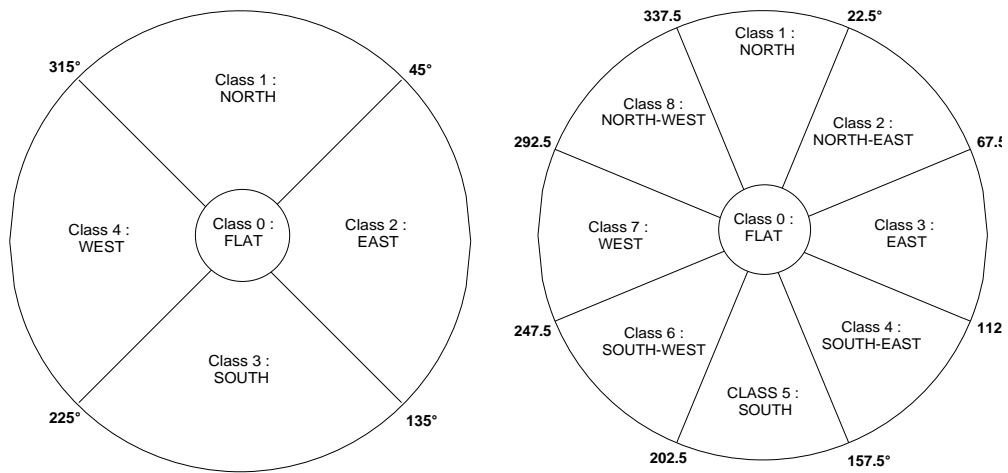
⑧ [Elevation zone size]: Defines the extent of an elevation zone. These zones are commonly used for aggregation of meteorological input data and definition of hydrological response units (HRUs). The value should be selected with respect to the intended spatial model resolution and quality of the meteorological data available. The value of 100 meters is recommended for most applications.

9 [Aspect classes], [Slope classes] and [Topoindex classes]: Define the aggregation of the respective grids to classed value grids. Several numbers of classes are available, although it is recommended to use the default values.

Classification of different topographic parameters into categories using WINHRU

Source feature	Source grid	Categories	Target grid
Digital elevation model	[*.DHM]	Defined by size of the elevation zone	[*.PHK]
Aspect	[*.EXP]	Defined into 5, 9 or more categories	[*.EXK]
Slope	[*.SLP]	Defined into 3 to 8 default categories	[*.SLK]
Soil-Top-Index	[*.ABB]	Split into categories between	[*.ABK]
Area-Top-Index	[*.ATB]	minimum and maximum	[*.ATK]

Classification of aspect:



Classification of aspect into 5 (left) and 9 (right) exposition classes. The classification into 5 classes is recommended

Classification of aspect into 3, 4, 6 or 8 categories (the classification into 4 classes is recommended)

Category	3 Classes	4 Classes	6 Classes	8 Classes
1	< 3°	< 10°	< 3°	< 3°
2	3° – 15°	10° – 22°	3° – 9°	3° – 9°
3	> 15°	22° – 36°	9° – 17°	9° – 15°
4		> 36°	17° – 27°	15° – 22°
5			27° – 36°	22° – 30°
6			> 36°	30° – 38°
7				38° – 45°
8				> 45°

C.3.3 HRU definition (ⓐ)

For defining hydrological response units (HRUs), WINHRU offers several criteria for possible selection. The grids for HRU determination may be selected in their appropriate order through the grid dropdown boxes (ⓐ) and include Watersheds, Altitude zones, Aspect, Slope, Land use, Soil, Soil-Topographic index, Area-topographic index, Geology, Glaciers, Meteo zones and Soil variance. The reference of these generic grids to actual grid file extension may be specified and altered in the WINHRU Options dialog (see Section C.3.4). Select [<SKIP>] to exclude a grid from the HRU definition process. A grid must not appear more than once.

In the Digits column (ⓑ), WINHRU displays the number of digits that are used by a grid in the HRU code as well as the total number of digits used (ⓒ). It is suggested to use a limited number of grids for HRU definition since the advantage of the HRU approach is that it evades the time-consuming, cell-by-cell processing in model runs. If the HRUs are too small, this advantage is abandoned. Therefore, an upper limit of 8 to 9 digits is recommended.

Finally, the number of grids serving as meteo zones [Meteo zones until grid #] (ⓓ) may be changed. Usually, only the first grid (altitude zones by default) is used for specification of meteo zones. There is no need to make changes to this default setting for standard model runs in small watersheds. For larger catchments, it is recommended to include the watersheds grid (second or third order watersheds) at the top of the list of criterion for the generation of HRUs followed by the criterion altitude zones. In this case, the [Meteo zones until grid #] option must be set equal to 2. Push the [Reset] button (ⓔ) if you want to begin again.

C.3.4 PREVAH project settings (ⓐ)

In this part of the main dialog window, some settings for the PREVAH project generated by WINHRU may be entered. [Name] is the catchment name for the new project. [File root name] is the file stem which will be used to denote the grids and tables created by WINHRU. Enter the mean northern latitude of your new catchment in [Latitude]. Finally, specify the official area provided for the basin in scope in [Expected area]; this is updated automatically if LHG gauge site has been selected as the catchment definition method (see Catchment definition settings, ⓐ, Section C.3.1 above).

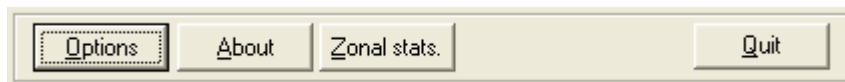
C.3.5 Progress bar and launch button (ⓐ)

The two progress bars show the state of the currently running WINHRU components when WINHRU has been started with the [GO!] button.

C.3.6 Quick profile selector (ⓐ)

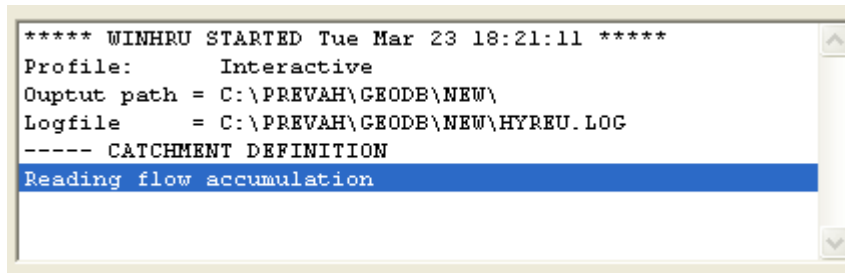
Use this selector to conveniently switch between different settings of the dialog elements in WINHRU.

C.3.7 Program runtime buttons (ⓐ)



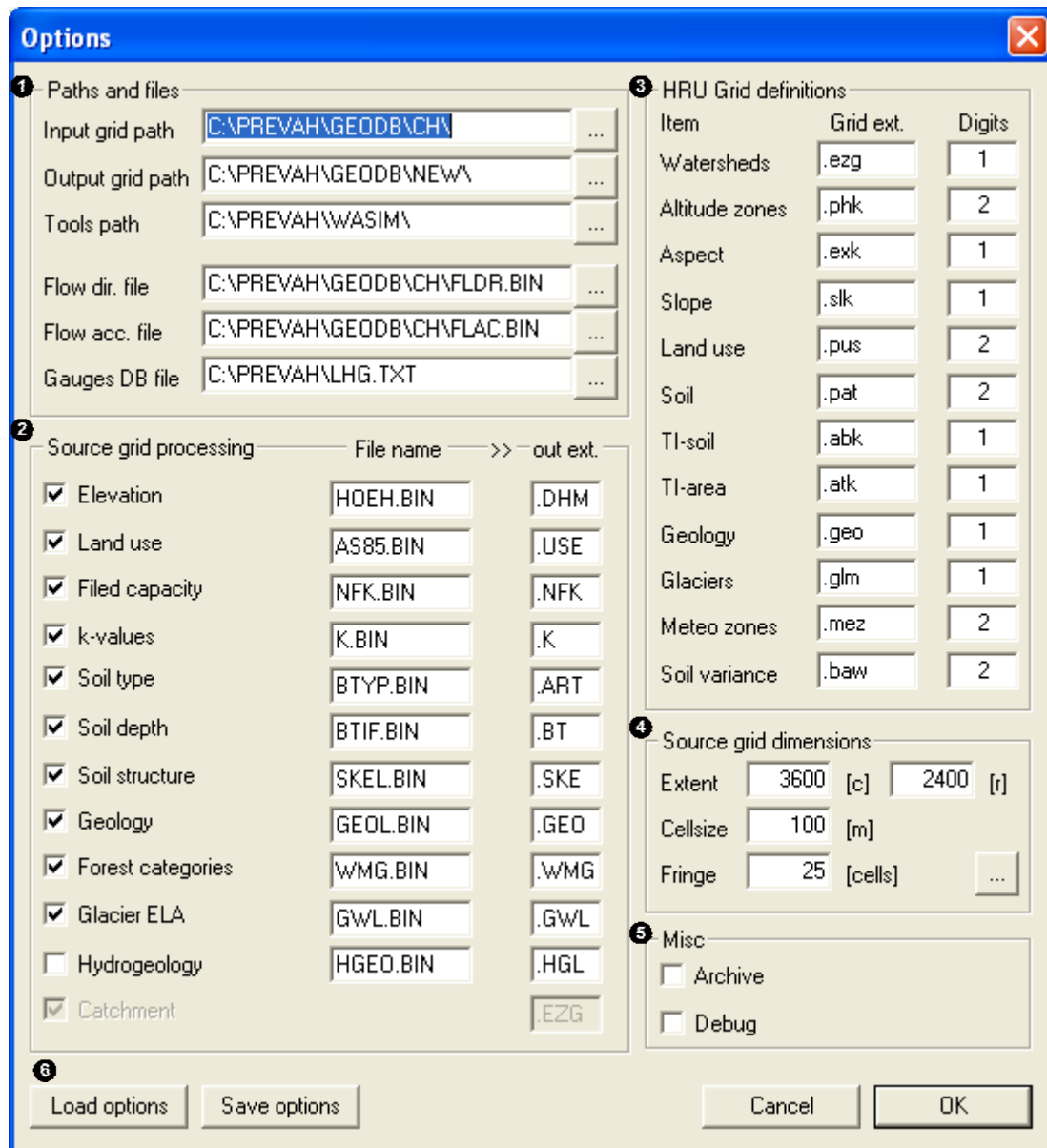
[Options] opens the options dialog window (see Section C.3.4). [About] shows program credits and version. [Zonal stats.] launches a dialog which allows the easy computation of zonal statistics. [Quit] terminates the present WINHRU session.

C.3.8 Console output (ⓐ)



This section of the main dialog window provides information on the operations currently in progress when WINHRU has been started with the [GO!] button (see Progress bar and launch button, ⓐ, Section C.3.5 above). Use this output to find errors if any WINHRU process should fail or not deliver the desired results.

C.4 Options



This dialog is launched with the [Options] button in the main WINHRU dialog (see Program runtime buttons, ③, Section C.3.7 above). It serves to adjust a number of settings that affect the main WINHRU program.

Use [Paths and files] (①) to adjust WINHRU to the file system of your computer. Match these settings if you are not using default paths and filenames.

- [Input grid path] specifies the location where the source grids are stored, i.e. the grids containing information on the entire geographic domain from which the windowed and resampled maps are extracted (see also [Source grid processing], ②, below)
- [Output grid path] is where the new grids created by WINHRU are written. Since these tables and grids are path-independent, they may conveniently be moved from this directory to a final target directory after completion of WINHRU. However, the final target directory may also be indicated directly as the output grid path.
- [Tools path] is a path where a set of additional, necessary files are stored. These files are: tanalys.exe, tanpur.dat, sample.inp.

- [Flow direction file] and [Flow accumulation file] indicate the grids used for determination of upstream areas when WINHRU operates in the gauge site or free pour point mode (see Catchment definition settings, **A**, Section C.3.1). These two files have to be generated by topographical analysis prior to the first use of WINHRU in a particular region. To generate alternative versions of the two files you can use common GIS commercial software with support of hydrological analysis or the tool GRIDMATH (see Chapter A).
- [Gauges database file] is the ASCII-formatted text file containing name, location and catchment area of gauging stations available for the gauge site mode of WINHRU (see Catchment definition settings, **A**, Section C.3.1). A sample of a gauge database file is given below. It consists of one header column, followed by the actual records; each column lists a station name (59 characters), area in square kilometres (5 characters) as well as station northing (12 characters) and easting (12 characters) in meters, each separated by one blank character. You may edit this file preserving the given format rules. To add or remove stations you may also use the respective buttons in the gauge site or free pour point dialogs (see Catchment definition settings, **A**, Section C.3.1)

GAUGING STATION	AREA_KM^2	EASTING_M	NORTHING_M
Rhône-Porte du Scex	5220	557660	133280
Rhône-Sion	3349	593770	118630
Ticino-Bellinzona	1515	721245	117025
Vispa-Visp	778	634150	124850
Drance-Martigny, La Bâtiaz	678	571280	105680
Fiescherbach-Fiesch	81.0	653450	139350
Inn (En)-Scanfs	615	794560	165230
Engelberger Aa-Stans, Wil	226	672310	201340
Birs-Münchenstein, Hofmatt	911	613570	263080

[Source grid processing] (**2**) lists all available source grids which are available for processing in WINHRU. Check or uncheck the grids according to whether you want WINHRU to process them. The filename of the source grid may be entered in the File name column. The output extension column specifies the extensions of the grids that are later created by WINHRU through windowing and resampling. Note that the following grids must be present:

- Digital elevation model for the source grid [Elevation]
- Land use map for the source grid [Land use]
- Soil map for the source grids [Field capacity], [k-values], [Soil type] and [Soil Depth]

[HRU grid definitions] (**3**) enables identifying the grid types which are used for defining the hydrological response units (HRUs). Enter the desired grid type extension for an item in the grid extension column; the number of digits used for a grid in the HRU code may be specified in the Digits column.

In [Source grid dimensions] (**4**), the maximum grid extent that will be processed has to be entered (extent in [c]olumns and [r]ows), along with the resolution of the source grids (Cellsize, in [m]eters). These settings may be conveniently gathered from an existing source grid file using the ["..."] button. Fringe is a buffer zone that will be added when windowing the source grids according to the extent of the catchment area.

[Misc] (**5**) contains checkboxes to enable or disable Archiving and Debugging mode (turned off by default).

Use the [Save options] button (**6**) to save the current dialog settings to a default settings file which will be loaded at each program start of WINHRU. Press [Load options] to reload these settings. To reset WINHRU options to default, simply delete the "winhru.ini" file located in the folder from which you start WINHRU.

C.5 Outputs

Gridded output:

WINHRU produces several grids for the full domain in the neighbourhood of your selected catchment, stored as files FULL_ File-root-name.*.

For your specific catchment, WINHRU produces a series of grids for the full catchment and stores them as File-root-name.*.

If you selected to use sub-catchments for the definition of the HRUs and the meteorological zones, a series of grids is saved for each of the sub-catchments. The basic name of such files is File-root-name##.*, with ## equal to the ID of the sub-catchment.

A list of file extensions (*.*) is provided in the Appendix.

Tabular Output:

The main result of WINHRU is the table which PREVAH needs to assimilate the HRU-based spatial information on the investigated catchment. Such information is written in the so-called control file for spatial information which is stored as tabFile-root-name.gkw for the full catchment and tabFile-root-name.g## for the sub-catchments, with ## equal to the ID of the sub-catchment. The file is structured as follows (divided into two parts for display reasons):

PREVAH control file for spatial information (Columns 1–14):

HYDROTOPCODE	NR	AETF	COUN	HOEHE	LN	EXP	ASP	SLO	NFC	BTIE	KWT	BA	BT	TOPI
1041084		0.6075	3	325	8	1	329	19	17.5	1.25	3.60E+00	0	0	28.2
1042044		0.2025	1	280	4	2	53	7	17.5	1.25	3.60E+00	0	0	29.1
1042084		1.62	8	303	8	2	101	14	17.5	1.25	3.60E+00	0	0	28.4
1043084		1.215	6	302	8	3	158	14	17.5	1.25	3.60E+00	0	0	28.4
1044084		1.215	6	306	8	4	280	13	17.5	1.25	3.60E+00	0	0	28.5
1051044		0.2025	1	356	4	1	315	26	17.5	1.25	3.60E+00	0	0	27.7
1051084		1.0125	5	397	8	1	18	15	17.5	1.25	3.60E+00	0	0	24.7
1052081		0.405	2	426	8	2	122	36	2	0.1	3.60E+00	0	0	20.5
...	

PREVAH control file for spatial information (Columns 1 and 15–27):

HYDROTOPCODE	NR	BTOP	GEO	GLE	MEZ	PHK	SKE	FREE1	FREE2	FREE3	FREE4	EZGNR	EZGID	ID
1041084		35.1	0	0	104	4	0	-9.9	-9.9	-9.9	-9.9	1	1	1
1042044		36	0	0	104	4	0	-9.9	-9.9	-9.9	-9.9	1	2	2
1042084		35.3	0	0	104	4	0	-9.9	-9.9	-9.9	-9.9	1	3	3
1043084		35.3	0	0	104	4	0	-9.9	-9.9	-9.9	-9.9	1	4	4
1044084		35.4	0	0	104	4	0	-9.9	-9.9	-9.9	-9.9	1	5	5
1051044		34.6	0	0	105	5	0	-9.9	-9.9	-9.9	-9.9	1	6	6
1051084		31.6	0	0	105	5	0	-9.9	-9.9	-9.9	-9.9	1	7	7
1052081		27.4	0	0	105	5	0	-9.9	-9.9	-9.9	-9.9	1	8	8
...	

The definition of the 27 columns of the control file for spatial information generated by WINHRU and assimilated by PREVAH at model initialisation follows in the next table:

Column	Header	Description	Source grid(s)	Unit	Status
1	CODE NR.	Code of the HRU	[* .HRU]	-	category
2	AETF	Area of the HRU	[* .IDH]	km ²	summation
3	COUN	Count of cells for this HRU	[* .IDH]	-	summation
4	HOEHE	Elevation	[* .DHM]	m a.s.l.	average
5	LN	Land use	[* .PUS]	-	category
6	EXP	Aspect class	[* .EXK]	-	class
7	ASP	Aspect	[* .EXP,* .AZM]	Degree	average
8	SLO	Slope	[* .SLP]	Degree	average
9	NFC	Available field capacity	[* .PFC]	Vol%	average
10	BTIE	Soil depth	[* .BTK]	m	average
11	KWT	Hydraulic conductivity	[* .KWT]	mm h ⁻¹	average
12	BA	Soil type	[* .PAT]	-	category
13	BT	Soil structure	NO-DATA	-	no data
14	TOPI	Area-TopIndex	[* .ATB]	[-]	average
15	BTOP	Soil-TopIndex	[* .ABB]	[-]	average
16	GEO	Geology	[* .GEO];[* .HGL]	-	category
17	GLE	Glacier morphology	[* .GLM]	-	category
18	MEZ	Meteorological zones	[* .MEZ]	-	category
19	PHK	Elevation Zones	[* .PHK]	-	category
20	SKE	Stones content	[* .SKE]	-	category
21–24	FREE1–4	Free columns	NO-DATA	-	no data
25	EZGNR	Sub-catchment	[* .EZG]	-	category
26	EZGID	ID in sub-catchment	[* .EZG]	-	category
27	ID	ID of the HRU	[* .IDH];[* .I##]	-	category

Source grid is the extension of the grid(s) needed to generate a particular column. Status declares whether the source grid consists of physical information (averages and summations) or categorical data. NoData represents columns which are currently not assigned, but are available for future extensions of PREVAH.

Default Control File for WINPREVAH:

A standard control file for WINPREVAH is produced by WINHRU. This file is stored as runFile-root-name.inp. This control file can be loaded and edited with WINPREVAH and used to initialise the model simulation. Further, the control file for spatial information and the grid with the HRU identifiers have to be linked to the control file with WINPREVAH. Further information is available in the WINPREVAH documentation.

Files for spatial interpolation of meteorological variables:

The digital elevation model grid (*.dhm), watershed limits grid (*.ezg) and grid of the meteorological zones (*.mez) have to be declared in the control files of the tools used for the spatial interpolation of meteorological variables (WINMET).

D DATAWIZARD: Assimilation of hydrometeorological ASCII data

D.1 Introduction

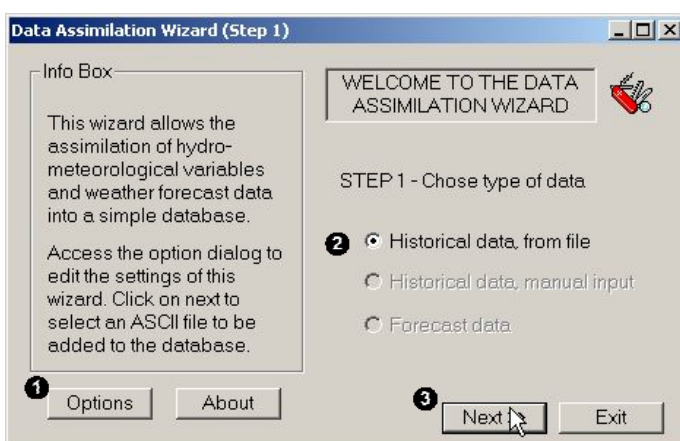
The assimilation and management of hydrometeorological data from a network of stations is crucial for the distributed application of hydrological models. DATAWIZARD is a tool allowing the assimilation and verification of hydrometeorological data and provides a link to WINMET, the spatial interpolation tool of the PREVAH modelling system (see Chapter E). DATAWIZARD has already been adopted for managing data in Switzerland, Austria, China, Germany, Italy, Kenya, Kyrgyzstan, Sweden, the United States and Uzbekistan.

D.2 Basic features of DATAWIZARD

DATAWIZARD has been developed to easily manage the hydrometeorological information needed for operating PREVAH.

- It is designed for the stepwise assimilation of raw meteorological information (precipitation, air temperature, wind speed, global radiation, relative humidity, water vapour pressure, sunshine duration, runoff and two user defined variables).
- It makes a simple plausibility/acceptability test of the data.
- It creates and edits a formatted station table, which includes all the attributes needed for running the interpolation of these hydrometeorological variables.
- It creates a simple database of hydrometeorological information.

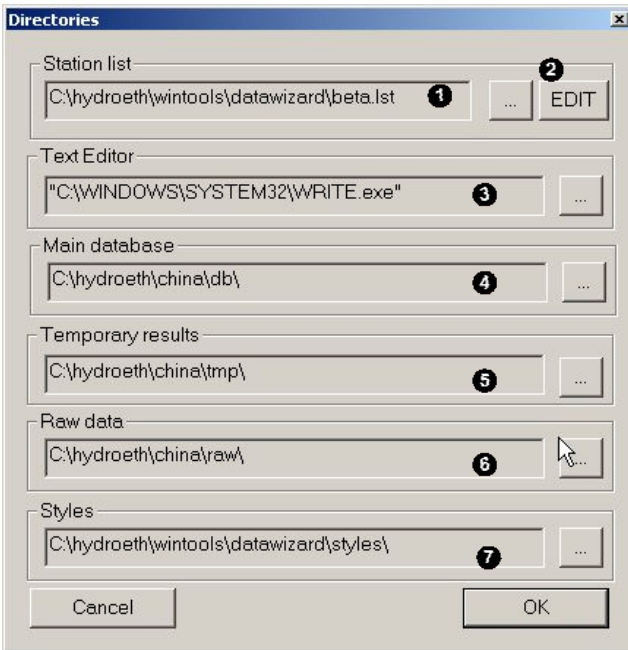
D.3 Step 1: Welcome



Launching the Wizard: Step 1 of DATAWIZARD.

- ❶ Click the [Options] button to access the options dialog.
- ❷ Choose whether you desire to assimilate historical data from file, or manually (not yet implemented) or forecast data (not yet implemented).
- ❸ Click the [Next >>] button to launch step 2 of DATAWIZARD.

D.3.1 Options Dialog

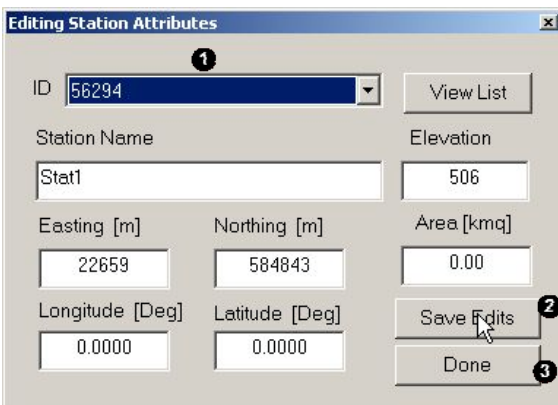


Setting the options of DATAWIZARD.

Through the options Dialog you have to link DATAWIZARD to a set of user defined files and directories. The following links have to be set:

- ❶ Link to the file containing the list and attributes of the stations available in the current database. By clicking the [EDIT] button (❷) you can access a dialog that allows you to update the attributes of each station. It is very important that you keep your attribute table as updated as possible and that you assign unique names and numbers to each station.
- ❸ Link to a default text editor (needed to view/edit the raw data and the station list files).
- ❹ Link to the directory where the database has to be stored.
- ❺ Link to the directory where the temporary files have to be stored.
- ❻ Link to the directory where you plan to transfer the raw data you want to assimilate with DATAWIZARD.
- ❼ Link to the directory where the format style macros have to be stored.

D.3.2 Edit the attributes of a station



This Dialog can be accessed through the OPTIONS Dialog (see above) by clicking the [EDIT] button. By clicking [View List] the station attribute table is opened with the selected Default Text Editor.

- ❶ Select the ID of a station to load its attributes in the dialog. Change the attributes accordingly:
 - Name: As a CHARACTER
 - Elevation, Northing, Easting: As an INTEGER in meters
 - Area: As a FLOAT in km²
 - Longitude and Latitude: As a FLOAT in degrees
- ❷ Click [Save Edits] to store the changes
- ❸ Click [Done] to leave the Dialog

D.3.3 Station attributes table

The station attributes table contains the following information:

Col	Definition	Position	Format	Notes	Sample
1	Station ID	Left	Chars 20 – 1X		56814
2	Station name	Left	Chars 30 – 1X		Sample_stat
3	Elevation [m a.s.l.]	Standard	Integer 6 – 1X		365
4	Area [km ²]	Standard	Float 12.2 – 1X	For runoff data	0.0
5	Easting [m]	Standard	Integer 12 – 1X		645233
6	Northing [m]	Standard	Integer 12 – 1X		187954
7	Latitude (Deg)	Standard	Float 10.3 – 1X		31.5
8	Longitude (Deg)	Standard	Float 10.3 – 1X		110.
9	DT-String-1	Standard	Chars 15 – 1X	Precipitation	NNNNNNNNNNNNNNNN
10	DT-String-2	Standard	Chars 15 – 1X	Air temperature	NNNNNNNNNNNNNNYNN
11	DT-String-3	Standard	Chars 15 – 1X	Wind speed	NNNNNNNNNNNNNNYNN
12	DT-String-4	Standard	Chars 15 – 1X	Global radiation	NNNNNNNNNNNNNNYNN
13	DT-String-5	Standard	Chars 15 – 1X	Relative humidity	NNNNNNNNNNNNNNYNN
14	DT-String-6	Standard	Chars 15 – 1X	Vapour pressure	NNNNNNNNNNNNNNNN
15	DT-String-7	Standard	Chars 15 – 1X	Sunshine duration	NNNNNNNNNNNNNNYNN
16	DT-String-8	Standard	Chars 15 – 1X	Runoff	NNNNNNNNNNNNNNNN
17	DT-String-9	Standard	Chars 15 – 1X	Free variable 1	NNNNNNNNNNNNNNNN
18	DT-String-10	Standard	Chars 15 – 1X	Free variable 2	NNNNNNNNNNNNNNNN

A 15 character text string is assigned to each of the 10 variables that can be assimilated by DATAWIZARD. Each character of such strings indicates the availability of data at a particular time resolution in minutes (DT). If a variable time resolution (e.g. 60 minutes temperature) is available for a particular station, then DATAWIZARD will put an 'Y' in the appropriate position of the time resolution string (e.g. DT-string-2 = NNNNNYNNNNNNNNNN).

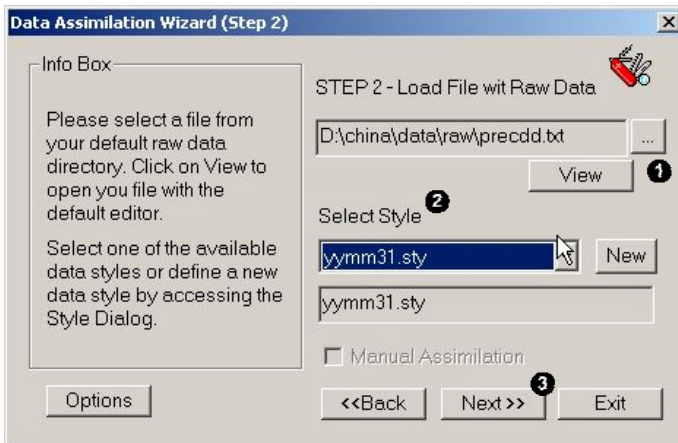
Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DT (MIN)	5	10	15	20	30	60	120	180	240	360	480	720	1440	From-To	Void
DT (HOURS)	-	-	-	-	-	1	2	3	4	6	8	12	24	-	-
Available	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Not available	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Example of stations attribute table:

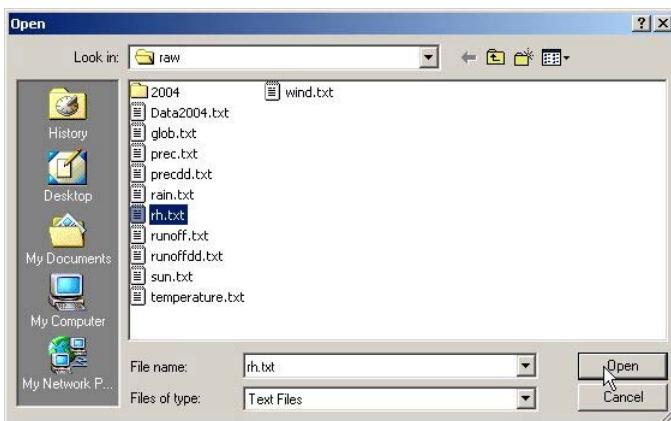
Station.ID Station Name Elev Area Easting Northing Lat Lon DT-Strings

460	Davos	1590	0.00	783580	187480	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
1030	St. Gallen	779	0.00	747940	254600	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
2220	Saentis	2490	0.00	744180	234920	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
3700	Zuerich_SMA	556	0.00	685125	248090	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
9400	Locarno-Mont	379	0.00	704220	114370	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
9480	Lugano	273	0.00	717880	95870	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
9850	Sever	1712	0.00	787840	158320	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
1940	Basel-Binnin	316	0.00	610850	265620	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
4140	Altdorf	451	0.00	691000	191750	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
5520	Bern-Liebefe	570	0.00	598610	197470	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
6340	Neuchatel	487	0.00	563110	205600	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
7500	Sion	542	0.00	593850	120700	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
7520	Sion-Aerodro	483	0.00	592130	118700	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
8390	Geneve_Obser	405	0.00	500720	117300	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
8440	Geneve-Point	420	0.00	498580	122320	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
40	Platta_(Mede	1375	0.00	708300	168400	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
60	Disentis	1190	0.00	708230	173780	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
280	Hinterrhein	1611	0.00	733900	153980	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
289	Spluegen	1504	0.00	744380	157620	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
380	Evio	1770	0.00	769800	148950	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
440	Weisseluhjoc	2690	0.00	780600	189630	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
510	Alvaneu-Dorf	1178	0.00	768880	172060	0.000	0.000	NNNNNNNNNNNNYNN	NNNN
600	Arosa	1840	0.00	770730	183320	0.000	0.000	NNNNNNNNNNNNYNN	NNNN

D.4 Step 2: Loading raw data



Step 2 of DATAWIZARD: Loading a file with raw data and selecting the format.



1 Click the button [...] to access a dialog (here on the right) for selecting a file with raw data from the defined raw data default directory. By clicking [View] the selected file is opened with the Default Text Editor. You can use this to identify the format of the file you are going to process with DATAWIZARD and integrate in the database.

2 Select a Style macro from the list of the available macros. Style macros govern the assimilation of raw data. New Style macros can be created by clicking the [New] button.

3 Click the button [Next >>] to launch step 3 of the DATAWIZARD.

D.4.1 The file format dialog

For the assimilation of the hydrometeorological information from files containing raw data, the format of the file has to be defined through the [File Format Wizard] Dialog, which can be accessed by clicking the [New Style] button during the second step of the data assimilation procedure. Every defined style is then stored as a macro in the assigned directory. Style macros (*.sty) are formatted as follows:

```
[Style file for data formats]
ID YY MM DD Ed Ed Ed Ed Ed      ! Nine IDs to define the content of the format columns
Headers = 0001                  ! Number of headers/rows to be skipped in the file
Columns = 0001                  ! Column after the format where data have to be read from
1st Hour = 0000                 ! Begin hour (only for time steps smaller than 1 day)
```

This means that your raw data file may have up to nine columns to define the date format. The content of each column can be defined through a key. The previous example of style macro defines raw data available in the following format:

			Global Radiation		Temperature
57516	1990	1	1	422	25.2
57516	1990	1	2	573	26.7
57516	1990	1	3	116	24.2
57516	1990	1	4	151	23.9
57516	1990	1	5	364	25.5
57516	1990	1	6	40	26.1
.....

The first row is a header and therefore skipped. Only non-numeric information is allowed in the headers! The first column in this raw data file represents the Station ID, the second the year (YY), the third the month (MM) and the fourth the day (DD). Only four columns are needed here for a complete definition of the date format. The other five possible format columns are not needed, thus they maintain the initial setting of "Edit" (Ed). The data are stored in the first and second column after the columns required to define the date, in this case the fifth column. In the given example of style macro the first column after the format columns will be assimilated in the database, in this case the global radiation. To assimilate the temperature (second column) you have to define a new style macro, where you assign the 2nd column after the format to be read from.

```
[Style file for data formats]
ID YY MM DD Ed Ed Ed Ed Ed      ! Nine IDs to define the content of the format columns
Headers = 0001                  ! Number of headers/rows to be skipped in the file
Columns = 0002                  ! Column after the format where data have to be read from
1st Hour = 0000                 ! Begin hour (only for time steps smaller than 1 day)
```

Special case:

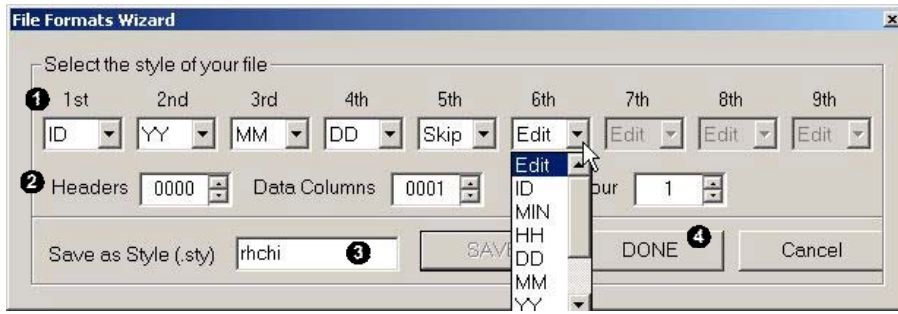
Station ID	Year	Month	Day1	Day2	Day3	Day4
60535600	1988	1	0	0	0	....
60535600	1988	2	0	0	0	....
60535600	1988	3	0	0	0	....
60535600	1988	4	0	0	0	....
60535600	1988	5	0	0	0	....
60535600	1988	6	0	0	0	....
60535600	1988	7	0	40.1	12	....
60535600	1988	8	0	0	0	....
60535600	1988	9	0	21	0	....
60535600	1988	10	0	0	0	....
60535600	1988	11	0	0	0	....
60535600	1988	12	0	0	0	....
....	1989	1	....	....	....	....

To assimilate daily data in the following format, such a style macro has to be defined:

```
[Style file for data formats]
ID YY MM Ed Ed Ed Ed Ed Ed      ! Nine IDs to define the content of the format columns
Headers = 0000                  ! Number of headers/rows to be skipped in the file
Columns = 0031                  ! Column after the format where data have to be read from
1st Hour = 0000                 ! Begin hour (only for time steps smaller than 1 day)
```

In this case the assimilation tool will search for raw data according to the current month and current year in up to 31 columns.

Style macros can be either edited manually and stored with the extension "*.sty" in the defined style macros directory (see above) or created through the implemented [File Format Wizard] dialog, which can be accessed by clicking the [New Style] button during the second step of the data assimilation procedure with DATAWIZARD.



File format wizard of DATAWIZARD: Defines the format of raw data.

❶ With this [File Format Wizard] Dialog you can define the format of your raw data files interactively by assigning a key to each column. These are the recognised keys:

Key	Full name	Definition
Ed	Edit	Initial settings for each column.
ID	Station ID	Assign ID to the column in your raw data file that defines the station identifier (as an INTEGER). If no column with station identifier is available, the station identifier has to be provided later interactively.
MI	Minutes	Assign MI to the column in your raw data file that defines the minutes (required only if the time step is smaller than 1 hour)
HH	Hours	Assign HH to the column in your raw data file that defines the hours (required only if the time step is smaller than 1 day)
DD	Days	Assign DD to the column in your raw data file that defines the hours (recommended, required only if the time step is smaller than 1 day)
MM	Month	Assign MM to the column in your raw data file that defines the month (always required)
YY	Year	Assign YY to the column in your raw data file that defines the year (always required)
Sk	Skip	Assign Sk if you desire to skip a certain column
FR	From	Not yet implemented
TO	To	Not yet implemented

❷ Additionally you have to declare how many headers have to be skipped and in which column after the format the data have to be read. If you assimilate data with a time resolution smaller than one day (1440 minutes) a start hour can be assigned. If you sample six-hourly data (360 minutes) at 2:00, 8:00, 14:00 and 20:00, then you should assign "begin hour"=2 and time resolution 360.

❸ You can save the settings of the [File Format Wizard] dialog as a Style macro in the defined style macros directory. Thus, give a name to the macro and save it by clicking the button [Save].

❹ Leave the dialog by clicking the button [Done].

The assimilation algorithm will then process the different columns of the selected file with raw data according to the keys assigned in the style macro.

D.5 Step 3: Selection of date range and time step



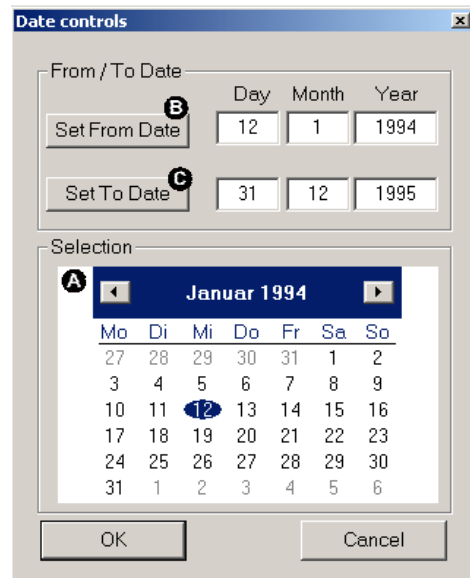
Step 3 of DATAWIZARD: Allows the selection of the start and end date for the data import and declaration of the raw data time step.

❶ Declare the start and end date for the available raw data. Attention: Do not be too generous with the selection of the start and end date. If data begins on April 15 1995 do not set as [From Date] January 1 1995. Otherwise the assimilation process could last much longer than due.

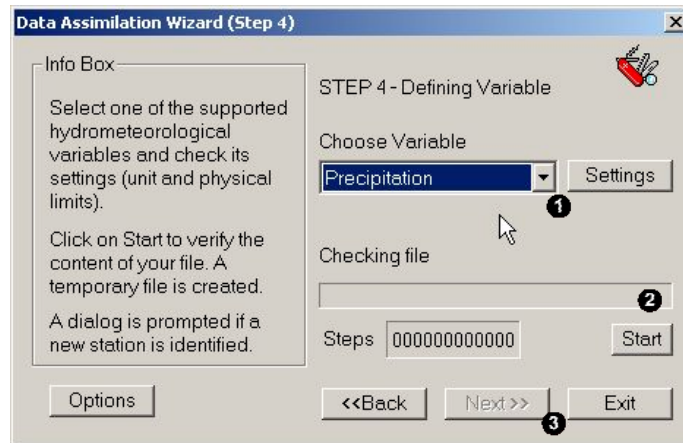
❷ By clicking the [Calendar Tool] button, you can access a [Date controls] dialog that allows you to set the date limits interactively. To change the 'From Date', select the envisaged start date in the Wizard (❶) and click the [Set From Date] (❷) button. To change the 'To Date', select the desired end date in the Wizard and click the [Set To Date] (❸) button.

❸ Select the time step. To date, DATAWIZARD has been successfully tested for a time resolution of 60, 360, 480 and 1440 minutes.

❹ Click the button [Next >>] to launch step 4 of the DATAWIZARD.



D.6 Step 4: Variable definition and quality check



Step 4 of DATAWIZARD: The variable to be assimilated is defined here.

1 Select the variable to assimilate. Many settings have to be carefully assigned to each of the hydrometeorological variables processed by DATAWIZARD. To set and edit such information click the [Settings] button to access the [Physical Limits] dialog. In this dialog you can then:

A Choose the variable

B Click [Start editing]

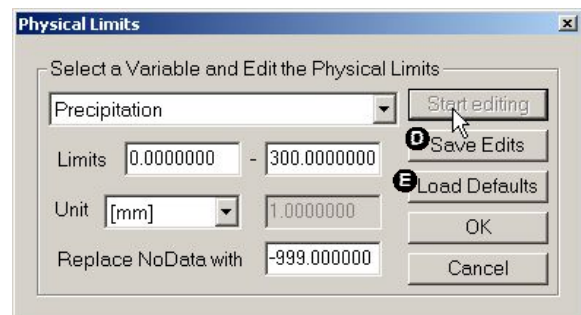
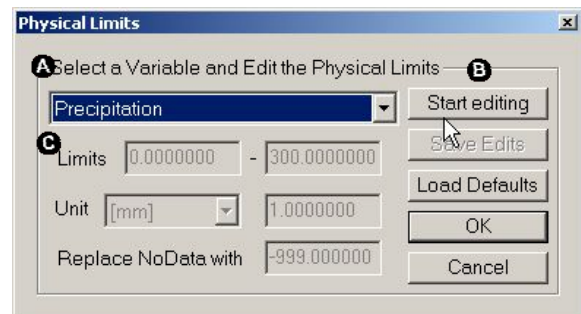
C Edit the physical limits, choose the input unit, select the NoData value

D Click [Save Edits]

E Defaults for daily time resolution (see the following table) can be loaded by clicking the [Load Defaults] button.

2 Start the verification of the data you are assimilating with DATAWIZARD.

3 Click the button [Next >>] to launch step 5 of DATAWIZARD.



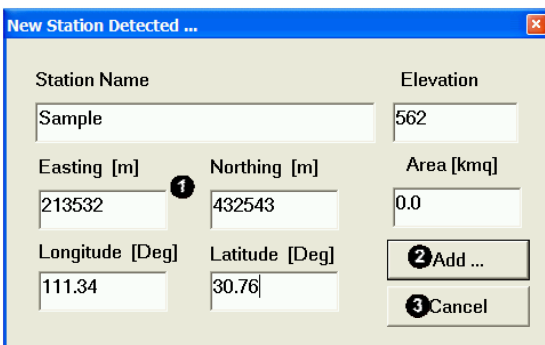
Recommended NoData value, physical unit and minimal x_{\min}^{phys} and maximal x_{\max}^{phys} physical limits for daily hydrometeorological variables assimilated and controlled by DATAWIZARD.

Variable	NoData	Unit	x_{\min}^{phys}	x_{\max}^{phys}
Precipitation	-998	[mm day ⁻¹]	0	500
Air Temperature	-998	[°C]	-50	50
Wind Speed	-998	[m s ⁻¹]	0	70
Global Radiation	-9998	[W m ⁻²]	0	1360
Relative Humidity	-998	[-]	0	1
Water Vapour Pressure	-998	[hPa]	0	123
Sunshine Duration	-998	[-]	0	1
Runoff	-9998	[m ³ s ⁻¹]	0	user
Free1	-9998	[-]	user	user
Free2	-9998	[-]	user	user

D.7 Data verification

During the fourth step of the data assimilation procedure, the following phases (a to e) are completed:

- a) Identification of the station from where data were obtained. If the Style macro (and the raw data) contains a column with the ID of the station that provided the data, then this ID is compared to all IDs of the stations included in the stations attribute table. If no STATION-ID is provided, then a small dialog is prompted and you have to declare a STATION-ID. If the STATION-ID is already available, the data verification goes to phase b). If the STATION-ID is not yet included in the stations attribute table, then a dialog is prompted:



- ❶ Give the stations attributes accordingly:
 Name: As a CHARACTER
 Elevation, Northing, Easting: As an INTEGER in meters
 Area: As a FLOAT in km²
 Longitude and Latitude: As a FLOAT in degrees
- ❷ Click [Add...] to include the new station into the stations attribute table.
- ❸ Click [Cancel] to leave the Dialog without adding the station to the stations attribute table.

Do take enough time to maintain the station attribute table. The name of the station should be unique and allow you to have a clear idea on the location of the station.

- b) Once the STATION-ID is known, all the raw data records are checked for quality. The absolute value of each x_i record must be smaller than the absolute value of the defined NoData value. If this condition is not satisfied (Equation D1), DATAWIZARD sets the value to NoData for this record and switches to the next record.

$$\begin{cases} |x_i| < |\text{NoData}| & \text{then Data are available} \\ |x_i| \geq |\text{NoData}| & \text{then Data are missing, } |x_i| = |\text{NoData}| \end{cases} \quad (\text{D1})$$

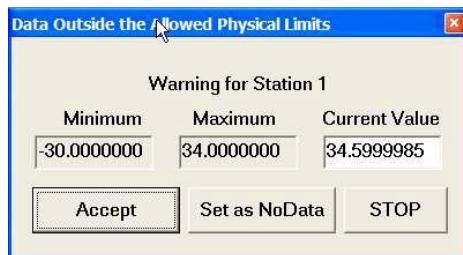
- c) If the condition set by Equation D1 is fulfilled, the raw data records are ready for a second test. Prior to the second test an internal unit adjustment is completed. If the processed raw data records are not available in the required physical unit, they are transformed into this unit according to the coefficients given by the settings of the [Physical Limits] dialog (see above).

Units conversion table as supported by DATAWIZARD. The default units are marked in yellow.

Variable	Option	Unit	Adjustment factor	Variable	Option	Unit	Adjustment factor
Precipitation	1	[mm]	1.0	Relative humidity	1	[-]	1.0
	2	[^{1/10} mm]	0.1		2	[%]	0.01
Air temperature	1	[°C]	1.0		3	[‰]	0.001
	2	[^{1/10} °C]	0.1	Water vapour Pressure	1	[hPa]	1.0
	3	[K]	-273.15		2	[^{1/10} hPa]	0.1
	4	[°F]	(x _i -32)·5/9	Sunshine duration	1	[min]	60 ⁻¹
Wind speed	1	[m s ⁻¹]	1.0		2	[h]	24 ⁻¹
	2	[^{1/10} m s ⁻¹]	0.1		3	[^{1/10} h]	240 ⁻¹
Global radiation	1	[W m ⁻²]	1.0		4	[-]	1.0
	2	[J cm ⁻²]	8.64 ⁻¹	Runoff	1	[mm]	1.0
Runoff	1	[mm]	1.0		2	[l s ⁻¹]	1.0
	2	[J cm ⁻²]	8.64 ⁻¹		3	[m ³ s ⁻¹]	1.0

- d) The main task of the data quality check is the test of plausibility against user defined minimal x_{\min}^{phys} and maximal physical limits x_{\max}^{phys} (see the Table above).

$$\left\{ \begin{array}{ll} x_{\min}^{\text{phys}} < x_i < x_{\max}^{\text{phys}} & \text{then Data are accepted} \\ x_i \leq x_{\min}^{\text{phys}} \quad \text{or} \quad x_i \geq x_{\max}^{\text{phys}} & \text{then Warning Dialog} \end{array} \right. \quad (\text{D2})$$



If the conditions set by Equation D2 are not fulfilled, a warning dialog is prompted. The current record x_i and the defined physical limits x_{\min}^{phys} and x_{\max}^{phys} are shown. You can decide here if you [Accept] the current value. You can also modify the value before accepting it or discard the value and [set as NoData].

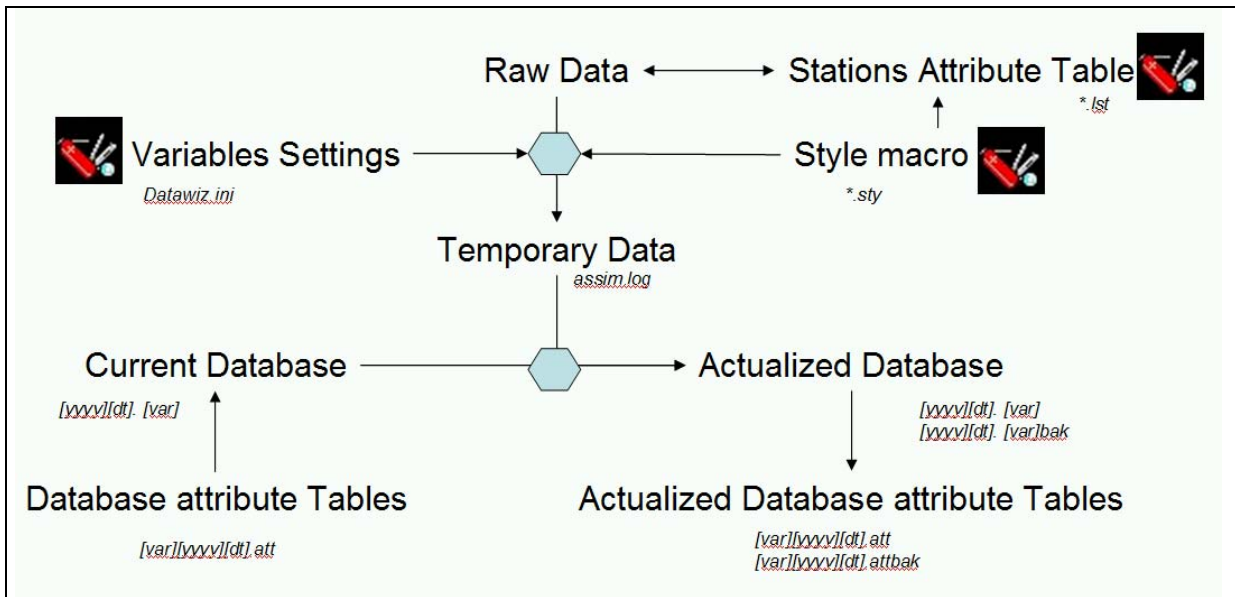
You can also [Stop] the data verification if you feel that you have set the physical limits too restrictively.

For a more sophisticated data plausibility test, we suggest a detailed data pre-processing (homogenisation, cross correlations, plausibility tests ...) before assimilating the data with DATAWIZARD.

- e) The results of the data verification are written in the default temporary directory. A file per station is stored. The file name is defined by the STATION-ID, the file extension is defined by the variable that is currently being assimilated (see later in this document). A log-file (assim.log) is written to control the transfer of the verified data into the simple database.

D.7.1 Structure of the database

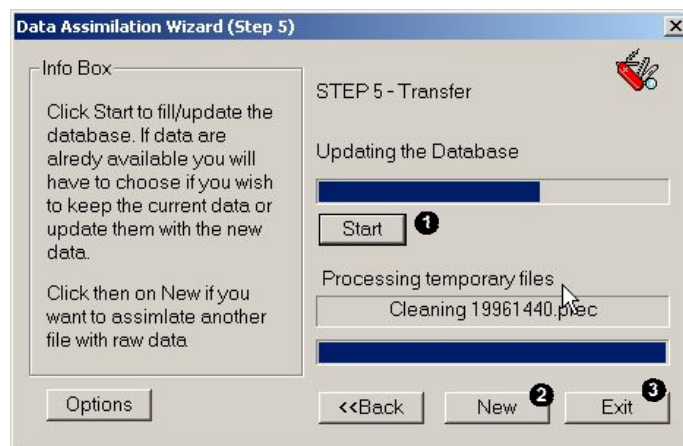
The simple database created by DATAWIZARD works as depicted in the following scheme:



Database records consist of two files per year for each variable and time resolution: A data table and attribute table. The following table exemplifies how file names are built:

Variable	Time resolution	Year	Data Table	Attribute Table
[var]	[dt]	[yyyy]	[yyyy][dt].[var]	[var][yyyy][dt].att
Air Temperature	60 Minutes	2000	200060.tair	tair200060.att
Precipitation	1 Day	1988	19881440.prec	prec19881440.att
Runoff	6 hours	1995	1995360.runo	runo1995360.att

D.8 Step 5: Transfer of data into the database



Step 5 of DATAWIZARD: Data are transferred into the database.

- ❶ The data transfer can be initialised by clicking the [Start] button.
- ❷ After successful assimilation you can either begin with a new assimilation job.....
- ❸ or leave DATAWIZARD.

D.8.1 Database attribute table

For each year [yyyy], time resolution [dt] and variable [var] assimilated by DATAWIZARD an attribute table is maintained. The name of the attribute table is composed as follows:

backup copies as

[var][yyyy][dt].att

[var][yyyy][dt].attbak

The accepted variables are labelled as follows [var]

Variable	[var]
Precipitation	prec
Air Temperature	tair
Wind Speed	wspd
Global Radiation	radg
Relative Humidity	rhum
Water Vapour Pressure	vapo
Sunshine Duration	sund
Runoff	runo
Free1	fre1
Free2	fre2

[dt] accepts the following values

DT (MIN)	5	10	15	20	30	60	120	180	240	360	480	720	1440

Database attribute tables are formatted as follows:

```
Attribute Table 2000 Air temperature      ! Header
00001      57516                          ! 1st Station-ID
00002      57461                          ! 2nd Station-ID
00003      57237                          ! 3rd Station-ID
00004      57411                          ! .....
00005      57355                          ! .....
```

The database attribute tables basically contain a link between the Stations attribute table and the columns in the Database data table. The example given above shows that, for the year 2000, there are 5 stations providing data. The first column after the DATE-ID in the Database data table will include data from station '57516', the second from station '57461' ...and so on.

Thus, DATAWIZARD can, at every time step, check which station is providing data for a certain year and hydrometeorological variable. This also allows for updating the data of a certain station without having to reload previously processed data.

D.8.2 Database data table

For each year [yyyy], time resolution [dt] and variable [var] assimilated by DATAWIZARD a data table is maintained. The name of each data table is composed as follows:

[yyyy][dt]. [var] backup copies as [yyyy][dt]. [var]bak

Database data tables are formatted as follows:

YYYYMMDDhhmmbegiendd	57516	57461	57237	57411	57355
20000101240000000000	5.2000	7.2000	5.6000	4.4000	9.8000
20000102240000000000	6.8000	8.2000	2.5000	5.6000	7.6000
20000103240000000000	7.4000	8.4000	6.0000	6.3000	8.2000
20000104240000000000	8.2000	8.3000	7.0000	7.4000	9.2000
20000105240000000000	9.9000	5.8000	7.6000	8.3000	8.2000
20000106240000000000	10.2000	6.9000	7.7000	8.6000	7.8000
20000107240000000000	10.1000	4.4000	5.9000	8.5000	4.7000
20000108240000000000	9.8000	3.3000	5.6000	8.4000	5.8000
20000109240000000000	9.0000	4.6000	6.3000	6.4000	7.4000
20000110240000000000	10.0000	5.0000	7.2000	8.6000	7.5000
20000111240000000000	11.7000	4.6000	5.1000	9.8000	6.6000
20000112240000000000	10.1000	4.7000	5.3000	7.4000	6.3000
20000113240000000000	10.7000	5.6000	2.2000	7.8000	6.6000

The header of the Database data tables contains the information on the STATIONS-ID. This allows a link with the Database attribute tables and Stations attribute table. Every file contains a full year at the given time resolution, even if only portions of the year are available. The first column is the DATE-ID. The DATE-ID is composed as follows:

[YYYY][MM][DD][hh][mm][begi][endd]

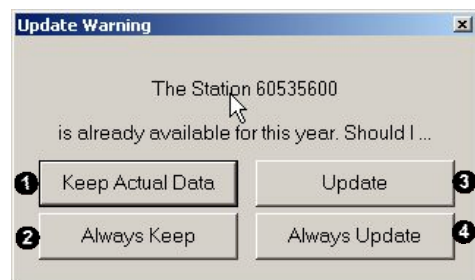
with

[YYYY]	Year	[MM]	Month
[DD]	Day	[hh]	Hour
[mm]	Minutes	[begi]	Start Time (hhmm) – not implemented
		[endd]	End Time (hhmm) – not implemented

The DATE-ID is computed internally for each of the year time steps. The columns of the raw data file that build the date are used to compute a second DATE-ID. A loop is made to compare the DATE-ID from the raw data to the internal DATE-ID. If both DATE-IDs match, the data for this time step are loaded into the database file. Thus, it is possible to assimilate only parts of the data. Gaps in the raw data are automatically filtered when an internal DATE-ID does not match any DATE-ID from the raw data file.

DATAWIZARD recognises if data from a station are already loaded into the corresponding database data table. In such cases a warning dialog is prompted at the beginning of each year. The user can then decide to:

- ❶ Keep the actual records for that station and year, and update only where NoData are stored.
- ❷ Keep the actual records for all years and that station. Update only where NoData are stored.
- ❸ Update the records for that year and that station. Keep only where raw data show NoData.
- ❹ Update the records for all years and that station. Keep only where NoData are stored.



E WINMET: Spatial interpolation of hydrometeorological variables

E.1 Introduction

WINMET has been developed to easily interpolate meteorological information required by PREVAH. Currently, WINMET integrates two versions in one. The first version (Swiss version) is specifically designed for applications based on the hydrometeorological data provided by MeteoSwiss. The second version (international version) is designed to interact with DATAWIZARD, another tool of the PREVAH modelling system (see preceding Chapter). This documentation will focus on the second, international version.

E.2 Start-up and welcome

After launching WINMET, a dialog is prompted for choosing the Swiss or international version. When using the command line, the version choice for WINMET may be skipped using the following arguments:

`winmet /s` for the Swiss version
`winmet /i` for the international version



E.2.1 Basic features of WINMET international

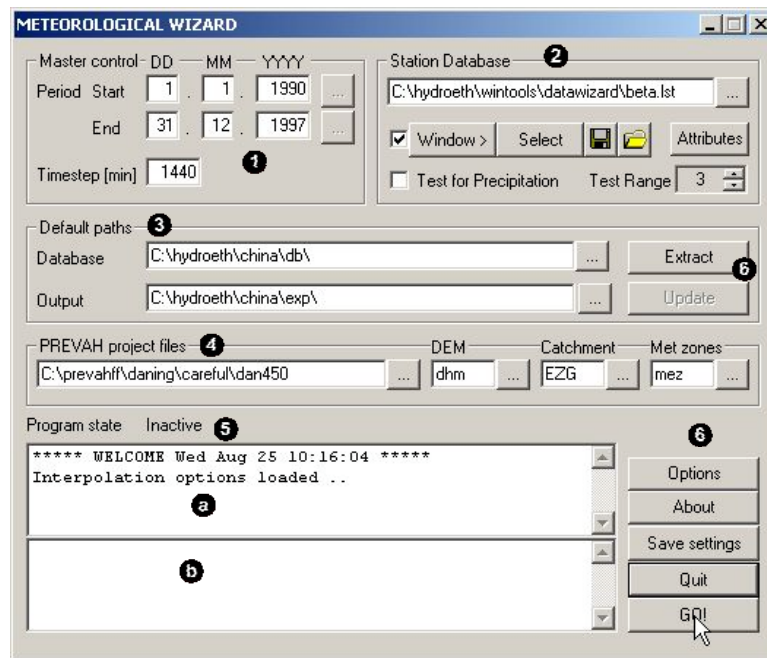
- Extracts meteorological information from a simple database created by DATAWIZARD.
- Different methods for a user friendly selection of hydrometeorological stations.
- Creates elevation dependent regressions of the analysed variables.
- Implements different approaches for the spatial interpolation of hydrometeorological information.
- Checks whether the interpolated values are reasonable.
- Creates tables of hydrometeorological information required to operate PREVAH.

E.2.2 Plug-ins

The `regr.exe` and `regrasci.exe` programs have to be copied in the directory where the simple database of hydrometeorological information created by DATAWIZARD is stored. `regr.exe` determines elevation dependent gradients for input data of any time step. The regression is completed for two separate altitudinal ranges which can be specified by the user. The profile may consist of up to three sections (see Chapter 3.4.2 in Part II of the PREVAH documentation). `regrasci.exe` converts a binary regression as generated by `regr.exe` into an ASCII-regression file. This may be desired for file transfer between different systems (e.g. DOS/WINDOWS or UNIX) or for looking into the file for data checking. The specifications of both formats are described later in this documentation.

The station attribute table [`*.lst`] created and maintained by DATAWIZARD has to be available.

E.2.3 Main dialog of WINMET international



International version: Main dialog of WINMET

The main dialog of the WINMET international version is divided into sectors:

❶ In the [Master control] sector, you have to specify the time range of the interpolation job. The start and end dates both have to be given as day (DD), month (MM) and year (YYYY). You also have to indicate the time step of the data you intend to process with WINMET.

❷ The [Station Database] sector is where you can access Station selection tools and the station attribute table. In this block, you may also activate an acceptability test for precipitation data.

❸ The [Default Paths] sector allows the setting of links to the directory where the database maintained by DATAWIZARD is stored and where WINMET outputs have to be transferred. In the output directories, four sub-directories will be created:

- *Database_Path/Stations/*: Data extracted from the database.
- *Database_Path/Input/*: Results of elevation dependent analysis.
- *Database_Path/Tables/*: Tabular interpolation results.
- *Database_Path/Grids/*: Gridded interpolation results.

If such directories contain data from previous interpolation jobs, WINMET will ask if you desire to delete their content before running the current interpolation job.

❹ The [PREVAH Project Files] sector links WINMET with spatial data of the investigated catchment. The file extensions for the digital elevation model [DEM], watershed limits [Catchment] and meteorological zones [Met zones] have to be indicated. The DEM grid is required for elevation dependent interpolation approaches. The watershed limits grid is required to define the domain of interest for the spatial interpolation. The grid of the meteorological zones is needed to generate separate output for different sub-units within the domain of interest.

❺ The [Message] window displays information on the current processes: Station availability (❶); files availability (❷); and progress of the interpolation procedure.

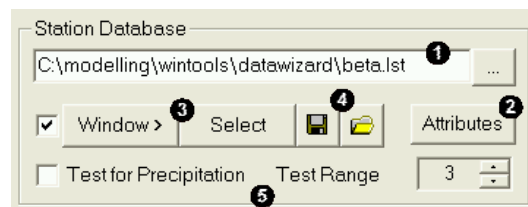
6 The [Commands] sector contains the main controls for WINMET. By clicking the appropriate button you can:

- Extract station data from the database and save them as a formatted table in the *Database_Path/Stations/* directory.
- Access the options dialog.
- Save the current settings.
- Start the interpolation job [GO!].
- Leave WINMET.

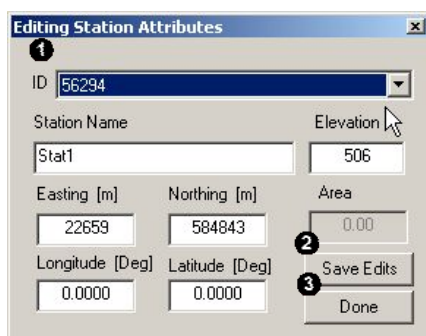
E.2.4 Station database

The Station Database sector of WINMET's main dialog serves for setting a link between WINMET and the Station attribute table generated by DATAWIZARD. The format specifications of this table are provided in the documentation of DATAWIZARD.

- 1 Link to the Station attribute table file of the current database.
- 2 By clicking the [Attributes] button you can access a dialog that allows you to update the attributes of each station.
- 3 By clicking the [Window] button you can access a dialog that allows you to select the domain where available stations are sought. The [Select] button prompts a window with a list of all available stations. You can then mark or unmark stations and save the final configuration of stations.
- 4 The current selection of stations can be saved to [] and loaded [] from a file.
- 5 The acceptability of precipitation records can be tested. Click the check box to activate the test during the extraction of data from the database. The test range may vary between 1 (very rigorous test) and 5 (very weak test).



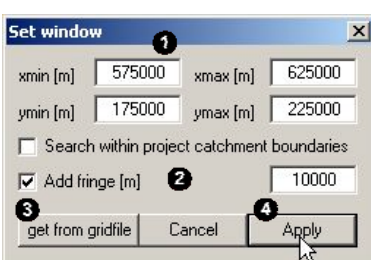
E.2.5 Edit the attributes of a station



This dialog can be accessed through the Station database sector of WINMET's main dialog by clicking the [Attributes] button.

- 1 Select the ID of a station to load its attributes. Change the attributes accordingly: Name: As a CHARACTER; Elevation, Northing, Easting: As an INTEGER in meters; Area: As a FLOAT in km²; Longitude and Latitude: As a FLOAT in degrees
- 2 Click [Save Edits] to store the changes
- 3 Click [Done] to leave the dialog

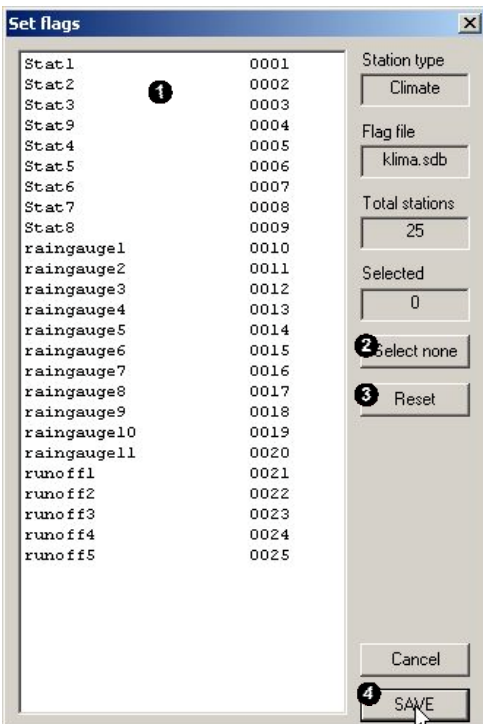
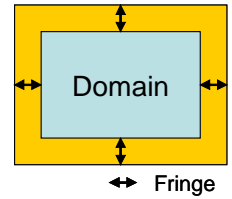
E.2.6 Selection of stations



By clicking the [Window] button, the [Set Window] dialog is prompted. Two methods for selecting the station to be extracted from the database and used for spatial interpolation are available.

When selecting the appropriate station for interpolation, you can define the co-ordinates of a window (❶ xmin, xmax, ymin, ymax) where stations have to be located. A so-called fringe area (❷) can be defined to extend the search area. To reduce the search area to the area of the investigated basin, activate the checkbox [Search within project catchment boundaries].

To simplify the selection of the window, set the co-ordinates of the window of interest equal to the domain of a catchment. Thus click the [get from gridfile] button (❸) and select a grid of the domain you are interested in. In this case, the xmin, xmax, ymin, ymax settings (❶) are set automatically, according to the co-ordinates of the loaded grid. Further, you can add a fringe to expand the area of the domain of interest. Stations located in the defined window (± fringe) will then be selected, after clicking [Apply] (❹).



A second dialog will be prompted to confirm the selection.

Stations can also be selected through the [Set Flags] dialog. This is prompted automatically after the [Set Window] dialog and can also be accessed by clicking the [Select] button in the Station Database sector of the main WINMET.

All stations included in the Station attribute table are listed in a selection field (❶). You can select the stations of interest by clicking on their name. For multiple selection press "SHIFT" or "CTRL" while you are clicking. To cancel all selections, click [Select none] (❷). To discard the changes click [Reset] (❸). Once you have made the right selection, click [SAVE] to store a station flag file (❹).

The Station flag file is needed for the extraction of data from the available database. It is a reduced copy of the station attribute table and is formatted as follows:

Flag No.	W	Name	H	Easting	Northing
1	1	Stat1	506	22659	584843
0	2	Stat2	1892	-138483	-36689
1	3	Stat3	133	720284	579827
1	4	Stat9	23	991990	579941
0	5	Stat4	259	254925	456134
1	6	Stat5	674	408446	729820
1	7	Stat6	303	22245	590031
--	--	---	-----	-----	-----

The Flag indicates whether a station was selected or not. "No." is an internal incremental number assigned by WINMET to each station in the Station attribute table. Name is the name of the station. H is the elevation of the station. Easting and Northing are the x,y co-ordinates, respectively, of the station in the co-ordinate system defined by the digital elevation model of the investigated area. This information is assimilated from the Station attribute table provided by DATAWIZARD. Previous to using both WINMET and DATAWIZARD, the user has to transform the co-ordinates of the stations intended for modelling into the same co-ordinate

system of the spatial data available for the investigated area – co-ordinates must be in meters, and using UTM co-ordinates is recommended.

E.3 WINMET options

Options dialog of WINMET

The Options dialog of WINMET is also divided into sectors:

❶ In the Interpolation variables sector, you may for each variable:

- Define the method used for interpolating each variable
- Assign a name to the input and output files
- Indicate the NoData value which indicates missing data to be skipped
- Edit a factor for transforming the interpolation results into the physical unit required by the model
- Set the physical limits for accepting the interpolation results. If such limits are exceeded, the value of the limit is assumed as an interpolated value
- Activate or deactivate optional gridded and tabular output

Further details on the Interpolation variables sector follow in the next section.

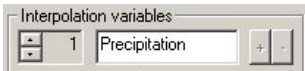
❷ The Regression variables sector sets the options controlling 'regr.exe', the plug-in that determines the coefficients of the elevation dependent regression.



❸ The Kriging and IDW sectors allow the modification of basic options of the two interpolation approaches. The maximum distance for IDW interpolation can be modified. The constant temperature trend for the "Lapse Rate" interpolation method can be modified. By checking a box you can obtain grids of the IDW-weights for each station. Such grids are saved in the Database_Path/Grids/ directory with the extension [*].wid]. The Kriging settings can be modified within a separated dialog, which is opened by clicking the [Access] button.

❹ The General controls sector provides access to miscellaneous features of WINMET.

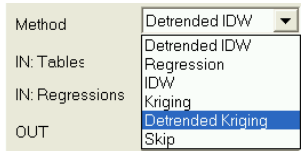
E.3.1 Defining the interpolation variables

Select the variable



The Interpolation Variables sector allows editing of the interpolation option of up to six hydrometeorological variables. You can edit the name of the variable (e.g. change from water vapour pressure to relative humidity). Use   to change from one variable to the next or previous.

Select the method



Each variable can be interpolated using a user defined approach:

The following methods are implemented in WINMET:

- Detrended IDW (DTIDW)
- Simple Elevation Dependent Regression (EDR)
- Simple Inverse Distance Weighting (IDW)
- 2D Kriging (KRI)
- Detrended Kriging (DTKRI)
- IDW Lapse Rate
- Kriging Lapse Rate

Select 'Skip', if you do not want to interpolate a particular variable. Recommendations follow at the end of this chapter.

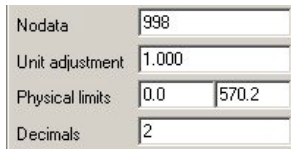
Assign the names for input/output



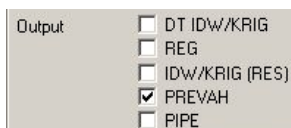
The root name of the input file needs to be specified.

- Tables: The year format has to be declared either as \$\$ (if two digits) or as \$\$\$\$ (if four digits).
- Regressions: As for Tables.
- OUT: The basic name for the output files regarding a specific variable has to be set.

The default names for Tables and Regressions files are optimised for using WINMET together with DATAWIZARD. Only advanced users should change these settings. The OUT name may be chosen freely, although the default names are strongly recommended for first time users.



Data in the input tables may be erroneous or missing. DATAWIZARD substitutes such data with a NoData value. WINMET skips these data if the NoData value is declared correctly. A value can be provided to transform the interpolated value into another physical unit. After the unit adjustment, the interpolated data shall not under-run or exceed given physical limits (left is minimum, right is maximum). If such limits are exceeded, then the value of the limit is assumed as the interpolated value. Further, the precision (in digits of 0–5) of the tabular output may be specified. Recommendations follow at the end of this chapter.



WINMET is designed to generate gridded and tabular results of the spatial interpolation of hydrometeorological variables. File formats are specified in the Appendix.

The following outputs can be optionally saved at each time step:

- DT IDW/KRIG: GRID interpolated by DTIDW/DTKRI Name **[Out]MMDDHH.d\$\$\$\$**. A grid is written for each time step.
- REG: GRID interpolated by EDR / Name **[Out]MMDDHH.r\$\$\$\$**
- IDW/KRIG(RES): GRID interpolated by IDW/KRI (the residuals in case of method DTIDW/DTKRI) / Name **[Out]MMDDHH.i\$\$\$\$**
- PREVAH: Meteorological table for PREVAH, a value per time step and meteorological zone, formatted as an ASCII file / Name **[Out][GRID].s\$\$\$\$**
- PIPE: Not yet implemented.

Grid output	Daily	None
	Monthly	Sum
	Yearly	Sum

The user can decide whether additional grids are saved in the Database_Path/Grids/ directory. Grids can be written at the end of each day [DD], month [MM] and year [YYYY]. You can choose to save either the sum [Sum] or the average [Avg] of the data. The following rules apply for naming the grids.

DAILY GRID: Database_Path/Grids/ [OUT]YYYYMM.[S/A]DD

MONTHLY GRID: Database_Path/Grids/ [OUT]YYYY.[S/A]MM

YEARLY GRID: Database_Path/Grids/ [OUT]YYYY.[S/A]yy

[OUT] is the general character string for the outputs of a certain hydrometeorological variable.


Save

After each change in the Interpolation Variables block, the save button is activated. Click to save your edits. If you forget to save a warning will be prompted.

E.3.2 Defining the elevation dependent regression

Select the variable

Regression variables	
1	precipitation
<input checked="" type="checkbox"/>	Do regression

The Regression Variables sector allows the editing of the interpolation option of up to seven hydrometeorological variables. Click  1 to change from one variable to the next or previous. For disabling the estimation of regression for a certain variable you have to deactivate the corresponding checkbox [Do regression].

Assign the names for input/output

Infile 1	sund
Infile 2	
Infile for precip.	
Outfile	ssd_

The basic name of the input files where station data are stored is required. The default names are optimised for using WINMET international together with DATAWIZARD. Only advanced users should change these settings.

Error if above	998
Lower limit	500
Upper limit	1000
Dynamic range	200
Spread at least	100

The elevation dependent regressions of meteorological variables are controlled by changing some basic settings:

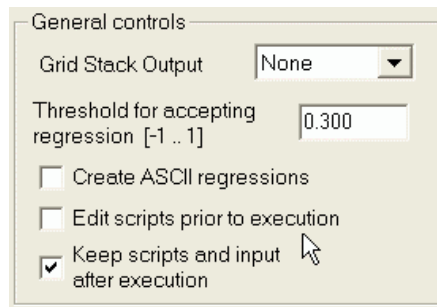
- Error if above: This value is used to skip NoData from the tables created by DATAWIZARD. To skip data an algorithm is used.
- Lower limit is required to define the elevation in meters above sea level where a first inversion has to be identified.
- Upper limit is required to define the elevation in meters above sea level, where a second (higher) inversion has to be identified.
- Dynamic range is a tolerance interval in meters, above or below one of the two given elevations, where the inversion has to be searched.
- Spread range is the minimum elevation difference between two inversions, in meters.

Again, the default values are optimised for using WINMET international together with DATAWIZARD. Only advanced users should change these settings.

Save

After each change in the Interpolation Variables block, the save button is activated – click to save your edits.

E.3.3 Managing general controls



Grid Stacks: Stacks may be activated either as ASCII or binary elements. Stacked output writes a file per time step where gridded data of all variables are saved. Contact the developers if you think you need this feature. Set tolerance for accepting regressions of precipitation

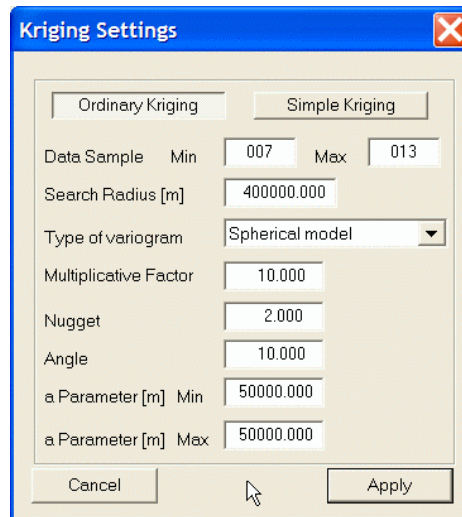
A threshold can be assigned to avoid accepting regressions of precipitation that are not well correlated with the observations and would cause artefacts. A correlation value between [-1 to 1] has to be declared. If you declare "-1", then all regressions are accepted. A noncommittal threshold of "0.3" is recommended for accepting regressions of precipitation.

Creation of ASCII Regression Files: Regression files are stored either in binary or ASCII format. To generate the ASCII format, activate the corresponding check box [Create ASCII regressions].

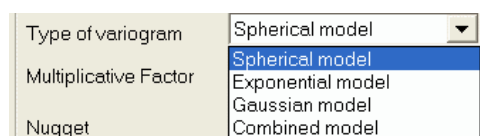
Viewing the Interpolation Script: To make changes by hand to the interpolation scripts (not recommended), activate the corresponding check box [Edit scripts prior to execution]

Management of scripts: By activating (default) the corresponding checkbox [Keep scripts and input after execution], the content of the Output_Path/Input/ directory is kept.

E.3.4 Managing Kriging options



Four variogram models are available (View section):



- The Spherical model is perhaps the most commonly used variogram model. It has a linear behaviour at small separation distances near the origin but flattens at larger distances. If the nugget variance is impor-

tant but not too large, and there is a clear range and sill, the spherical model usually fits observed variograms well.

- The Exponential model is another commonly used transition model. This model reaches its sill asymptotically, but it is linear at very short distances from the origin as in the spherical model. However, it rises more steeply and then flattens more gradually. It is usually a good option if there is a clear nugget and sill, but only a gradual approach to the range.
- The Gaussian model is a transition model often used to model extremely continuous phenomena. Like the exponential model, it is reaching the sill asymptotically. The Gaussian model is indicative of very continuous phenomena, so this estimation procedure makes much more use of the closest samples.
- The Combination model is the fourth model. It is a weighted combination of the spherical, exponential and Gaussian model. Weights for the three models are all equalised in WINMET. Near the origin, the combination model is almost equal to the spherical model, but it flattens earlier than this model.

Increasing the nugget effect makes the distribution of weights more equal, which in turn causes the estimated value to be somewhat higher and the estimation procedure to become more like a simple averaging of the available data. A pure nugget effect model entails a complete lack of spatial correlation. The graph of a pure nugget effect model would be a horizontal line.

Changing the range has a relatively minor effect on the Kriging weights and estimates. If the range is becoming very small, all sample points appear to be equally far away from the point being estimated and from each other. This gives a result similar to that of the pure nugget effect. If the range is set very large, all sample points are included for the interpolation of all grid cells, but they are weighted in succession to their lag distance and chosen variogram model. For irregularly gridded data, the search neighbourhood should be slightly larger than the average spacing between the sample data. As a final condition, at least four samples should be within the range, but in practice, one typically tries to have at least 12 samples.

Ordinary Kriging is often associated with the acronym BLUE for "best linear unbiased estimator": The estimates of Ordinary Kriging are weighted linear combinations of the available data, thus it is "linear"; it is "unbiased" since it tries to have the mean residual or error equal to 0; and it is the "best" because it aims to minimise the variance of errors, which distinguishes Ordinary Kriging from most other interpolation methods.

Simple Kriging is based on three assumptions:

- Observations are a partial realisation of a random function
- The realisation is second order stationary
- The mean is known.

These are the same conditions as for Ordinary Kriging, except that the third condition is more restrictive. In Ordinary Kriging, the mean only has to be stationary.

E.4 Recommendations

Variable	Name	ASCII Tables	Binary regression	Recommended Unit
Precipitation	<i>precYYYY</i>	*.txt	*.out	[mm day ⁻¹]
Air temperature	<i>tempYYYY</i>	*.txt	*.out	[°C]
Global radiation	<i>globYYYY</i>	*.txt	*.out	[W m ⁻²]
Wind speed	<i>windYYYY</i>	*.txt	*.out	[m s ⁻¹]
Sunshine duration	<i>ssd_YYYY</i>	*.txt	*.out	[-]
Water vapour pressure	<i>vapoYYYY</i>	*.txt	*.out	[hPa]
Relative humidity	<i>hum_YYYY</i>	*.txt	*.out	[-]

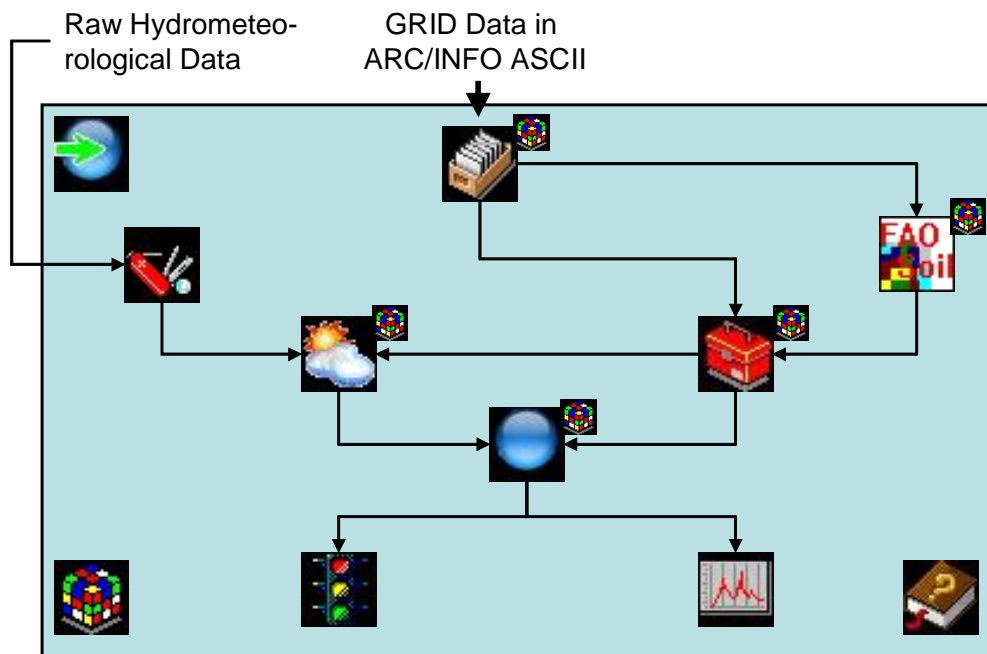
Variable	DTIDW	EDR	IDW	KRI	DKRI	LIDW	LKRI
Precipitation	Yellow	Red	Green	Green	Yellow	Red	Red
Air temperature	Green	Yellow	Red	Red	Green	Green	Green
Global radiation	Green	Yellow	Green	Green	Green	Red	Red
Wind speed	Green	Yellow	Green	Green	Green	Red	Red
Sunshine duration	Green	Yellow	Green	Green	Green	Red	Red
Water vapour pressure	Green	Yellow	Red	Red	Green	Red	Red
Relative humidity	Green	Yellow	Green	Green	Green	Red	Red












<i>Recommended</i>
<i>Avoid if possible</i>
<i>Do not use</i>

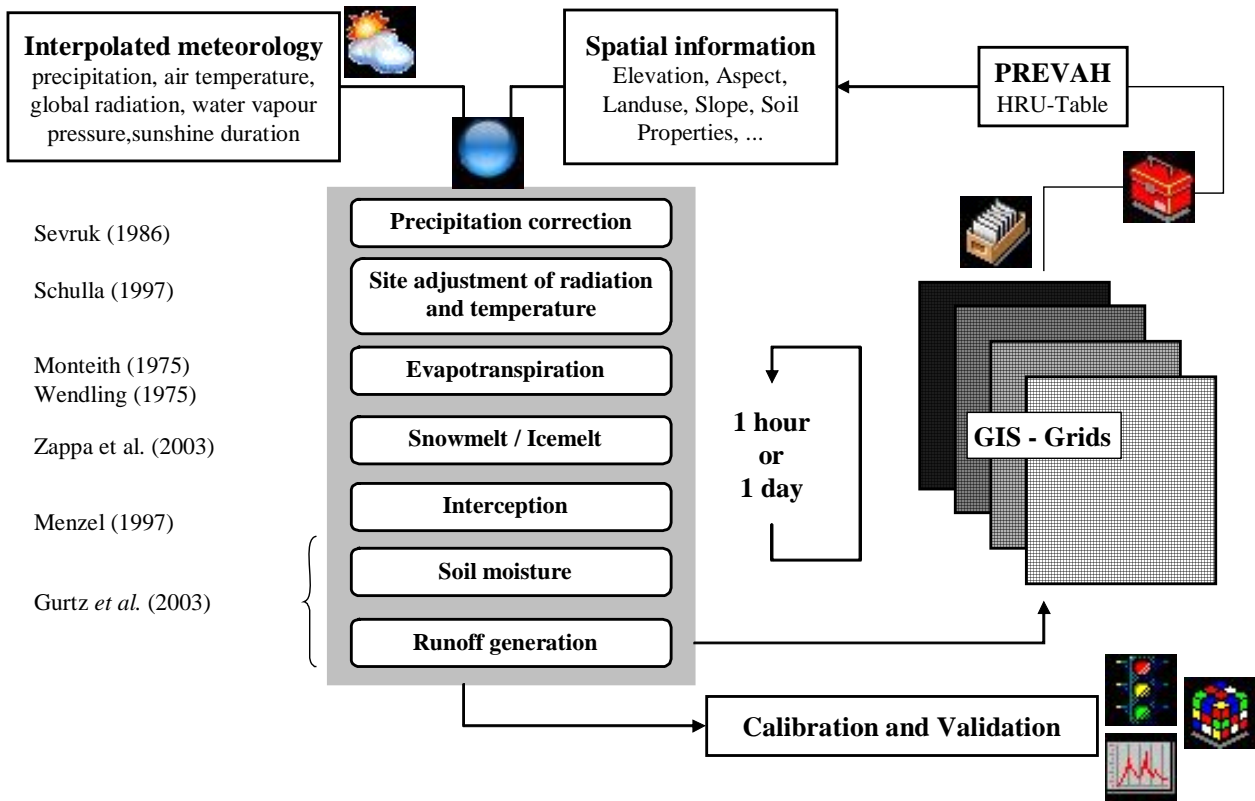
F WINPREVAH: Running and controlling the PREVAH model core

F.1 Introduction

The spatially distributed hydrological model PREVAH (Precipitation-Runoff-EVApotranspiration-Hydrotope model) was originally developed by Joachim Gurtz of the Institute for Atmospheric and Climate Sciences, ETH Zürich, for the simulation of influences of climate change on hydrological processes in mountainous catchments (Gurtz et al., 1997). Since then, PREVAH has developed into a complete system for the spatially distributed simulation of the hydrological cycle at different spatial scales and with different kinds of meteorological input (Zappa, 2002). WINPREVAH was subsequently developed as a plug-in to the PREVAH modelling system in order to facilitate application (Viviroli, 2007).



- | | | | |
|---|--|---|---|
|  | LAUNCHER
Toolbar |  | WINHRU
Pre-processes spatial information |
|  | WINPREVAH
Model core |  | DATAWIZARD
Assimilates hydrometeorological data |
|  | VIEWOPTIM
Visualises the results of calibration runs |  | WINMET
Interpolates meteorological information |
|  | WINGRID
GRID visualiser and editor |  | FAOSoil
Generates soil grids from FAO classes |
|  | GRIDMATH
GRID calculations |  | HYDROGRAPH
Visualises model tables as line graphs |
|  | Documentation | | |



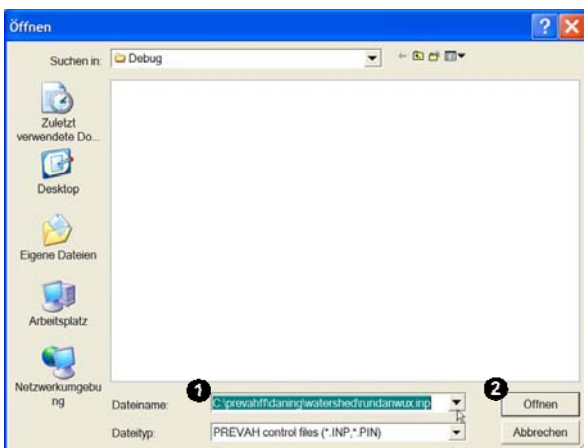
The flow chart of the PREVAH modules including the assimilation of physiographic and meteorological information and the gridded or table-oriented model outputs

F.2 Installation and start-up

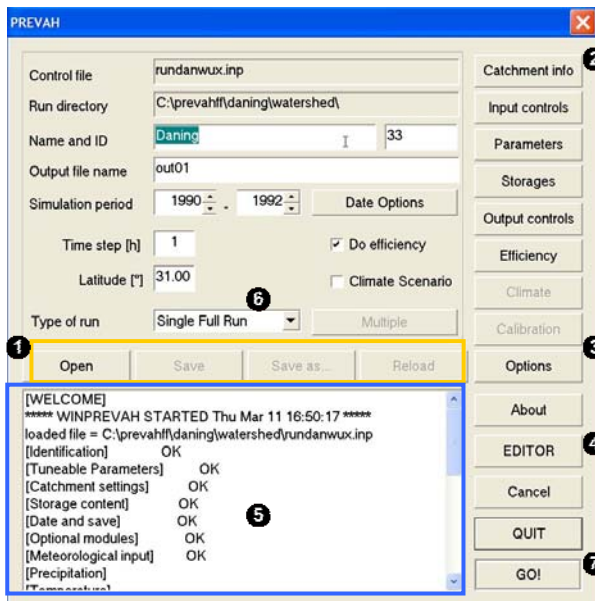
Several preprocessing steps are needed prior to the start of PREVAH / WINPREVAH:

- Creation of a project directory
- Assimilation and full analysis of the spatial data with WINHRU
- Assimilation and interpolation of meteorological information with WINMET
- Generation of tables with observed runoff data for the investigated catchment
- Setting the WINPREVAH options
- Editing the PREVAH control file either with a text editor and/or WINPREVAH

F.3 The main dialog

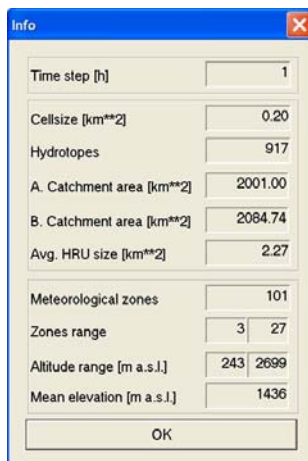


After launching winprevah.exe, a file open dialog is automatically prompted. Choose a PREVAH control file (1) and click [Open] (2). After this, the main dialog of WINPREVAH is prompted.



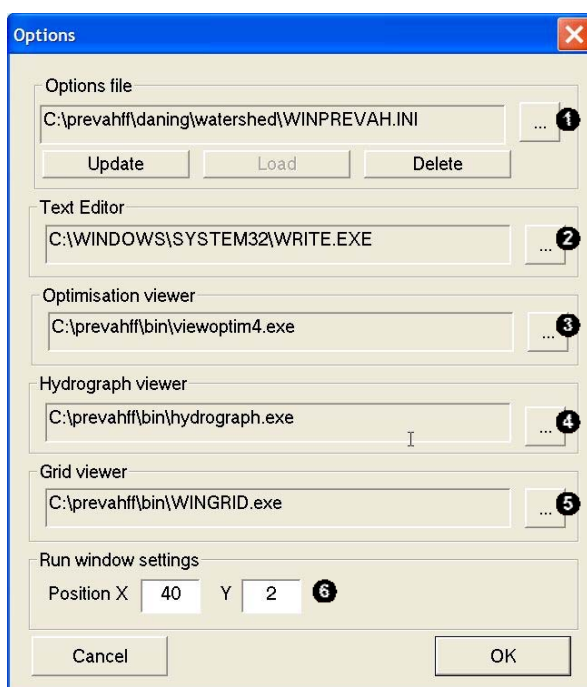
Basic operations in the main dialog of WINPREVAH are:

- 1 Management of the Control File [Open], [Save], [Save As..], [Reload].
- 2 Prompt the visualisation of basic [Catchment info].
- 3 Prompt the [Options] settings.
- 4 Visualise and edit the control file with a text [EDITOR].
- 5 Follow the editing process in the LOG-Box. The content of the LOG-Box is also written in a log-file, which is automatically created in the same directory where the active PREVAH control file is stored.
- 6 Select the type of model run (see Section C).
- 7 Launch the simulation [GO!].



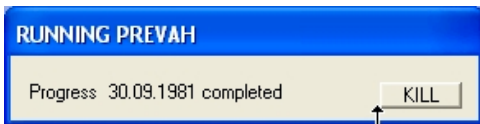
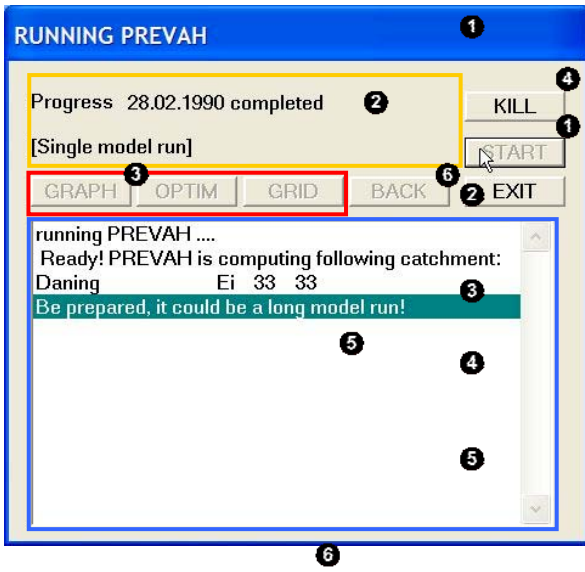
The [Catchment info] dialog displays basic characteristics of the catchment, derived from a control file of the spatial information created by WINHRU.

[Cellsize] is the area of each grid point in the basic grids used to run WINHRU and WINPREVAH. [Hydrotopes] is the number of HRUs as found in the control file for spatial information. The [A. Catchment area] is the true area of the investigated catchment in km². The [B. Catchment area] is the area of the catchment as derived by topographical analysis of the digital elevation model. The [Avg HRU size] is the average area in km² of each HRU, being equal to the catchment area divided by the number of hydrotopes. Additional information on average altitude and altitude ranges is also displayed.



The [Options] dialog allows the linking of WINPREVAH with other tools of the PREVAH modelling system:

- 1 [LOAD] and [UPDATE] the options file.
 - 2 Link PREVAH to a text editor. This allows the loading of the control file into a text editor (e.g. WRITE.EXE) and manual modification (click the [EDITOR] button in the main dialog of WINPREVAH).
 - 3 Link to the VIEWOPTIM tool which visualises the results of calibration runs.
 - 4 Link to the HYDROGRAPH tool which visualises model tables as line graphs.
 - 5 Link to the WINGRID tool which visualises gridded data stored in the binary format of the PREVAH modelling system.
 - 6 Select the starting position of the [RUNNING PREVAH] window; this window is displayed subsequently to launching the simulation with the [GO!] button in the main dialog of WINPREVAH
- Options are stored automatically after every change (see Section F.6).



The [RUNNING PREVAH] window is prompted to manage the model run as soon as the [GO!] button is clicked in the main dialog of WINPREVAH.

Here you may:

- 1 [START] the simulation.
- 2 View the progress of the simulation (updated at the end of each month).

Before or at the end of the simulation you may:

- 3 Launch HYDROGRAPH, VIEWOPTIM and/or WINGRID.

During the simulation you may:

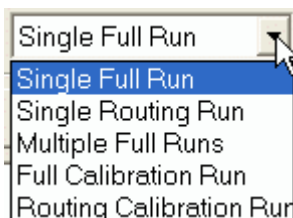
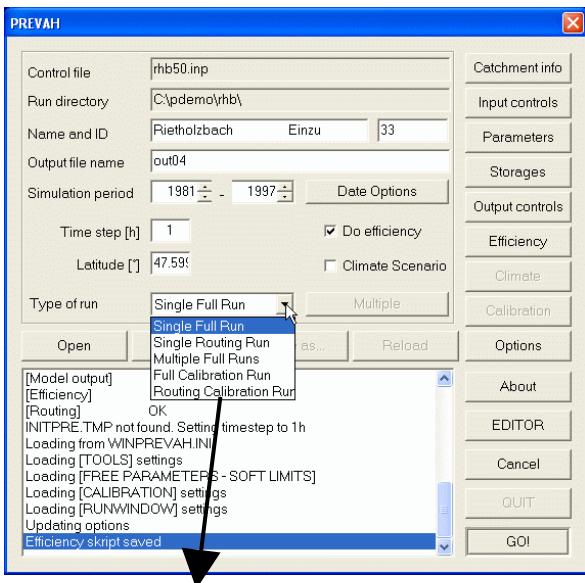
- 4 [KILL] the current job. After clicking this button, the simulation may be stopped at the end of the next month.

- 5 Follow the progress of the model run through the LOG-BOX.

After the simulation you can:

- 6 Go [BACK] to the main dialog or leave WINPREVAH.

F.3.1 Selection of the type of model run



PREVAH supports several types of model runs:

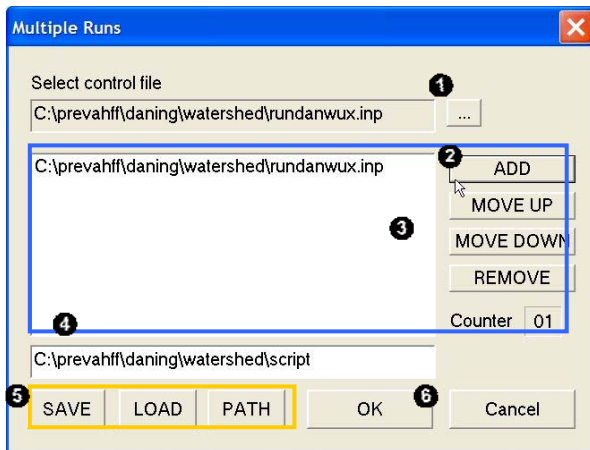
a. Typically, PREVAH is run in [Single Full Run] configuration. This type runs a simulation for the selected catchment between the given start and end dates.

b. The type [Single Routing Run] allows the routing of model results from two sub-catchments without the need of making a full model run (recommended only for experienced PREVAH users).

c. Selecting [Multiple Full Runs], you may prompt a dialog (click [Multiple]) for selecting several control files and run them automatically consecutively (recommended only for experienced PREVAH users).

d. Another important option is to start an automatic calibration of PREVAH. Select [Full Calibration Run] to configure the model for automatic calibration. The calibration options can be set by accessing the Calibration dialog (use the corresponding button in the main dialog of WINPREVAH). For further information on calibration, see Section F.5 in this part of the documentation and Chapter 8 in Part II of the documentation.

e. The type [Routing Calibration Run] allows the calibration of the routing options (recommended only for experienced PREVAH users).



The [Multiple Full Runs] dialog:

- ❶ Select PREVAH control files from your file system.
- ❷ Select whether you want to [ADD] the selected control file to the job-queue (❸).
- ❸ If you select a job in the queue you may then either [REMOVE] it from the queue, or set this job earlier [MOVE UP] or later [MOVE DOWN] in the queue. A counter displays how many jobs are currently in the queue.
- ❹ Provide a name for the job-list and...
- ❺ [SAVE] it in a script file. You may also [LOAD] a previously stored job-list and modify it or change the [PATH] of the directory where job-list scripts are stored.
- ❻ Leave the dialog.

F.4 The control file of PREVAH and WINPREVAH

Both the DOS and WINDOWS version of PREVAH are initialised with a control file which is ASCII-text formatted. The structure of this file consists of different modules:

[Identification]	[Tuneable Parameters]
[Catchment settings]	[Storage content]
[Date and save]	[Optional modules]
[Meteorological input]	[Climate scenario]
[Model output]	[Efficiency]
[Routing]	

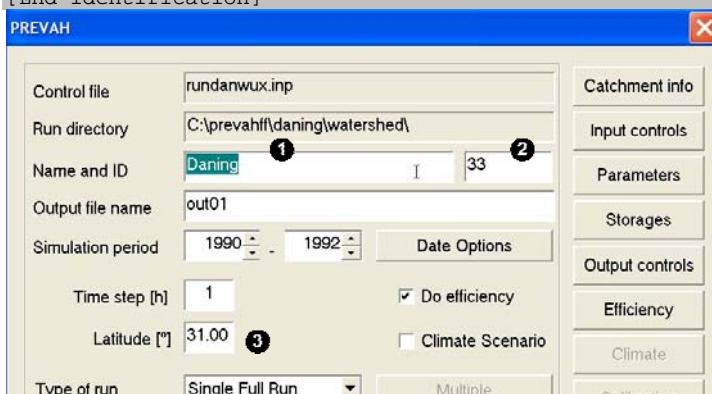
A default control file is generated during the preprocessing of spatial information with WINHRU. This default control file may be either edited in the dialog-based WINPREVAH or with any common text editor.

The following sections will explain the functions of the different settings modules, how they are edited with WINPREVAH and which options should be considered if the file is edited with a text editor.

F.4.1 [Identification] settings:

Syntax:

```
[Identification]
33      ! Watershed ID
Thur    ! Watershed Name
47.000 ! Latitude
493.00 ! Official area [km²]
0.25    ! Cell size
[End Identification]
```



This settings module is automatically written by WINHRU. Cell size in [km²] is equal to the square of the grid resolution in [km].

Watershed-ID (❷), watershed name (❶), time step (in hours) and latitude (❸) may be edited with WINPREVAH.

Edits are saved by clicking [Save].

F.4.2 [Tuneable Parameters] settings:

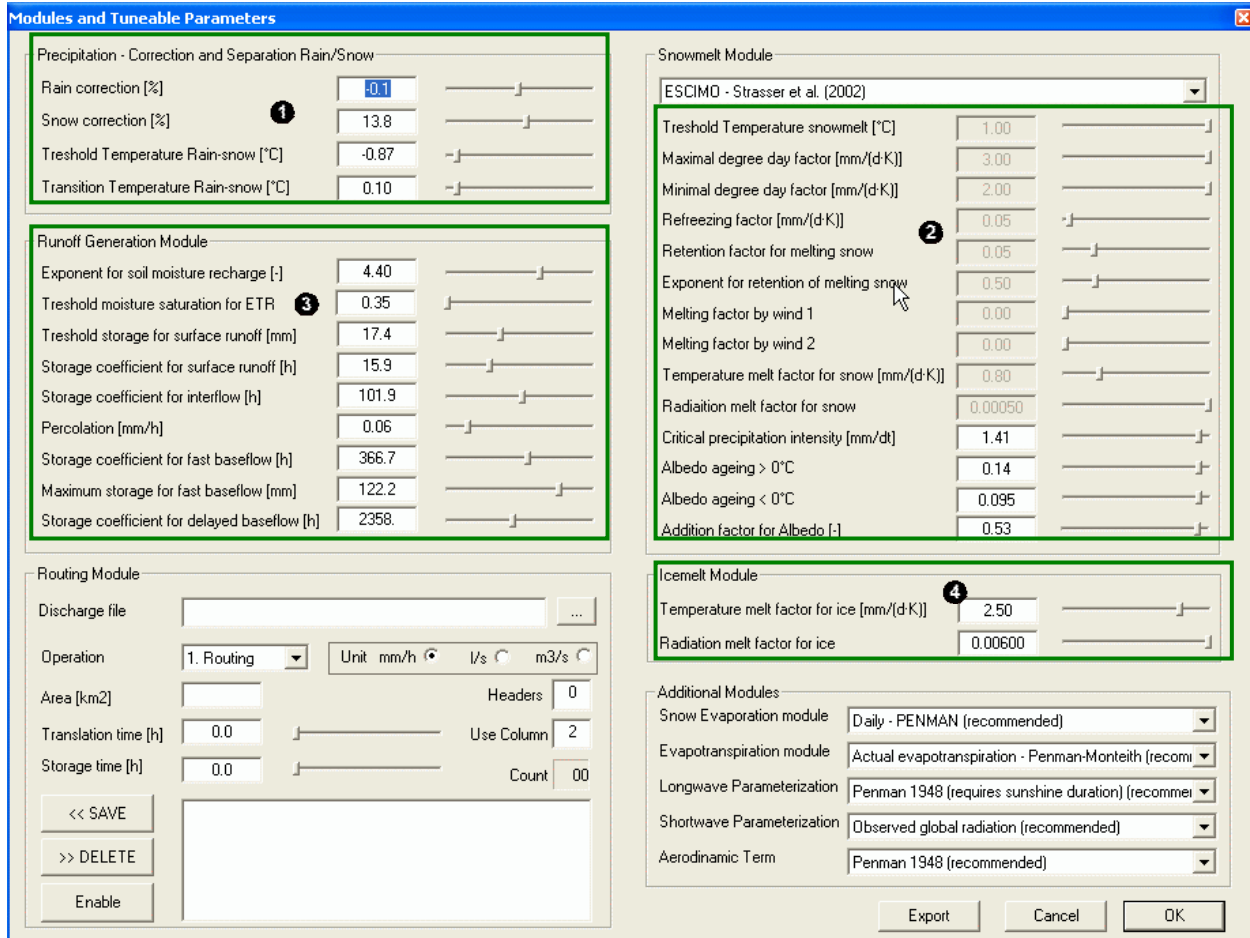
Syntax:

```
[Tuneable Parameters]
1          ! CREDV, Def=1
-4.8      ! Precipitation correction, Def=0.0
16.4      ! Snow correction, Def=0.0
-0.56     ! Threshold temperature snowfall, Def=0.0
0.33      ! Transition temperature snow-rain, Def=0.75
0.00      ! Threshold temperature snowmelt, Def=0.0
2.69      ! Maximal temperature-index melting factor, Def=2.0
0.42      ! Minimal temperature-index melting factor, Def=1.0
0.00      ! Melting factor by wind 1, Def=0.0
0.00      ! Melting factor by wind 2, Def=0.0
0.10      ! Retention factor for melting snow, Def=0.1
0.50      ! Exponent for retention of melting snow, Def=0.5
0.10      ! Coefficient for re-freezing, Def=0.1
1.5       ! Constant temperature melt factor for snow Def=1.5
0.000100  ! Constant radiation melt factor for snow, Def=0.0001
2.4       ! Non linearity parameter for infiltration module, Def=3.0
0.70      ! Threshold (0...1) for reduction ETP, Def=0.7
0.00      ! 0...1 maximal percentage of runoff generated by surface runoff, Def=0.0
28.0      ! Threshold coefficient for surface runoff, Def=30.0
28.0      ! Storage coefficient in hours for surface runoff, Def=10.0
130.2     ! Storage coefficient in hours for interflow, Def=75.0
3604.9    ! Storage coefficient in hours for base flow, Def=2500.0
440.7     ! Storage coefficient in hours for quick base flow, Def=750.0
37.3      ! Maximal content of the quick base flow storages, Def=150.0
0.184     ! Percolation rate in mm per hour, Def=0.1
0         ! Equilibrium line altitude of a glacier, Def=0
2.00      ! Constant temperature melt factor for ice, Def=2.0
0.000200  ! Constant radiation melt factor for ice, Def=0.00002
15.0      ! Coefficient for runoff generation from ice storage in hours, Def=15.0
30.0      ! Coefficient for runoff generation from snow storage in hours, Def=30.0
0.0       ! Coefficient for runoff generation from firn storage in hours, Def=0.0
1         ! Translation time for icemelt, Def=1
2         ! Translation time for snowmelt, Def=2
0         ! Translation time for firmelt, Def=0
0.0000    ! Critical precipitation intensity [mm/h], Def=1.5
0.0000    ! Albedo ageing for temperatures above 0°C, Def=0.1
0.0000    ! Albedo ageing for temperatures below 0°C, Def=0.05
0.0000    ! Addition factor for albedo, Def=0.5
[End Tuneable Parameters]
```

*Link of the tuneable variables to Equations in Chapter 3 and 4 of Part II of the PREVAH documentation.
The last column declares whether a parameter may be edited by WINPREVAH (Y) or only manually (N)*


Tuneable variable	Reference in script	Editable
CREDEV	-	N
Precipitation correction [%]	Equation 3.5-1	Y
Snow correction [%]	Equation 3.5-1	Y
Threshold temperature snowfall [°C]	Equation 4.3-1	Y
Transition temperature snow-rain [°C]	Equation 4.3-1	Y
Threshold temperature snowmelt [°C]	Equation 4.3-2	Y
Maximal temperature-index melting factor	Equation 4.3-2	Y
Minimal temperature-index melting factor	Equation 4.3-2	Y
Melting factor by wind	Equation 4.3-3	Y
Retention factor for melting snow	-	Y
Exponent for retention of melting snow	-	Y
Coefficient for re-freezing	Equation 4.3-5	Y
Constant temperature melt factor for snow	Equation 4.3-7	Y
Constant radiation melt factor for snow	Equation 4.3-7	Y
Non linearity parameter for infiltration module	Equation 4.5-1	Y
Threshold for reduction of ETP	Equation 4.4-33	Y
Maximal percentage of runoff generated by surface runoff	-	N
Threshold coefficient for surface runoff	Equation 4.5-5	Y
Storage coefficient for surface runoff [h]	Equation 4.5-5	Y
Storage coefficient for interflow [h]	Equation 4.5-5	Y
Storage coefficient for base flow [h]	Equation 4.5-11	Y
Storage coefficient for quick base flow [h]	Equation 4.5-10	Y
Maximal content of the quick base flow storages	Equation 4.5-8	Y
Percolation rate [mm h ⁻¹]	Equation 4.5-3	Y
Equilibrium line altitude of a glacier	WINHRU	N
Constant temperature melt factor for ice	Equation 4.3-8	Y
Constant radiation melt factor for ice	Equation 4.3-8	Y
Coefficient for runoff generation from ice storage in hours	Equation 4.3-8	N
Coefficient for runoff generation from snow storage in hours	Equation 4.3-8	N
Coefficient for runoff generation from firn storage in hours	Equation 4.3-8	N
Translation time for ice melt [h]	Equation 4.3-8	N
Translation time for snowmelt [h]	Equation 4.3-8	N
Translation time for firn melt [h]	Equation 4.3-8	N
Critical precipitation intensity [mm h ⁻¹]	Strasser et al., 2002	Y
Albedo ageing for temperatures above 0°C	Strasser et al., 2002	Y
Albedo ageing for temperatures below 0°C	Strasser et al., 2002	Y
Addition factor for albedo	Strasser et al., 2002	Y

Most of the tuneable parameters used by PREVAH may be edited with WINPREVAH. The dialog [Modules and Tuneable Parameters] is displayed by clicking the [Parameters] button in the main dialog of WINPREVAH:



The tuneable parameters are subdivided into 4 "families"; the chapter indication refers to Part II of the PREVAH documentation:

- ❶ Precipitation module (Chapter 3.5)
- ❷ Snowmelt module (Chapter 4.3.2)
- ❸ Runoff generation module (Chapter 4.3.3)
- ❹ Icemelt module (Chapter 3.5)

The value of each parameter may be edited by moving the corresponding slider () to the left or right. The minimal and maximal limits of the slider correspond to the soft limits defined for a specific variable. The edit field also accepts manual input of values larger than the soft limits, but within the defined hard limits.

Some parameters of the snowmelt module are editable only if a specific method for the determination of snowmelt is selected. For instance, if the method ESCIMO (Strasser et al., 2002) is selected, only the following parameters may be edited: Critical precipitation intensity, Albedo ageing for temperatures above 0°C, Albedo ageing for temperatures below 0°C and the addition factor for Albedo. Recommended initial values for each of the tuneable parameters are declared in the following table.

Assigned Hard and Soft Limits for the tuneable parameters used in PREVAH. The default value is recommended as initial the value for model calibration.

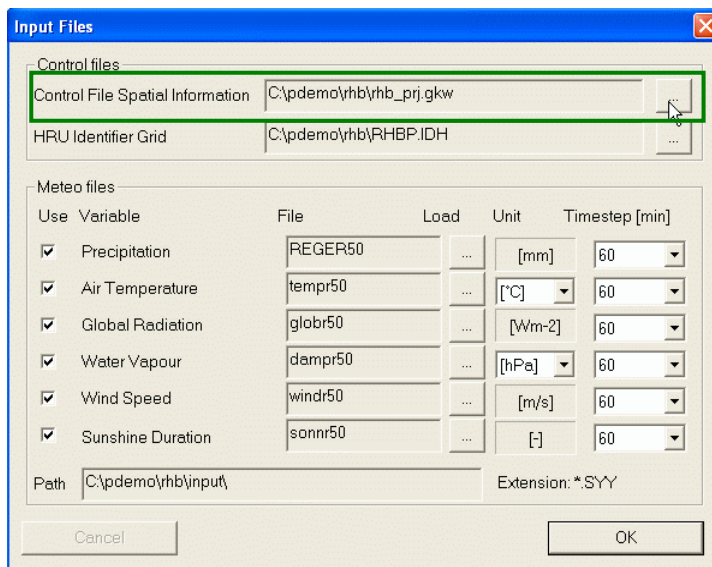
Tuneable Variable	Hard limit MIN	Soft limit MIN	Default	Soft limit MAX	Hard limit MAX
CREDV	0	0	1	1	1
Precipitation correction	-100	-30	0	30	200
Snow correction	-100	-30	0	50	200
Threshold temperature snowfall	-5	-1	0	1	5
Transition temperature snow-rain	0	0	0.75	1.5	5
Threshold temperature snowmelt	-5	-1	0	1	5
Maximal temperature-index melting factor	1	2	2	4	10
Minimal temperature-index melting factor	0.1	0.25	1	2	5
Melting factor by wind 1	0	0	0	1	2
Melting factor by wind 2	0	0	0	1	2
Retention factor for melting snow	0	0	0.1	0.25	0.5
Exponent for retention of melting snow	0.01	0.1	0.5	2	5
Coefficient for re-freezing	0	0	0.1	1.5	5
Constant temperature melt factor for snow	0.1	0.1	1.5	3	7
Constant radiation melt factor for snow	0.00001	0.00005	0.0001	0.0003	0.001
Non linearity parameter for infiltration module	0.1	1.5	3	6	10
Threshold for reduction ETP	0.1	0.4	0.7	0.9	1
Maximal percentage of runoff generated by surface runoff	-	-	0	-	-
Threshold coefficient for surface runoff	1	10	30	50	500
Storage coefficient in hours for surface runoff	1	10	10	30	500
Storage coefficient in hours for interflow	1	50	75	150	750
Storage coefficient in hours for base flow	1	1000	2500	4000	10000
Storage coefficient in hours for quick base flow	1	200	750	1000	2500
Maximal content of the quick base flow storages	1	25	150	250	500
Percolation rate in mm per hour	0.01	0.04	0.1	0.2	0.5
Equilibrium line altitude of a glacier	-	-	0	-	-
Constant temperature melt factor for ice	0.1	0.5	2	3	10
Constant radiation melt factor for ice	0.00001	0.00001	0.00002	0.0003	0.001
Coefficient for runoff generation from ice storage in hours	-	-	15	-	-
Coefficient for runoff generation from snow storage in hours	-	-	30	-	-
Coefficient for runoff generation from firn storage in hours	-	-	0	-	-
Translation time for icemelt	-	-	1	-	-
Translation time for snowmelt	-	-	2	-	-
Translation time for firmelt	-	-	0	-	-
Critical precipitation intensity [mm/h]	0.2	0.5	1.5	3	5
Albedo ageing for temperatures above 0°C	0.03	0.05	0.1	0.15	0.25
Albedo ageing for temperatures below 0°C	0.01	0.02	0.05	0.1	0.2
Addition factor for albedo	0.2	0.3	0.5	0.55	0.6

F.4.3 [Catchment settings] settings:

Syntax:

```
[Catchment settings]
c:\prevahff\daning\watershed\tabdanwux.gkw ! Control file of the Spatial Information
000917 ! Number of hydrological response units (HRUs)
Y ! Differentiation into meteorological zones [Y,N]
000101 ! Number of meteorological zones
      {# of HRUS per meteorological zone}
0005 ! 00001 HRUS pro meteorological zone
0009 ! 00002 HRUS pro meteorological zone
0012 ! 00003 HRUS pro meteorological zone
.....
0001 ! 00100 HRUS pro meteorological zone
0001 ! 00101 HRUS pro meteorological zone
[End Catchment settings]
```

Most of the content of this module is generated automatically by WINHRU; it defines how PREVAH assimilates the spatial information for the catchment under investigation. The number of meteorological zones is declared, and the number of HRUs in each of the meteorological zones is also indicated. Only the full path of the control file for spatial information (*.gkw, *.g##) has to be edited. This path may be loaded with WINPREVAH. The dialog [Input Files] is displayed if the button [Input Controls] is clicked in the main dialog of WINPREVAH.



To load the control file for spatial information (*.gkw, *.g##), click the corresponding [...] button (green box) and select the correct file from your system.

The control file for spatial information is stored in the output path of the current WINHRU project by default.

F.4.4 [Storage content] settings:

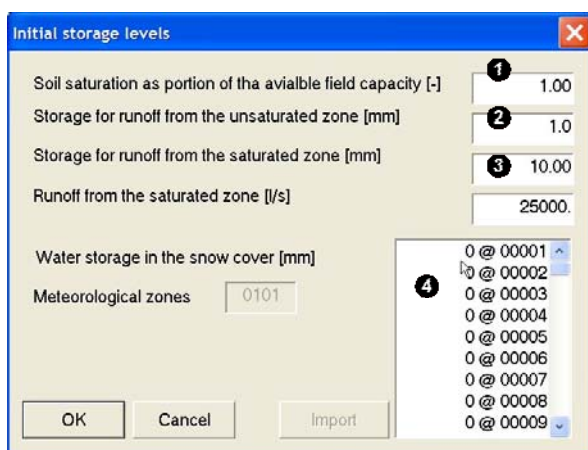
Syntax:

```
[Storage content]
{Snow water equivalent per meteorological zone}
00000          ! 00001 Snow cover per meteorological zone
00000          ! 00002 Snow cover per meteorological zone
.....
00000          ! 00100 Snow cover per meteorological zone
00000          ! 00101 Snow cover per meteorological zone
               {Soil moisture and runoff generation storages}
1.00           ! Initial saturation of soil moisture, Default=1.0
 1.0           ! Initial storage in unsaturated zone
-10.00        ! Initial storage in saturated zone
-25000.0      ! Initial baseflow
               [End Storage content]
```

Initial conditions may be very important for the model results, especially when applying the model to a short time period, to arid or semiarid regions or regions with high snow accumulation during winter. Therefore, PREVAH is able to read initial storage or reservoir content values. Because this information may also be written at the end of a model run, it may be used to initialise the following model runs. If no initialisation files are available, the internal states are initialised using constant values taken from the control file. The minimal information for sound model initialisation without information from previous model runs consists of:

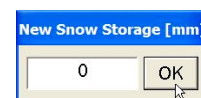
- ❶ Soil moisture saturation as a percentage of the available field capacity.
- ❷ The initial storage content of the unsaturated soil zone in millimetres.
- ❸ The initial base flow, as runoff in litre per second from the unsaturated zone.
- ❹ Snow water equivalent in each of the meteorological zones in millimetres.

The dialog [Initial storage levels] is displayed if the button [Storages] is clicked in the main dialog of WINPREVAH. This dialog allows the editing of the initial conditions at model initialisation.



❶, ❷ and ❸ and can be edited directly.

To edit the initial snow water equivalent in each of the meteorological zones (❹), you have to double-click the value you want to edit. This small dialog is prompted:



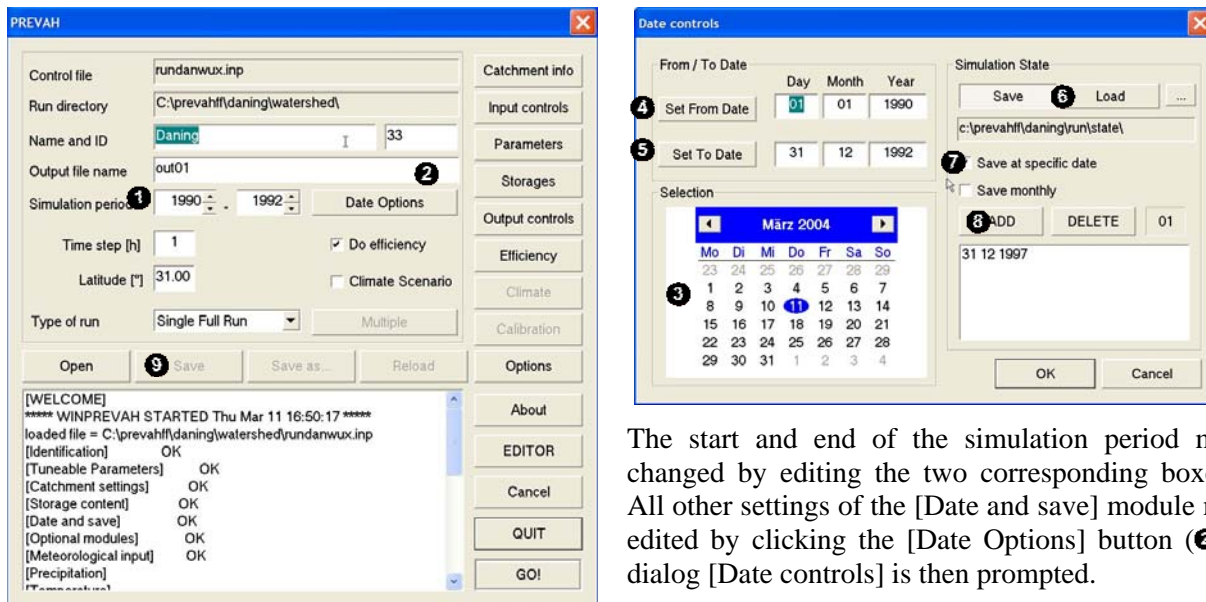
You may write the new value of the snow water equivalent for the selected meteorological zone and store it by clicking [OK]. You may also edit these values by loading the control file into a text editor.

F.4.5 [Date and save] settings:

Syntax:

```
[Date and save]
01 01 1990          ! Start date of simulation DD MM YYYY
N                  ! Load initial conditions from previous run (Y,N)
c:\prevahff\daning\run\state\ ! Directory where state-files of previous runs are stored
31 12 1998          ! Date of simulation end DD MM YYYY
Y                  ! Save model conditions for later run (Y,N)
N                  ! Save model conditions at the end of each month (Y,N)
Y                  ! Save model conditions at the end of a defined day (Y,N)
01                 ! How many other dates
31 12 1997         ! Declare the date: DD MM YYYY
[End Date and save]
```

The range of the simulation period and settings for saving or loading the state of the model at a specific time may be controlled through this module. To change only the years of the simulation period, the main dialog of WINPREVAH (1) is used:



The start and end of the simulation period may be changed by editing the two corresponding boxes (1). All other settings of the [Date and save] module may be edited by clicking the [Date Options] button (2). The dialog [Date controls] is then prompted.

Here, the extent of the simulation period is defined, either by editing the boxes or using the Date Wizard (3). To change the start or end date, select the date in the Wizard and click [Set From Date] (4) / [Set To Date] (5).

To activate the saving of model conditions, click [Save], to allow loading the state from a previous simulation, click [Load] (6). The directory where the model state is stored/loaded is set by clicking [...]. To save the model state at a specific date, activate the corresponding checkbox (7), and to select or deselect dates, use the wizard and click [ADD] / [DELETE] (8).

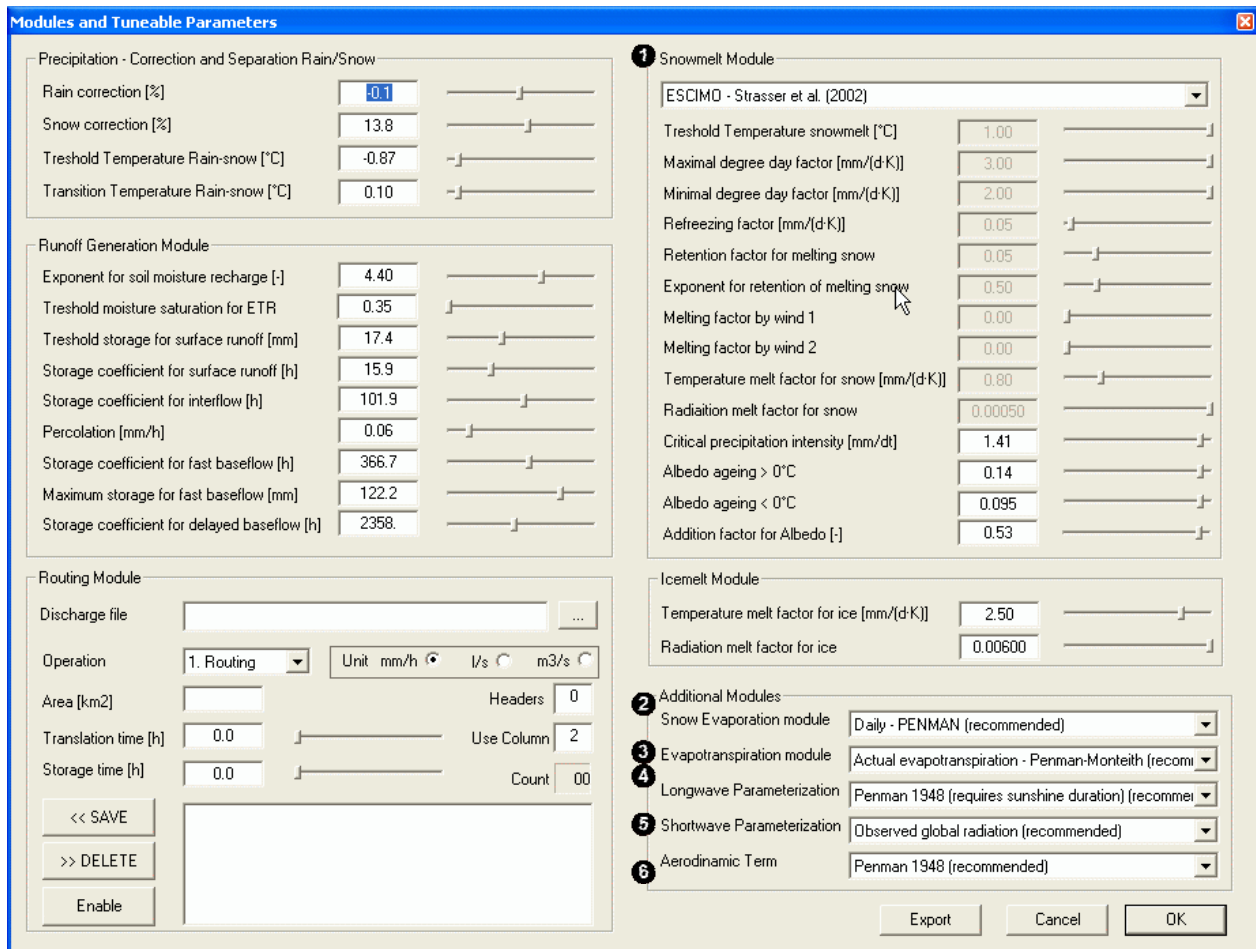
To save the model state at the end of each month, the corresponding check box has to be activated (7). Edits are saved by pushing the button [Save] in the main dialog (9).

F.4.6 [Optional modules] settings:

Syntax (parameters highlighted in yellow can only be edited manually):

```
[Optional modules]
1           ! Method for snow evaporation
0           ! Do shadowing correction (0=No, 1= Yes). Please use 0!!
0           ! Method for computing snowmelt
2           ! Method for computing evapotranspiration
5           ! Method for estimating incoming short-wave radiation
1           ! Method for estimating the long-wave radiation budget
1           ! Method for estimating the aerodynamic term of Penman's equa-
           ! tion
0           ! Activate Debugging output (0=No, 1= Yes).
[End Optional modules]
```

To change the [Optional modules] settings, the Modules and Tuneable Parameters dialog has to be accessed by clicking the button [Parameters] in the main dialog of WINPREVAH.



Six drop-down boxes may be modified to select the processes simulation methods of PREVAH:

- ❶ Method for computing snowmelt (see also Zappa et al., 2003 and Chapter 4.3.2 in Part II of the PREVAH documentation):

0. Positive degree day index (PDDI) or Combination Method (COMB): PDDI is used if both the melting factors by wind are set to a value below or equal 0.0; COMB is used if at least one of the melting factors by wind are set to a value above 0.0.
1. PDDI or COMB, but EMA (Hock, 1998) on glaciated areas with constant melt factor;
2. PDDI or COMB, but EMA (Hock, 1998) on glaciated areas with varying melt factor;
3. EMA, with constant melt factor;
4. EMA, with varying melt factor (recommended);
5. PDDI or COMB, but EMA with constant melt factor, if no precipitation;
6. PDDI or COMB, but EMA with varying melt factor, if no precipitation;
10. ESCIMO (Strasser et al., 2002).

Sensitivity of the tuneable parameters and meteorological requirements for the different snowmelt modelling approaches implemented in PREVAH.

Approach for snowmelt computation	PDDI	COMB	EMA	ESCIMO	
Tuneable Variable	Used in methods	0,1,2,5,6	0,1,2,5,6	1,2,3,4,5,6	10
Threshold temperature snowmelt					
Maximum temperature-index melting factor			2,4,6		
Minimum temperature-index melting factor			2,4,6		
Melting factor by wind 1	<= 0.0	> 0.0			
Melting factor by wind 2					
Retention factor for melting snow					
Exponent for retention of melting snow					
Coefficient for re-freezing					
Constant temperature melt factor for snow			1,3,5		
Constant radiation melt factor for snow					
Critical precipitation intensity [mm/h]					
Albedo ageing for temperatures above 0°C					
Albedo ageing for temperatures below 0°C					
Addition factor for Albedo					

Meteorological requirements

Precipitation	required	required	required	required
Air temperature	required	required	required	required
Global radiation				required
Wind Speed		required		required
Water vapour pressure / relative humidity		required		required
Sunshine duration				required

② Method for computing snow evaporation:

0. None (not available in the user interface)
1. Daily – Penman [including ageing of snow albedo] (recommended);
2. Daily – Penman-Monteith [including ageing of snow albedo];
3. Hourly – Penman [including ageing of snow albedo];
4. Hourly – Penman Monteith [including ageing of snow albedo];
5. Routine sublimation/condensation after Kuzmin (1960)
[function of air temperature and wind speed];
6. Routine sublimation/condensation after Anderson (1973)
[function of wind speed and saturation deficit].

- ③ Method for computing evapotranspiration (see also Chapter 4.4 in Part II of the PREVAH documentation; for details on the approaches, refer to DVWK, 1996 and Schroedter, 1985):

0. Potential evapotranspiration – Penman;
1. Potential evapotranspiration – Penman-Monteith;
2. Actual evapotranspiration – Penman-Monteith (recommended);
3. Potential evapotranspiration – Hamon (1961);
4. Potential evapotranspiration – Turc (1961);
5. Potential evapotranspiration – Wendling (1975).

Meteorological requirements for the different evapotranspiration approaches implemented in PREVAH

Variables	Methods	Penman-Monteith 0,1,2	Hamon 3	Turc 4	Wendling 5
Precipitation		required	required	required	required
Air temperature		required	required	required	required
Global radiation		required		required	required
Wind Speed		required			
Water vapour pressure / relative humidity		required			
Sunshine duration		required			

- ④ Method for estimating the long-wave radiation budget (see also the Appendix to Part II; for details on the approaches, refer to DVWK, 1996 and Schroedter, 1985):

0. Penman (1948) – requires sunshine duration (recommended);
1. Penman (1954) – requires sunshine duration;
2. Angstroem (1923) – requires sunshine duration;
3. Angstroem (1923) requires cloudiness;
4. Feussner – requires sunshine duration;
5. Feussner – requires cloudiness;
6. Kasten und Czeplak (1980) – requires sunshine duration;
7. Kasten und Czeplak (1980) – requires cloudiness;
8. Brutsaert (1975) – requires sunshine duration;
9. Schulla (1997) – requires sunshine duration.

- ⑤ Method for estimating incoming short-wave radiation (see also the Appendix to Part II; for details on the approaches, refer to DVWK, 1996 and Schroedter, 1985):

0. Penman (1948) – requires sunshine duration;
1. Penman (1954) – requires sunshine duration;
2. Golchert (1981) – requires sunshine duration;
3. Karsten und Czelpak (1980) – requires cloudiness;
4. Morecs (1981) – requires sunshine duration;
5. Observed global radiation (recommended);
6. Schulla (1997) – requires sunshine duration.

- ⑥ Method for estimating the aerodynamic term of Penman's equation:

0. Penman (1948) (recommended); See Equation 4.4-8 in Chapter 4, Part II;
1. Penman (1954);
2. Petznik (1988).

F.4.7 [Meteorological Input] settings:

Syntax (parameters highlighted in yellow may only be edited manually):

```
[Meteorological input]
c:\prevahff\daning\hydrometeo\modeloutput\      ! Path of meteorological tables
0003      ! Headers of meteorological tables
0001      ! Start columns of meteorological tables
4         ! Digits of year in extension 4=*.syyyy,
         2=*.syy

[Precipitation]
Y         ! Read (Y/N)
1440     ! Time step in minutes
precdanwux ! Name of precipitation file

[Temperature]
Y         ! Read (Y/N)
1440     ! Time step in minutes
tairdanwux ! Name of temperature file
0001     ! Unit (see Documentation)

[Global Radiation]
Y         ! Read (Y/N)
1440     ! Time step in minutes
rad_danwux ! Name of global radiation file

[Vapour Pressure / Humidity]
Y         ! Read (Y/N)
1440     ! Time step in minutes
hum_danwux ! Name of vapour/RH file
0002     ! Unit (see Documentation)

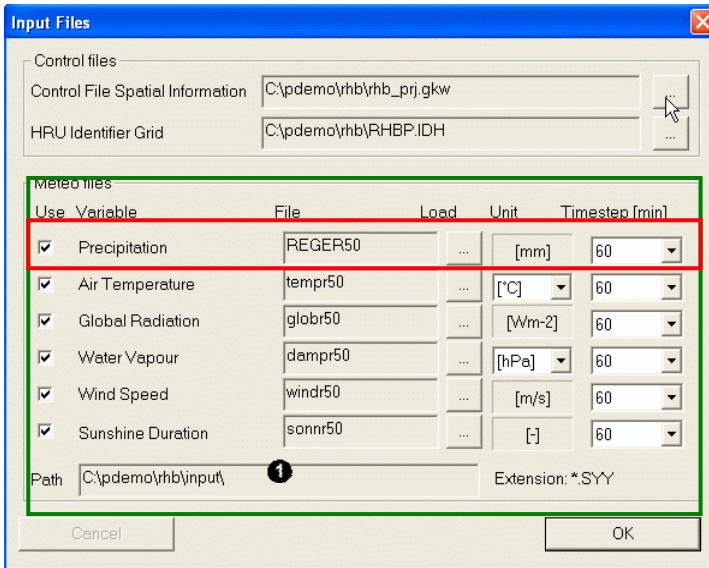
[Wind speed]
Y         ! Read (Y/N)
1440     ! Time step in minutes
winddanwux ! Name of wind speed file

[Relative sunshine duration]
Y         ! Read (Y/N)
1440     ! Time step in minutes
ssd_danwux ! Name of sunshine duration file

[End Meteorological input]
```

To edit the [Meteorological input] settings with WINPREVAH, the [Input files] dialog has to be accessed by clicking the button [Input Controls] in the main dialog of WINPREVAH.

The interpolation program WINMET always writes files with three headers. Thus, the number of headers in the meteorological tables is set by default equal to 3 lines. You may only edit this value manually. The start column of the meteorological tables is set, by default, to 1. Only advanced PREVAH users should modify these values for particular model applications. The number of digits for the declaration of the year in the meteorological values is set automatically by WINPREVAH and should not be modified. All other elements of the [Meteorological input] settings are edited with the [Input files] dialog.



The results of spatial interpolation with WINMET are used to force PREVAH and WINPREVAH. The files stored in the output path of the dtidw.exe (1) run for the investigated catchment may be linked to PREVAH by loading a file for each variable. The path of the precipitation file corresponds to the location of all meteorological files needed to force PREVAH.

For each required (and available) meteorological variable, the following settings have to be defined:



READ (Y/N)	Name of Used File	Select File	Required Unit	Time Step in minutes
------------	-------------------	-------------	---------------	----------------------

We recommend using air temperature values in [°C] and water vapour data as vapour pressure in [hPa] or as relative humidity. Other units are also accepted:

Temperature: [°C], [K] and [°F]

Water vapour: Water vapour pressure [hPa], relative humidity RH [-] (between 0 and 1), and dew point temperature in [°C], [°K] or [°F].

Meteorological files are automatically identified by WINPREVAH if named following the table below:

Variable	Recognised file names
Precipitation	pre*.s* rai*.s* reg*.s*
Air temperature	tem*.s* tai*.s*
Global radiation	rad*.s* rg*.s* gl*.s*
Wind speed	win*.s* wsp*.s*
Water vapour pressure / relative humidity	vap*.s* dam*.s* rh*.s* fe*.s* hu*.s*
sunshine duration	sun*.s* ssd*.s*

Accepted time steps to force PREVAH with meteorological information. For all variables, using the same time step and possibly hourly or daily time step is recommended

minutes	5	10	15	20	30	60	120	180	240	360	480	720	1440
hours	0.083	0.167	0.25	0.333	0.5	1	2	3	4	6	8	12	24

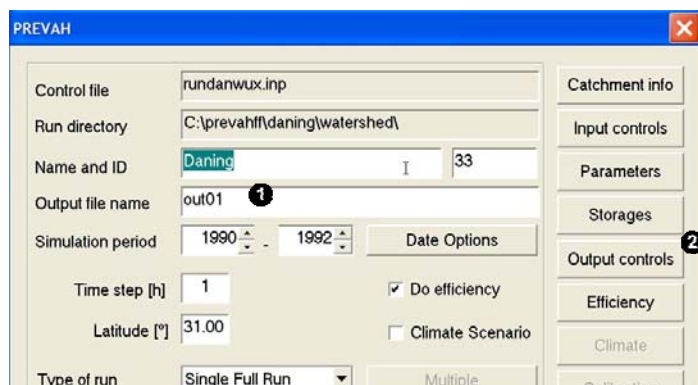
F.4.8 [Model Output] settings:

Syntax:

```
[Model output]
c:\prevahff\daning\run\           ! Directory for output
out01                             ! Basic name for output files
N-N-Y-Y-N-N-N-N                 ! Output Tables (see later in the documentation)
N                                 ! Do GRIDDED Output (Y/N)

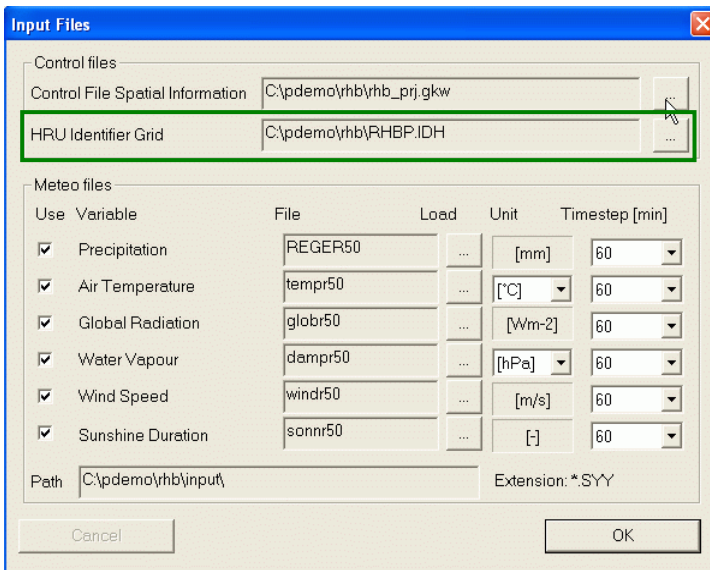
c:\prevahff\daning\watershed\danwux.idh      ! Basic GRID for GRIDDED Output (Full path!)
N-N-Y-N                               ! P:      DD-MM-YY-##      [Y/N] (see later in the Documentation)
N-N-N-N                               ! ETP:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-Y-N                               ! ETR:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! EI:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! EB:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-Y-N                               ! RGS:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! R0:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! R1:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! R2:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! GL0:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! GL1:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-Y-N                               ! SWA:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! GWN:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SSO:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SI:     DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SSM:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SUZ:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SLZ:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SL1:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SL2:    DD-MM-YY-##      [Y/N] (see Documentation)
N-N-N-N                               ! SL3:    DD-MM-YY-##      [Y/N] (see Documentation)

[End Model output]
```



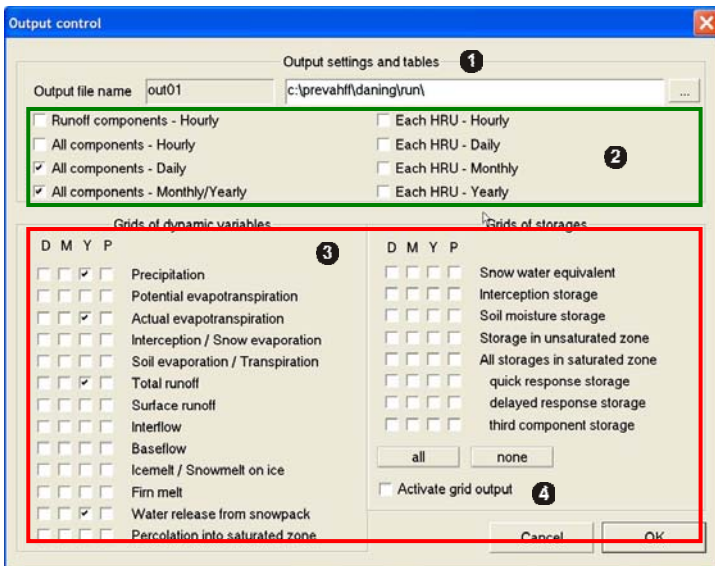
The basic name for output files may be changed by editing the corresponding box (1) in the main dialog of WINPREVAH. To define the basic grid for gridded output, the [Input files] dialog is accessed by clicking the button [Input controls].

All other settings of the Model Output module are edited clicking the [Output controls] button (2).



To load the basic grid for gridded output ([HRU Identifier grid], *.idh, *.i##), click the corresponding [...] button (green box) and select the correct file from your system.

This basic grid is stored by default in the output path of the WINHRU project you started for the catchment under investigation (see also the WINHRU documentation).



In the Output control dialog you can:

- 1 Define the Directory for output
- 2 Select the Output Tables that PREVAH should write during the simulation
- 3 Select the output grids that PREVAH should write during the simulation
- 4 Activate or deactivate the gridded output

2 Output Tables:

Up to eight tables are written by PREVAH during the model simulation; output is activated either manually (SET **Y** or **N** at the corresponding position in the control file!) or automatically through the [Output control] dialog:

File Description	Extension	Active	Not Active
1. Runoff components – hourly	*.q	Y	N
2. All components – hourly	*.std	.. Y.....	..N
3. All components – daily	*.mit	... Y.....	...N
4. All components – monthly/yearly	*.pri	....Y.....	....N
5. Each HRU – hourly	*.hou	.....Y.....	.....N
6. Each HRU – daily	*.tag	.....Y.....	.....N
7. Each HRU – monthly	*.mon	.....Y.....	.....N
8. Each HRU – yearly	*.tmp	.....Y.....	.....N

The different output tables of PREVAH are organised as follows (extension in the table header):

Column	*.q	*.std	*.mit	*.pri	*.hou	*.tag	*.mon	*.tmp
1	YYYY	YYYY	YYYY	BASINID	YYYY	YYYY	YYYY	YYYY
2	MM	MM	MM	YYYY	MM	MM	MM	HRU-ID
3	DD	DD	DD	MM	DD	DD	HRU-ID	ADJ-P
4	HH	HH	P	BASINID	HH	HRU-ID	BASINID	SWA
5	RTOT	ZERO	ADJ-P	P	HRU-ID	P	P	ETP
6	RTOT (l s ⁻¹)	P	SWA	ADJ-P	P	ADJ-P	ADJ-P	ETR
7	R0	ADJ-P	ETP	SWA	ADJ-P	SWA	SWA	EI
8	R1	SWA	ETR	ETP	SWA	ETP	ETP	EB
9	R2	ETP	EI	ETR	ETP	ETR	ETR	RTOT
10	RG1	ETR	EB	EI	ETR	EI	EI	SSO
11	RG2	EI	R0	EB	EI	EB	EB	SI
12	RG3	EB	R1	R0	EB	R0	R0	SSM
13		R0	R2	R1	R0	R1	R1	BASINID
14		R1	RTOT	R2	R1	R2	R2	
15		R2	SSO	RTOT	R2	RTOT	RTOT	
16		RTOT	SI	SSO	RTOT	SSO	SSO	
17		SSO	SSM	SI	SSO	SI	SI	
18		SI	SUZ	SSM	SI	SSM	SSM	
19		SSM	SLZ	SUZ	SSM	SUZ	SUZ	
20		SUZ	BIL	SLZ	SUZ	SLZ	SLZ	
21		SLZ	ICEM	ICEM	SLZ	BIL		
22			RG1			ICEM		
23			RG2					
24			RG3					
25			DIFGA					

The next four sub-sections describe in more detail the structure of the four output files related to the entire catchment (*.q, *.mit, *.std, *.pri)

Output files for the hourly runoff components (*.q):

Description of the data file:

year	month	day	hour	variable1	variable2	...
1981	1	1	1	0.03235 ...		
1981	1	1	2	0.03181 ...		
1981	1	1	3	0.03128 ...		
...		
1981	1	1	23	0.02842 ...		
1981	1	1	24	0.02902 ...		
1981	1	2	1	0.02851 ...		
1981	1	2	2	0.02825 ...		
1981	1	2	3	0.02804 ...		
...		
1981	12	31	24	0.02851 ...		
1982	1	1	1	0.02825 ...		
...		

There is no header in this data file. The data are written out continuously in hourly steps. The length of the file varies depending on the occurrence of leap years. In a leap year, there are 8784, in all the other years, there are 8760 data points. The following variables are written to this output file from left to right:

1. YYYY Year
2. MM Month
3. DD Day
4. HH Hour
5. RTOT Total runoff
6. RTOT (l s⁻¹) Total runoff in l s⁻¹

- 7. R0 Surface runoff
- 8. R1 Interflow
- 9. R2 Total baseflow
- 10. RG1 Fast response baseflow
- 11. RG2 Delayed baseflow
- 12. RG3 Third component baseflow

The values are dimensioned in [mm] and correspond to the selected time-step. RTOT is additionally provided in [s^{-1}].

Output files for all hourly components (.std):*

Scheme of the data file:

day	month	year	hour	var1	var2	...
1	1	1981	1	0	...	
1	1	1981	2	0	...	
1	1	1981	3	0	...	
...	
1	1	1981	24	0	...	
2	1	1981	1	0	...	
...	
31	12	1981	24	0	...	
1	1	1982	1	0	...	
...	

There is no header in this data file. The data is written out continuously in hourly steps. The length of the file varies depending on the occurrence of a leap year (see above). The following variables are written to this output file from left to right:

- 1. DD Day
- 2. MM Month
- 3. YYYY Year
- 4. HH Hour
- 5. ZERO Dummy variable
- 6. P Interpolated precipitation [mm h^{-1}]
- 7. ADJ-P Adjusted interpolated precipitation² [mm h^{-1}]
- 8. SWA Snow melt [mm h^{-1}]
- 9. ETP Potential evapotranspiration [mm h^{-1}]
- 10. ETR Actual evapotranspiration [mm h^{-1}]
- 11. EI Interception evaporation / snow evaporation [mm h^{-1}]
- 12. EB Transpiration / soil evaporation [mm h^{-1}]
- 13. R0 Surface runoff [mm h^{-1}]
- 14. R1 Interflow [mm h^{-1}]
- 15. R2 Total baseflow [mm h^{-1}]
- 16. RTOT Total runoff [mm h^{-1}]
- 17. SSO Snow water equivalent [mm]
- 18. SI Interception storage [mm]
- 19. SSM Plant available soil moisture storage [mm]
- 20. SUZ Runoff generation storage (unsaturated zone) [mm]
- 21. SLZ Runoff generation storage (saturated zone) [mm]

² Adjusted with water balance correction factors (PKOR, SNOKOR)

The output files for all daily components (.mit)*

Description of the data file:

year	month	day	variable1	variable2	...
Rietholzbach				3.310	
YYYY	MM	DD	P-uk	P-kor	
1981	1	1	2.558	...	
1981	1	2	8.632	...	
1981	1	3	13.161	...	
...	
1981	1	31	0.000	...	
1981	2	1	0.000	...	
...	
1981	12	21	8.632	...	
1982	1	1	0.000	...	
...	

This file contains a header. The first line lists the name and size of the concerned catchment area. In the second line, the name of each variable is declared. The actual data follow on the subsequent lines, written out continuously in daily steps. The values are dimensioned in [mm d⁻¹], storage values have the dimension [mm]. The following variables are written to this output file from left to right:

1. YYYY Year
2. MM Month
3. DD Day
4. P-UK Interpolated precipitation [mm d⁻¹]
5. P-KOR Adjusted interpolated precipitation³ [mm d⁻¹]
6. P-SME Snowmelt [mm d⁻¹]
7. EPOT Potential evapotranspiration [mm d⁻¹]
8. EREA Actual evapotranspiration [mm d⁻¹]
9. EI Interception evaporation / snow evaporation [mm d⁻¹]
10. EB Transpiration / soil evaporation [mm d⁻¹]
11. R0 Surface runoff [mm d⁻¹]
12. R1 Interflow [mm d⁻¹]
13. R2 Total baseflow [mm d⁻¹]
14. RGES Total runoff [mm d⁻¹]
15. S-SNO Snow water equivalent [mm]
16. SI Interception storage [mm]
17. SSM Plant available soil moisture storage [mm]
18. SUZ Runoff generation storage (unsaturated zone) [mm]
19. SLZ Runoff generation storage (saturated zone) [mm]
20. BIL Balance from previous time step [mm d⁻¹]
21. GLAC Ice melt [mm d⁻¹]
22. RG1 Fast response baseflow [mm d⁻¹]
23. RG2 Slow response baseflow [mm d⁻¹]
24. RG3 Third component baseflow [mm d⁻¹]
25. DIFGA Input to DIFGA [mm d⁻¹]

³ Adjusted with water balance correction factors (PKOR, SNOKOR)

Output files for all monthly/yearly components (*.pri)

Description of the data file:

basinID	year	month	basinID	var1	var2	...
33	1981	1	33	145.6	...	
33	1981	2	33	61.4	...	
33	1981	3	33	140.1	...	
...	
33	1981	12	33	290.3	...	
33	1981	0	33	1820	...	
33	1982	1	33	226.3	...	
...	
33	0	0	33	1675	...	
33	1	-1	1	0.0	...	
33	2	-2	2	1.8	...	
33	3	-3	3	1.4	...	
33	4	-4	4	0.0	...	

There is no header in this data file. The data is written out in monthly steps. After each year, an additional line follows, containing the values for the whole year. This is recognised by the '0' in the month-column. At the end of the file, more lines are added: The first shows the variable values of the entire period (0 in year- and month-column), the following ones show the data of the different meteo zones (meteo zone ID in year-, month- and second basinID-column), also for the whole period. The following variables are written to this output file from left to right:

1. BASINID Basin ID
2. YYYY Year / zero / meteo zone ID
3. MM (MM-0) Month / zero / neg. meteo zone ID
4. BASINID Basin id / meteo zone ID
5. P Interpolated precipitation [mm month⁻¹] or [mm year⁻¹]
6. ADJ-P Adjusted-interpolated precipitation [mm month⁻¹] or [mm year⁻¹]
7. SWA Snow melt [mm month⁻¹] or [mm year⁻¹]
8. ETP Potential evapotranspiration [mm month⁻¹] or [mm year⁻¹]
9. ETR Actual evapotranspiration [mm month⁻¹] or [mm year⁻¹]
10. EI Interception evaporation / snow evaporation [mm month⁻¹] or [mm year⁻¹]
11. EB Transpiration / snow evaporation [mm month⁻¹] or [mm year⁻¹]
12. R0 Surface runoff [mm month⁻¹] or [mm year⁻¹]
13. R1 Interflow [mm month⁻¹] or [mm year⁻¹]
14. R2 Total baseflow [mm month⁻¹] or [mm year⁻¹]
15. RTOT Total runoff [mm month⁻¹] or [mm year⁻¹]
16. SSO Snow water equivalent [mm]
17. SI Interception storage [mm]
18. SSM Plant available soil moisture storage [mm]
19. SUZ Runoff generation storage (unsaturated zone) [mm]
20. SLZ Runoff generation storage (saturated zone) [mm]
21. ICEM Ice melt [mm]

3 Output grids

PREVAH is able to generate output in form of grids for 13 dynamic variables and 8 state variables (storages). In the [Output control dialog you may activate the gridded output for their variables and select how often you desire to write a grid: Every day; at the end of every month; at the end of every year or; as a yearly average for all the years in the simulation period. The grids are stored in the binary format of the PREVAH modelling system.

List of the 22 variables for which PREVAH is able to generate grid output. Dynamic variables are highlighted yellow, static variables blue.

Written grid	Extension
Adjusted Interpolated Precipitation	P
Potential evapotranspiration	ETP
Actual evapotranspiration	ETR
Interception evaporation / snow evaporation	EI
Transpiration / soil evaporation	EB
Total runoff	RGS
Surface runoff	R0
Interflow	R1
Total baseflow	R2
Icemelt / snowmelt on ice	GL0
Firn melt	GL1
Water release from snowpack	SWA
Percolation into saturated zone	GWN
Snow water equivalent	SSO
Interception storage	SI
Plant available soil moisture storage	SSM
Runoff generation storage (unsaturated zone)	SUZ
Runoff generation storage (saturated zone)	SLZ
Runoff generation storage (fast baseflow)	SL1
Runoff generation storage (delayed baseflow)	SL2
Runoff generation storage (third component baseflow)	SL3

Structure of the file names in the grids generated by PREVAH

Time step for gridded output	Unit	Filename	Active	Not Active
Daily	mm day ⁻¹	gdDDMMYY.EXT	Y-...-..	N-...-..
Monthly	mm month ⁻¹	[Grid]MMYY.EXT	..-Y-...-	..-N-...-
Yearly	mm year ⁻¹	[Grid]YYYY.EXT	...-Y-..	...-N-..
Period average	mm year ⁻¹	[Grid]_AVG.EXT	...-...-Y	...-...-N

Notes: [Grid] = Name of basic grid for gridded output (without extension)

DD = Day

MM = Month

YY = Year (two digits)

YYYY = Year (four digits)

EXT = Extension of desired dynamic or static variables (see previous table).

F.4.9 [Efficiency] settings

Syntax:

```
[Efficiency]
Y                      ! Compute Model Efficiency
01                    ! Number of Efficiency scripts
C:\prevahff\daning\watershed\danc.effs ! Name of the first efficiency script
[End Efficiency]
```

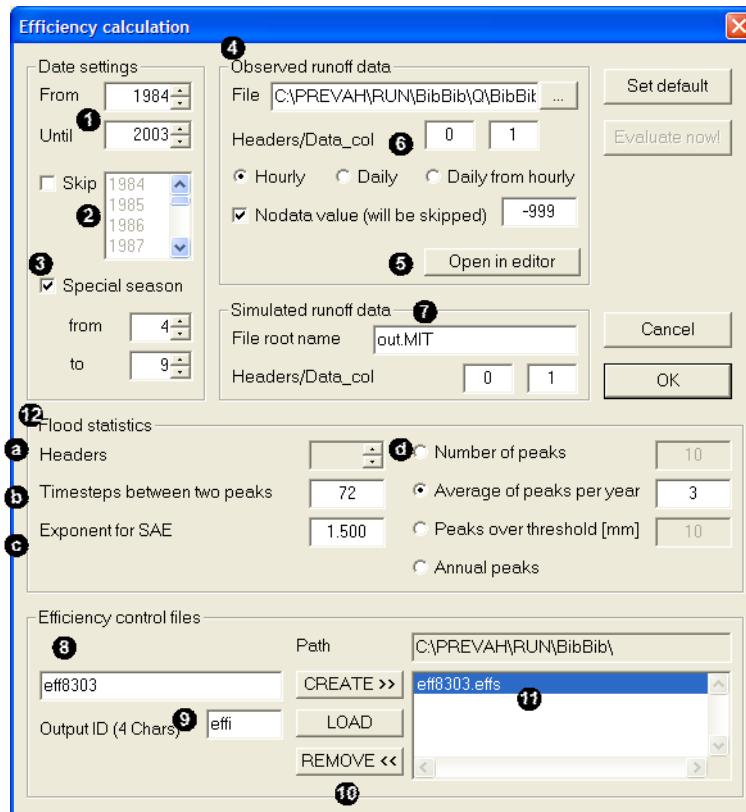
To evaluate the model performance, you have to link your PREVAH control file with a file where the observed runoff values are stored. The link occurs through a script file which is generated through the Efficiency calculation dialog of WINPREVAH. If a new efficiency script (*.effs) is created, or an available script is deleted, WINPREVAH updates the [Efficiency] settings automatically.

The efficiency script

Syntax:

```
[Begin]
1990                  ! Start year
1992                  ! End year
Y                    ! Do flood statistics (Y/N)
out01.MIT            ! Simulated file (filled automatically)
02 14 14             ! Headers/Columns/Take Column
C:\prevahff\daning\hydrometeo\tables\rundaning.day           ! File with Observed runoff [mm]!
01 02 02             ! Headers/Columns (After Date)/Take Column
DD                   ! Time resolution DD=Daily data; HH=Hourly data
cdan                 ! Basic name for Output
Y                    ! Consider special season (Y/N)
06                   ! Number of months in this season
04 05 06 07 08 09   ! Declaration of months in this season (e.g. April-September)
N                    ! Skip years (Y/N)
0                    ! How many years should be skipped?
1900                 ! Which years have to be skipped? (=1900 if no year is skipped)
[End]

[FLOOD EFFICIENCY CONTROL FILE] ! Optional ....
HEADRS = 00         ! Headers
OBSCOL = 4          ! Column with observed data (output file from efficiency computa-
                    ! tion)
SIMCOL = 5          ! Column with simulated data (idem)
TIMEST = D          ! Time resolution D=Daily data; H=Hourly data
WAEEXP = 0.00       ! Exponent for WAE computation (See later in the Documentation)
POTNUM = 9903       ! Options for POTNUM computation (See Documentation)
POTSEP = 0          ! Options for POTSEP computation (See Documentation)
[End]
```



In the Efficiency calculation dialog you have to:

- ❶ Define the period for the computation of the model efficiency (e.g. the calibration period)
- ❷ Decide whether some years should be skipped from the calibration (mark them in the list).
- ❸ Decide whether a separate output for a particular season (e.g., summer) is desired (select the beginning and end of this season in the box).
- ❹ Load the file where the observed runoff values are stored.
- ❺ This file may be opened with the standard editor linked to WINPREVAH to be sure that you have the correct formats, to look for the number of headers and the number of columns after the date (the date columns do not count), and which column number contains the observed runoff data. Do keep in mind that these data have to be given in mm per time step.
- ❻ The number of headers, the number of columns after the date and the column where the model should read observed runoff data have to be declared, together with whether daily or hourly data is used for the computation of the efficiency.
- ❼ The contents of this box are edited automatically by the model.
- ❽ Provide a name for the efficiency script and ...
- ❾ ... a 4-character string to assign a name to the outputs of the efficiency script.
- ❿ To save an efficiency script, click [CREATE>>]; you may also add a script saved earlier by clicking [LOAD]; the stack of efficiency scripts to be executed is displayed in a list box (⓫). To remove an efficiency script from the stack, mark it in the list box and click [REMOVE<<].

⑫ In order to specifically analyse runoff peaks (e. g. when calibrating PREVAH for flood estimation purposes), the peak-specific efficiency component FLOODSTAT has been implemented. It has the following options:

- Ⓐ Headers applies to the number of header columns to be skipped in the runoff record file used (0 by default, no adjustment necessary)
- Ⓑ Time-steps between two peaks specifies the number of time steps (as declared in the WINPREVAH main dialog window, e.g. 1 h) that has to occur between two peaks in order for them to be regarded as independent events. If two peaks occur within the specified interval, (3 time steps by default) only the larger of the two is used for computing the flood statistics.
- Ⓒ Exponent for SAE declares the exponent for computing the SAE score (1.5 by default)
- Ⓓ The radio buttons allow the specification of how the peak record is being derived from the complete runoff record:
 - Number of peaks extracts exactly the specified amount of peak values
 - Average of peaks per year (recommended, with value 3) derives an average of n peaks per efficiency-year (with n the number of peaks and efficiency-years the modelled years included in the common efficiency computation). A total of $n \times$ efficiency-years peaks are derived.
 - Peaks over threshold extracts only peaks that are larger than the value entered (in [mm], remember that this unit corresponds with the modelling time-step as declared in the WINPREVAH main dialog window).
 - Annual peaks derives exactly one peak per year (only recommended for large records)

FLOODSTAT provides a variety of data which may be interpreted by the user or may serve to calibrate the model on peak runoff. FLOODSTAT writes an ASCII-formatted text file with the ending "_FLS.dat" which may be viewed with any text editor.

Objective functions for flood peaks

ID	TYPE	NSE	WAE	P-QT	P-SAE	SPM_R	SPM_P
91	9999	0.7811	31822	4.859	27.12	0.58	0.946

Ⓔ <ANNUAL> Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ

OBS_HQA	DATE	SIM_HQA	DATE
49.6918	1982-01-06	40.9100	1982-01-06
28.6384	1981-12-16	34.0200	1981-09-29
23.9764	1983-11-28	21.0100	1983-11-28

Ⓗ <P-REC:N> 12

OBS_HQ	DATE	SIM_HQ	DATE
49.6918	1982-01-06	40.9100	1982-01-06
37.9200	1982-01-09	34.0200	1981-09-29
28.6384	1981-12-16	28.5500	1981-12-16
23.9764	1983-11-28	27.3700	1981-07-19
22.3372	1981-10-15	26.3500	1982-01-30
21.6033	1981-09-29	25.3600	1981-10-15
20.3786	1981-10-11	21.0100	1983-11-28
20.0309	1981-07-19	20.3800	1981-10-30
19.2324	1981-12-01	18.5600	1983-04-06
18.8043	1982-01-12	18.1500	1981-03-13
18.3409	1983-04-07	17.8900	1981-01-04
17.8013	1982-01-30	17.3700	1982-07-27

The third line lists the FLOODSTAT scores obtained for the peak record as it has been defined in FLOODSTAT OPTIONS (see above). The corresponding legends are found in line two. The following figures are provided:

Ⓐ NSE: Nash-Sutcliffe efficiency score for the entire runoff record (same as in standard efficiency output, see Chapter 6 in Part II of the PREVAH documentation).

- Ⓒ WAE: Sum of weighted absolute errors in peak flow record.
- Ⓓ P-QT: Sum of time- and size-weighted peak errors.
- Ⓔ P-SAE: Sum of absolute errors in peak flow record
- Ⓕ SPM_R: Spearman rank-correlation coefficient for peak records
- Ⓖ SPM_P: Significance level of SPM_R (assuming normal distribution)

The following text block headed by <ANNUAL> (Ⓒ) lists the magnitude and occurrence date of annual maximum peaks in the observed (OBS_HQA) and simulated (SIM_HQA) flow record. If the chosen modelling time-step is smaller than 24 hours (see WINPREVAH main dialog), DATE also provides the hour of the peak occurrence.

In the last text block, Ⓖ reveals the peak flow record used for computation of the FLOODSTAT scores (observed, OBS_HQN and simulated, SIM_HQA peaks, DATE same as above) in descending order. If the user has specified a number of peaks to be extracted (total or average per year, see FLOODSTAT OPTIONS), the block header is <P-REC:N>, followed by the number of peaks in the record (12 in the example above). If the user has provided a threshold value for peak extraction, the last text block will be headed by <P-REC:T> (Ⓔ, see below) and the specified threshold value in [mm] (20 in the example). If annual peaks have been chosen as the basis of the scores (not recommended for small samples), the last text block will be headed <P-REC:A>, followed by the number of considered years (3 in the example far below, Ⓕ).

```
<P-REC:T> 20.0000 Ⓔ
  OBS_HQ    DATE    SIM_HQ    DATE
  49.6918   1982-01-06   40.9100   1982-01-06
  I 37.9200   1982-01-09   34.0200   1981-09-29
    28.6384   1981-12-16   28.5500   1981-12-16
    23.9764   1983-11-28   27.3700   1981-07-19
    22.3372   1981-10-15   26.3500   1982-01-30
    21.6033   1981-09-29   25.3600   1981-10-15
    20.3786   1981-10-11   21.0100   1983-11-28
    20.0309   1981-07-19   20.3800   1981-10-30
```

```
<P-REC:A> 3 Ⓕ
  OBS_HQ    DATE    SIM_HQ    DATE
  49.6918   1982-01-06   40.9100   1982-01-06
  37.9200   1982-01-09   34.0200   1981-09-29
  II 28.6384   1981-12-16   28.5500   1981-12-16
```

The efficiency script generates 6 ASCII-formatted text files which may be opened with any text editor. [...] refers to the output ID name given in the Efficiency calculation dialog.

Name	Definition
[...]_ost.dat	Statistics for observed runoff
[...]_sst.dat	Statistics for simulated runoff
[...]_dst.dat	Difference between simulated and observed runoff
[...]_eli.dat	Linear efficiency score
[...]_eln.dat	Logarithmic efficiency score
[...]_fls.dat	Flood statistics file (see Part II, Section 4.9.2)

Statistics for observed and simulated runoff (\$\$\$\$_ost.dat / \$\$\$\$_sst.dat)

Statistics for Observed Runoff									
ID	TYPE	Maximum	Minimum	Average	Summation	Variance	St.Dev	AV-STD	AV+STD
1	9999	49.6918	0.1206	2.6356	4812.61	14.8831	3.8579	-1.2223	6.4935
1	1981	28.6384	0.2464	3.1515	1150.28	16.9880	4.1217	-0.9702	7.2731
1	1982	49.6918	0.1971	2.9254	1067.78	20.5377	4.5319	-1.6064	7.4573
...
1	1985	19.5804	0.1325	2.2181	809.62	9.5519	3.0906	-0.8725	5.3087
1	1	49.6918	0.5481	4.4765	693.86	41.3962	6.4340	-1.9575	10.9105
1	2	33.8152	0.6468	3.6382	512.99	21.4918	4.6359	-0.9977	8.2742
1	3	15.6878	0.5814	3.3864	524.88	7.2267	2.6883	0.6981	6.0746
...
1	12	28.6384	0.4437	3.6112	559.74	19.7687	4.4462	-0.8350	8.0574
1	8888	23.4069	0.1206	2.0801	1903.28	9.6414	3.1051	-1.0250	5.1851

The output of the statistical function is divided into three different files. They all contain a header which describes whether the observed ('_ost') or simulated ('_sst') statistic is calculated. Most of the variable names are self-explanatory. The second column TYPE contains different markers. The line with 9999 represents the entire period. This is followed by the statistics for the mentioned years (1991–1985 in this example) by twelve lines which represent one month for the entire period each. In this example, all Januarys from 1981 to 1985 are used to build monthly statistics. The last line with the 8888 identifier shows the statistical values of an individually chosen season. The last three columns have the following meaning:

- St.Dev Standard deviation
- AV-STD Average – standard deviation
- AV+STD Average + standard deviation

Statistics on differences between observed and simulated runoff (\$\$\$\$_dst.dat)

The third file is set up similarly. It contains the differences ('_dst') of the statistics between the observed and simulated values, and therefore is a combination of the two files \$\$\$\$_ost.dat and \$\$\$\$_sst.dat.

Efficiency for linear and logarithmic data (\$\$\$\$_eli.dat / \$\$\$\$_eln.dat)

Efficiency for linear data							
ID	TYPE	E0.25	E0.50	E1.00	E2.00	E4.00	
2	9999	0.2990	0.4732	0.6477	0.7960	0.9449	
2	1981	0.2954	0.4711	0.6495	0.7851	0.9231	
2	1982	0.2546	0.4012	0.5577	0.7586	0.9446	
...	
2	1985	0.2977	0.4761	0.6590	0.8092	0.9366	
2	1	0.3139	0.4916	0.6572	0.7895	0.9375	
2	2	0.2859	0.4282	0.5378	0.6558	0.9235	
2	3	0.0923	0.1737	0.3248	0.6344	0.9414	
...	
2	12	0.3064	0.4750	0.6264	0.7462	0.9133	
2	8888	0.2852	0.4628	0.6576	0.8154	0.9269	

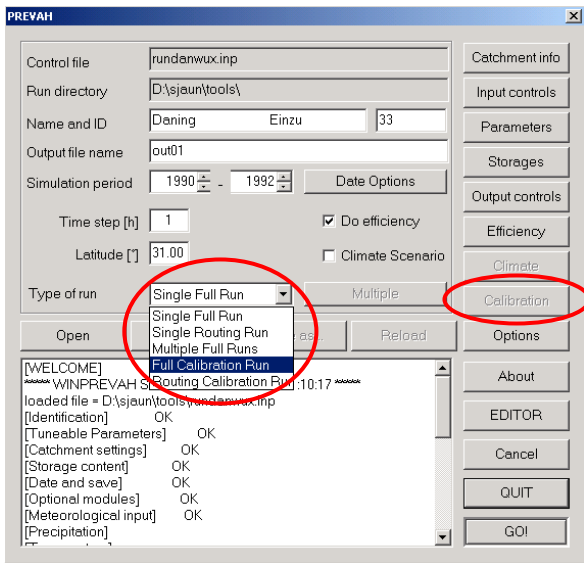
The efficiency score for the model is calculated and written in a linear (\$\$\$\$_eli.dat) and logarithmic (\$\$\$\$_eln.dat) version. More information on the efficiency score can be found in Chapter 6, Part II of the PREVAH documentation. The files in the same format as the statistics files, except for the different variables. E2.00 corresponds to the original Nash-Sutcliffe equation, whereas the others are based on a more generalised version of this equation (Legates and McCabe, 1999; Equation F1). The exponent j of the generalised Nash-Sutcliffe equation corresponds to the second part of the variable name.

$$E_j = 1 - \frac{\sum_{i=1}^n |O_i - S_i|^j}{\sum_{i=1}^n \left| O_i - \left[\frac{1}{n} \sum_{i=1}^n O_i \right] \right|^j} \tag{F1}$$

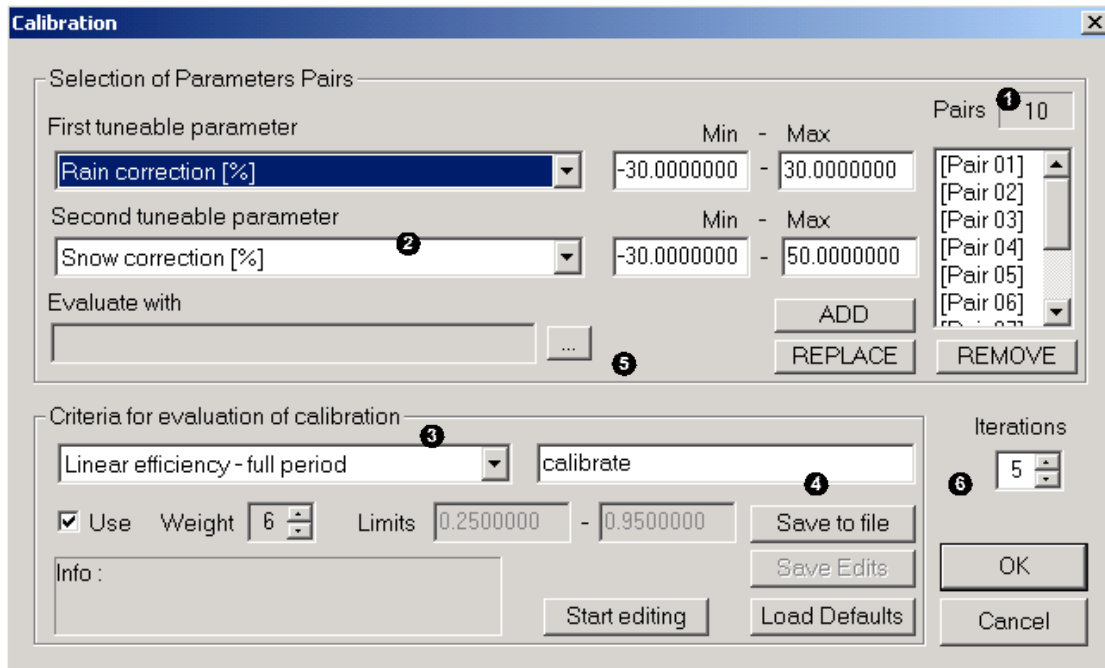
The efficiency module also provides two files needed to load the results of the model simulation in the tool HYDROGRAPH.

F.5 The calibration dialog

F.5.1 Dialog settings



To run the calibration, choose "Full Calibration Run" from the type of run. With this, the button [Calibration] (on the right side) is activated. Pressing it opens the calibration dialog.



In this dialog, the options for the automatic calibration of PREVAH are set.

Selection of Parameter Pairs:

❶ On the upper right side, the number of parameter pairs used is provided, the parameter pairs to be edited are found below. Parameter pairs may be added, removed or replaced using the drop-down menu (❷). The minimum and maximum values for calibration of each parameter is assigned in the corresponding edit boxes.

Criteria for evaluation of calibration:

❸ Different evaluation methods may be chosen from the dropdown menu. All available methods (efficiency scores and volume errors) are calculated for a model run if the checkbox [Use] is activated. To edit and adjust limits and weight of the respective score, press the [Start editing] button. Save your changes with the [Save Edits] button, and then proceed with the next method. After you adjusted the calibration criteria, press the [Save to file] button and your changes are saved under the name defined in box ❹ with extension .eopt. To undo your changes, press the [Load Defaults] button. To use the changed evaluation criteria with a parameter pair, they have to be linked to it. Click the [...] button (❺) to select the respective setting file and then click the button [REPLACE]. With this, different evaluation criteria may be assigned to every parameter pair.

❻ On the right side, the number of iterations is assigned. The [OK] button writes your calibration settings to the options file of WINPREVAH (see Section F).

The following four tables indicate the recommended settings for the CALIBRATION DIALOG.

Recommended settings for the nine objective functions used for the calibration of PREVAH

#	Description	SCORE	WEIGHT	LIMIT _{MIN}	LIMIT _{MAX}	Function
1	Linear efficiency – full period	ALIN _{PERIOD}	6	0.25	0.95	E_2^{lin}
2	Linear efficiency – year-by-year	ALIN _{YY}	4	0.1	0.01	STDEV(E_2^{lin})
3	Linear efficiency – month-by-month	ALIN _{MM}	2	0.5	0.02	STDEV(E_2^{lin})
4	Logarithmic efficiency – full period	ALOG _{PERIOD}	3	0.25	0.95	E_2^{log}
5	Logarithmic efficiency – year-by-year	ALOG _{YY}	2	0.1	0.01	STDEV(E_2^{log})
6	Logarithmic efficiency – month-by-month	ALOG _{MM}	1	0.5	0.02	STDEV(E_2^{log})
7	Volume error – full period	AVOL _{PERIOD}	10	0.1	0.01	DV
8	Volume error – year-by-year	AVOL _{YY}	4	0.15	0.02	STDEV(DV)
9	Volume error – month-by-month	AVOL _{MM}	3	0.10	0.02	STDEV(DV)

The column SCORE declares in which score the different functions are integrated (see equations 6.3-1 to 6.3-16 in the Part II of the PREVAH documentation). WEIGHT indicates the recommended (and default) weight of each function for building the corresponding score and overall score.

Default parameter pairs for automatic calibration of PREVAH for Swiss glaciated catchments. These default settings assume that the recommended snowmelt module "4. EMA with varying melt factor" (see Section 4.3, Part II of the PREVAH documentation) is used

PAIR	Parameter 1	Parameter 2
1	Rain correction [%]	Snow correction [%]
2	Threshold Temperature Rain-snow [°C]	Transition Temperature Rain-snow [°C]
3	Maximal degree day factor [mm (d·K) ⁻¹]	Minimal degree day factor [mm (d·K) ⁻¹]
4	Threshold Temperature Rain-snow [°C]	Threshold Temperature snowmelt [°C]
5	Exponent for soil moisture recharge [-]	Percolation [mm h ⁻¹]
6	Refreezing factor [mm (d·K) ⁻¹]	Radiation melt factor for snow
7	Threshold storage for surface runoff [mm]	Storage coefficient for surface runoff [h]
8	Storage coefficient for interflow [h]	Percolation [mm h ⁻¹]
9	Storage coefficient for fast baseflow [h]	Maximum storage for fast baseflow [mm]
10	Storage coefficient for delayed baseflow [h]	Percolation [mm h ⁻¹]
11	Temperature melt factor for ice [mm (d·K) ⁻¹]	Radiation melt factor for ice

Recommended parameter pairs for automatic calibration of PREVAH for large catchments with no glaciers and daily meteorological input. These default settings assume that the snowmelt module "0. Positive degree day index (PDDI)" (see Section 4.3, Part II of the PREVAH documentation) is used.

PAIR	Parameter 1	Parameter 2
1	Rain correction [%]	Snow correction [%]
2	Threshold Temperature Rain-snow [°C]	Transition Temperature Rain-snow [°C]
3	Maximal degree day factor [mm (d·K) ⁻¹]	Minimal degree day factor [mm (d·K) ⁻¹]
4	Refreezing factor [mm (d·K) ⁻¹]	Threshold Temperature snowmelt [°C]
5	Exponent for soil moisture recharge [-]	Percolation [mm h ⁻¹]
6	Threshold storage for surface runoff [mm]	Storage coefficient for surface runoff [h]
7	Storage coefficient for interflow [h]	Percolation [mm h ⁻¹]
8	Storage coefficient for fast baseflow [h]	Maximum storage for fast baseflow [mm]
9	Storage coefficient for delayed baseflow [h]	Percolation [mm h ⁻¹]

Recommendations for building tuneable parameter pairs for the full calibration of PREVAH. The description corresponds to the text reported in the CALIBRATION dialog of WINPREVAH. MODEL ID declares the name of these variables in the source code of PREVAH and WINPREVAH.

	Description	MODEL ID	Link To
1	Rain correction	PKORF	SNOKOR
2	Snow correction	SNOKOR	PKORF
3	Threshold Temperature Rain-snow	TGR	TTRANS or T0
4	Transition Temperature Rain-snow	TTRANS	TGR or T0
5	Threshold Temperature snowmelt	T0	TGR, TTRANS, CRFR, CRMFMIN, CRFRMAX
6	Exponent for soil moisture recharge	CBETA	CPERC, SGRLUTZ or K1H
7	Maximal degree day factor	CRMFMAX	CRMFMIN or T0
8	Minimal degree day factor	CRMFMIN	CRMFMAX or T0
9	Refreezing factor	CRFR	CWH, CEXLIQ or T0
10	Radiation melt factor for snow	RMFSNOW	CRMFMIN or CRMFMAX or TSFSSNOW
11	Threshold storage for surface runoff	SGRLUZ	K0H, K1H or CBETA
12	Storage coefficient for surface runoff	K0H	SGRLUZ or K1H
13	Storage coefficient for interflow	K1H	CBETA, CPERC, SGRLUZ or K0H
14	Percolation	CPERC	CBETA, SGRLUZ, K1H, K2H
15	Storage coefficient for fast baseflow	CG1H	SLZ1MAX, K2H
16	Maximum storage for fast baseflow	SLZ1MAX	CG1H, K2H
17	Storage coefficient for delayed baseflow	K2H	SLZ1MAX, CPERC or CG1H
18	Temperature melt factor for ice	CICEMF	CAICE or T0
19	Radiation melt factor for ice	CAICE	CICEMF or T0
20	Critical precipitation intensity	A0	AADD
21	Albedo ageing > 0°C	APOS	ANEG
22	Albedo ageing < 0°C	ANEG	APOS
23	Retention factor for melting snow	CWH	CRFR, CEXLIQ or T0
24	Melting factor by wind 1	CWU1	CWH2
25	Melting factor by wind 2	CWA2	CWU1
26	Exponent for retention of melting snow	CEXLIQ	CRFR, CWH or T0
27	Temperature melt factor for snow	TSFSSNOW	RMFSNOW or T0
28	Routing: Translation time [h]	TROUT	SROUT
29	Routing: Storage time [h]	SROUT	TROUT
30	Threshold moisture saturation for ETR	CRAFC	CBETA
31	Addition parameter for maximal Albedo	AADD	A0

F.5.2 Control file for the calibration *.eopt

The *.eopt files are resulting from the changes made in the calibration program module under "Criteria for evaluation of calibration". When you save a calibration control file, this kind of text file is written in the same directory as the control file of WINPREVAH:

Syntax

```
[Begin]
D:\sjaun\china\tools\rundanwux.inp      ! PATH of the PREVAH control file
C:\prevahff\daning\watershed\danc.offs  ! PATH of the model efficiency control file
9                                         ! Number of pairs
D:\sjaun\china\tools\runsts.cali        ! Name and location of the logfile of calibration.
[Linear efficiency - full period]       ! Name of the 1st efficiency score
1                                       ! Use this score
06                                      ! Weight
      0.1111111      0.9500000         ! Limits for fuzzy function
[Linear efficiency - year-by-year]     ! Name of the 2nd efficiency score
1                                       ! .....
04                                      ! .....
      0.1000000      0.0100000
[Linear efficiency - month-by-month]
...
[Logarithmic efficiency - full period]
...
[Logarithmic efficiency - year-by-year]
...
[Logarithmic efficiency - month-by-month]
...
[Volume error - full period]
...
[Volume error - year-by-year]
...
[Volume error - month-by-month]
...
[End]
```

This file is linked to the desired parameter pair and updates the default settings, storing them in the winprevah.ini file (see next section). Every available score (see previous section) is listed separately; its definition consists of three lines. The first line, either a 1 or a 0, specifies whether the score is used for calibration (1) or ignored (0). This entry corresponds to the checkbox "Use". The second line shows the weight, the third the selected limits for the fuzzy function (defined to reduce this score to a range between 0 and 1).

F.6 The options file of WINPREVAH

```
[TOOLS]
C:\WINDOWS\SYSTEM32\WRITE.EXE
C:\prevahff\bin\viewoptim4.exe
C:\prevahff\bin\hydrograph.exe
C:\prevahff\bin\WINGRID.exe
[END TOOLS]

[FREE PARAMETERS - SOFT LIMITS]
      -4.800000          -30.00000          30.00000
.....
.....
      0.000000E+00          0.3000000          0.5500000
[END FREE PARAMETERS - SOFT LIMITS]

[CALIBRATION]
      10
      1          2
default.eopt
      3          4
default.eopt
      7          8
default.eopt
      6          14
default.eopt
      9          10
default.eopt
      11         12
default.eopt
      13         14
default.eopt
      15         16
default.eopt
      17         14
default.eopt
      18         19
default.eopt
      0.2500000          0.9500000          6.0000000          T
      0.1000000          0.0100000          4.0000000          T
      0.5000000          0.0200000          2.0000000          T
      0.2500000          0.9500000          3.0000000          T
      0.1000000          0.0100000          2.0000000          T
      0.5000000          0.0200000          1.0000000          T
      0.1000000          0.0100000          10.0000000         T
      0.1500000          0.0200000          4.0000000          T
      0.1000000          0.0200000          3.0000000          T
[END CALIBRATION]

[RUNWINDOW]
      40          2
[END RUNWINDOW]
```

The winprevah.ini file is used to store the options of the WINPREVAH program. It is separated into different sections, which are discussed below:

In the [TOOLS] section, the paths to the text editor, optimisation viewer, hydrograph viewer and grid viewer are set. Section A of this manual provides further information.

[FREE PARAMETERS – SOFT LIMITS]: The second and third column show the lower and upper soft limit of the corresponding parameter. The first column contains the last value that has been stored for the parameter. Changes are made in the parameters program which is described in Section F.4.2

[CALIBRATION]: This section controls the calibration program module. The first line of this section shows the number of parameter pairs used for calibration. The following lines first show the number of the two parameters which form a parameter pair, and the name of the file which contains the chosen limits and weight of the used efficiency scores and volume errors. More information on this file is found in Chapter 6 of Part II of the PREVAH documentation. If no changes were made to the initial settings, default.eopt is assumed as a placeholder. The default values for the limits and weights are assigned after the last parameter

pair. The first two columns show the lower and upper limit, the third column shows the weight. The fourth column either contains a T (true) or F (false) to decide whether the respective efficiency score or volume error is used for calibration.

[RUNWINDOW]: These specifications are used to place the WINPREVAH model run window (displayed after clicking the [GO!] button in the main dialog window). The first number and second number refer to on-screen x and y co-ordinates, respectively, with origin in the upper left corner, positive x-axis running down, and positive y-axis running right. This setting may also be updated in the program module "Options" under the "Run window settings".

G HYDROGRAPH: Quick visualisation of hydrological simulations

G.1 Introduction

Visualisation of results from hydrological models requires the availability of commercial software. During calibration, the visualisation of simulation results is often a time-consuming task. To avoid this, the HYDROGRAPH tool was developed to allow for a quick visualisation of the main results of PREVAH.

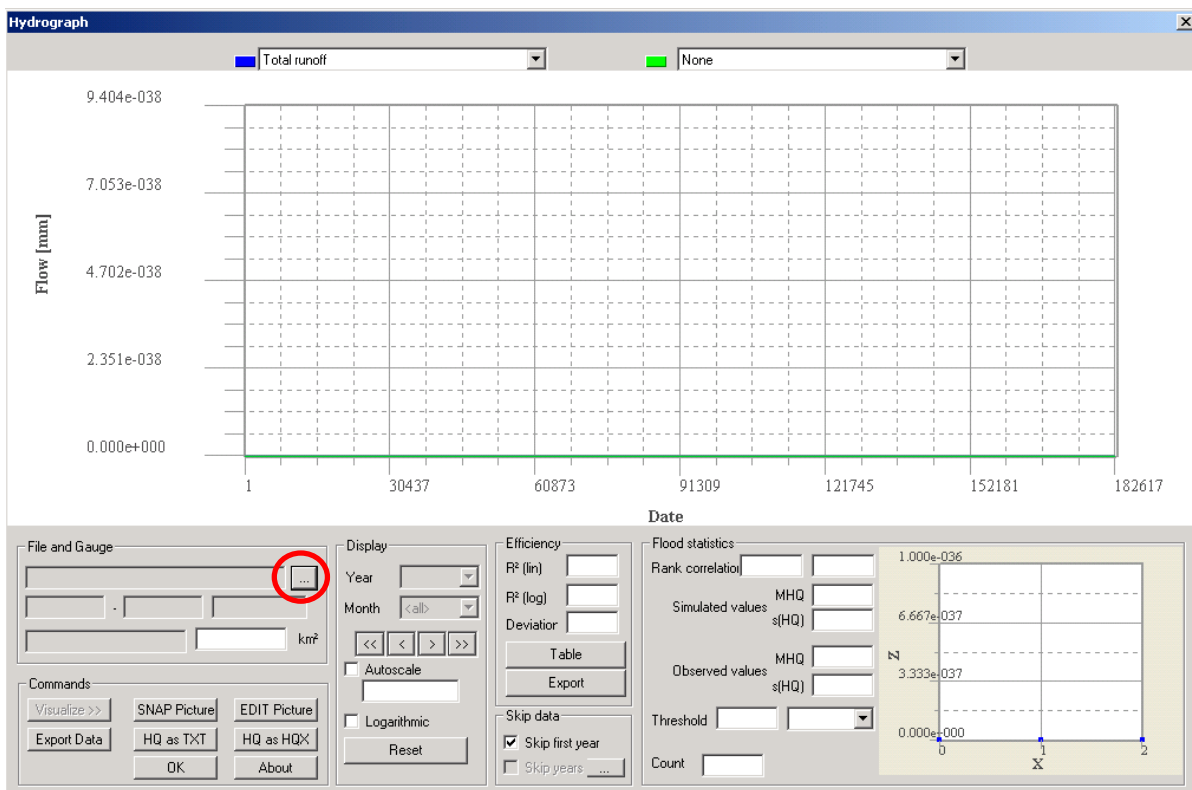
G.2 Program description

Two types of files may be plotted with this program:

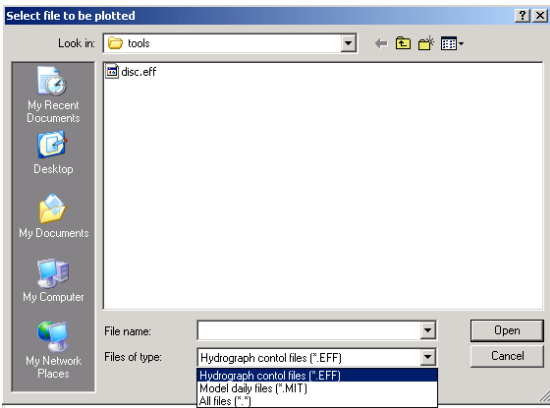
- xxxx.eff (modelled and observed runoff) (*.eff, *.ddd/*.hhh): Such files are an optional model output. The results of the model run may be compared to observed runoff values. Different time frames may be chosen and the efficiency score of the model is calculated. Various possibilities to export data and create screenshots are available.
- xxxx.mit (various parameters from model output): These files only contain model data. Therefore, the functions related to the efficiency score and display of observations are not available. Various model parameters may be chosen and plotted against each other. The format of this model output is described in the WINPREVAH manual.

G.3 Main dialog window

The following main dialog window is displayed after start-up:

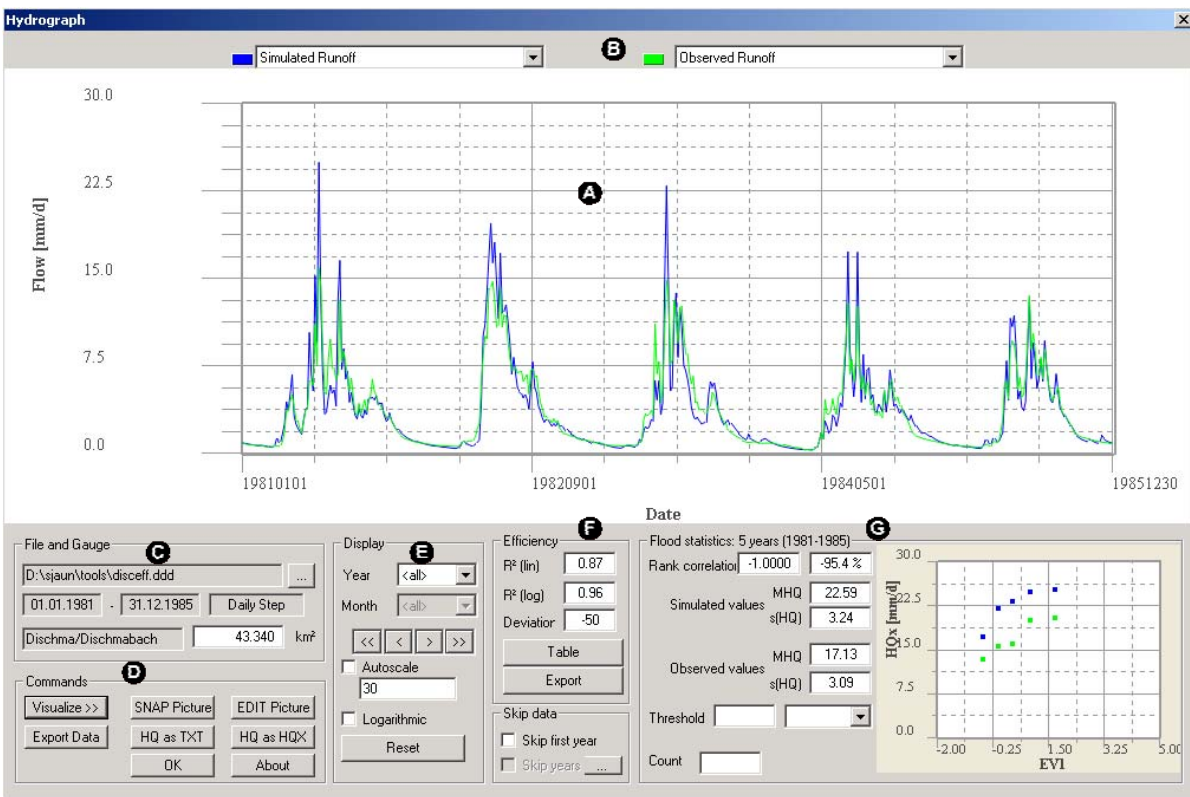


To select a file, press the [...] button (see red circle above). The file selection dialog opens:



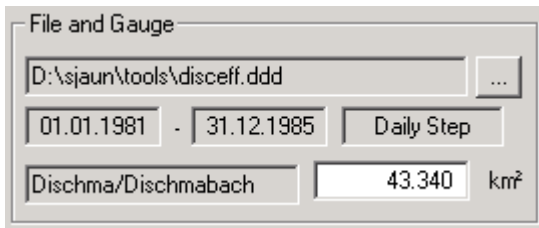
Select your data directory. Two types of files may be plotted with this program:

- xxxx.eff (link to the file containing the modelled and observed runoff values)
- xxxx.mit (file containing daily model output).



- Legend:
- A Plotting area
 - B Select line to be plotted
 - C File selection
 - D Commands
 - E Selecting a time frame
 - F Model efficiency
 - G Flood statistics

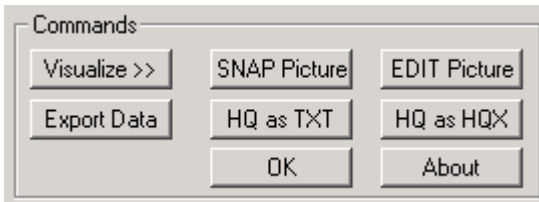
G.4 Display control



The first field shows the path to the selected data file. To select a different one, click the [...] button.

The second line shows the temporal range and time step of the data.

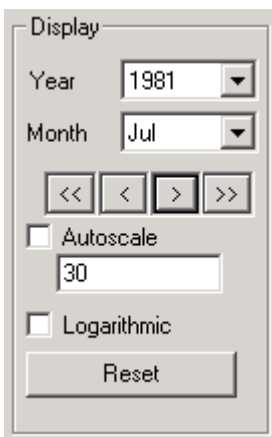
The third line shows the name of the observed/simulated catchment with its catchment size.



Every time a new data file is selected, the [Visualize>>] button has to be clicked in order to plot the data. With the [SNAP Picture] button, a screen shot of the main dialog is pasted to the clipboard. To edit the content of the clipboard, click the [EDIT picture] button. A new dialog is prompted.

The [HQ as TXT] and [HQ as HQX] buttons serve to export peak flow, as ASCII-formatted text file or HQ-EX-formatted exchange file (WASY, 1997).

The [OK] button closes the window and quits the program.



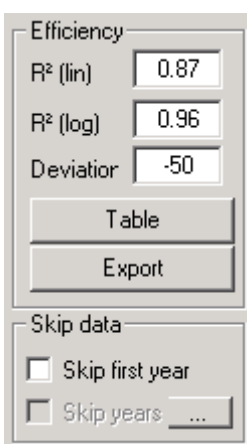
Initially, all discharge data of the file are plotted. To display only a part of the data set, the desired year and month can be selected. If no month is selected, the full year is plotted.

The arrow buttons are used to switch between the months [<] [>] and years [<<] [>>]. If a month is selected, [>>] shows the same month of the next year.

If [Autoscale] is checked, the y-axis of the plot is adjusted automatically to the data range.

To make a logarithmic plot of the data, activate the [Logarithmic] checkbox.

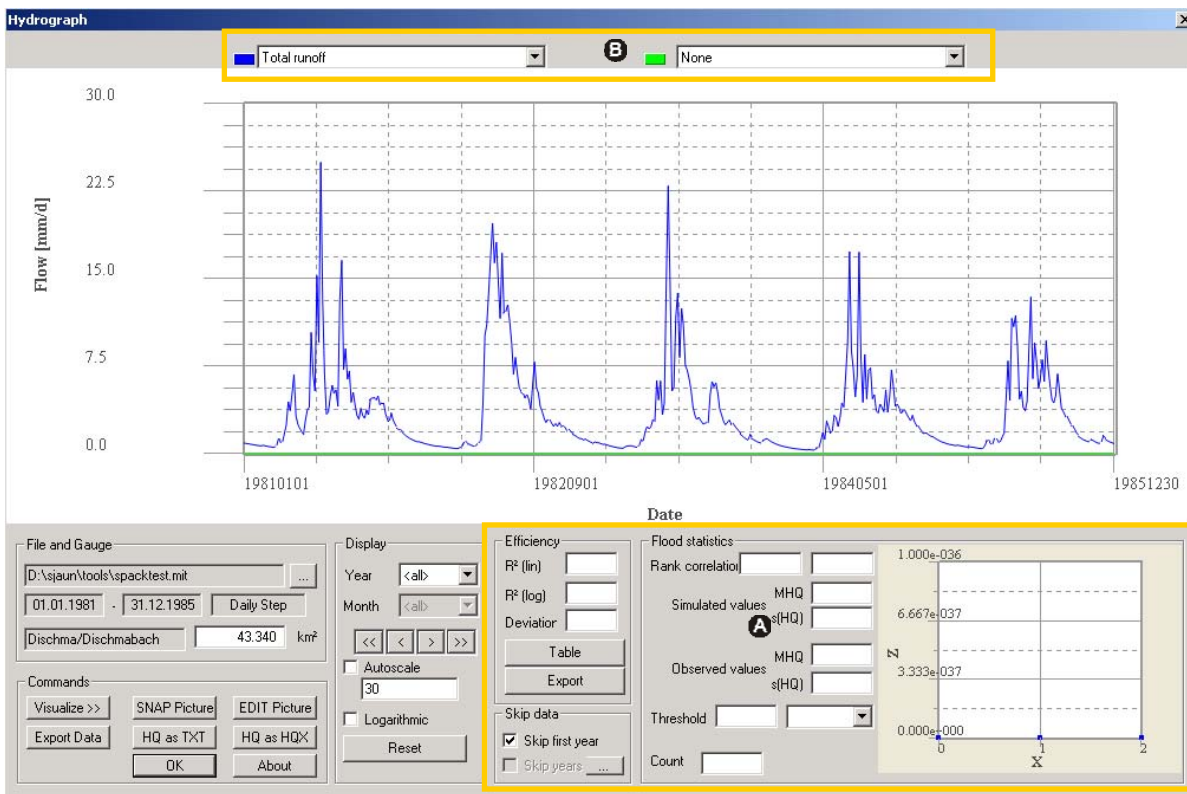
The [Reset] button restores the initial state.



The linear and logarithmic efficiency scores of the whole data range are showed. Additionally, the deviation (volume error) in [mm] between simulated and observed runoff is displayed. To see detailed yearly and monthly values, click the [Table] button. These values can also be exported and saved to a text file by pressing the [Export] button.

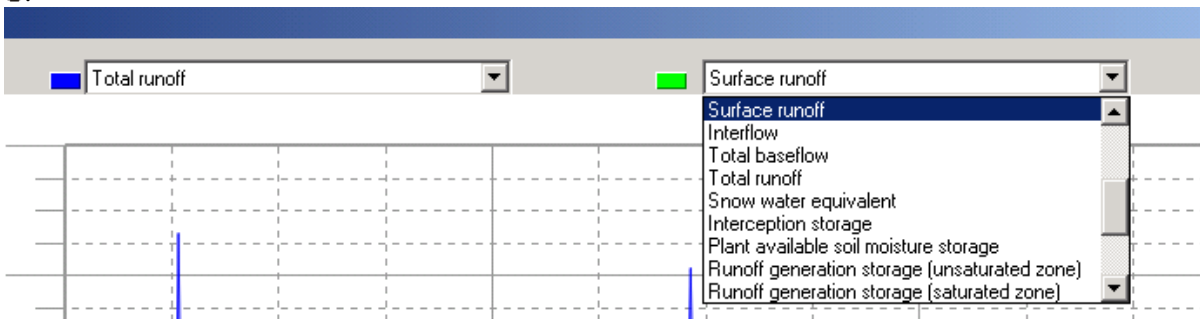
If the first year is used to initialise the model, it may be skipped and will not be considered by the efficiency calculation ([Skip first year] check box).

Differences when using the xxxx.mit files:



A If an xxxx.mit file is plotted, the marked area is not used and remains empty.

B:



The drop-down menus on the top allow the selection of different parameters from the model output. Two parameters may be chosen to be plotted in blue and green. The following parameters are available:

- P-UK: Interpolated precipitation [mm d⁻¹]
- P-KOR: Adjusted - Interpolated Precipitation [mm d⁻¹]
- P-SME: Snowmelt [mm d⁻¹]
- EPOT: Potential evapotranspiration [mm d⁻¹]
- EREA: Actual evapotranspiration [mm d⁻¹]
- EI: Interception evaporation / Snow evaporation [mm d⁻¹]
- EB: Transpiration / Soil evaporation [mm d⁻¹]
- R0: Surface runoff [mm d⁻¹]
- R1: Interflow [mm d⁻¹]
- R2: Total baseflow [mm d⁻¹]
- RGEN: Total runoff [mm d⁻¹]

- SSNO: Snow water equivalent [mm]
- SI: Interception storage [mm]
- SSM: Plant available soil moisture storage [mm]
- SUZ: Runoff generation storage (unsaturated zone) [mm]
- SLZ: Runoff generation storage (saturated zone) [mm]
- BIL: Balance from previous time step [mm d⁻¹] [mm]
- GLAC: Icemelt [mm d⁻¹]
- RG1: Fast response baseflow [mm d⁻¹]
- RG2: Slow response baseflow [mm d⁻¹]
- RG3: Third component baseflow [mm d⁻¹]
- DIFGA: Input to DIFGA [mm d⁻¹]

*.mit file: Header and columns 1–14

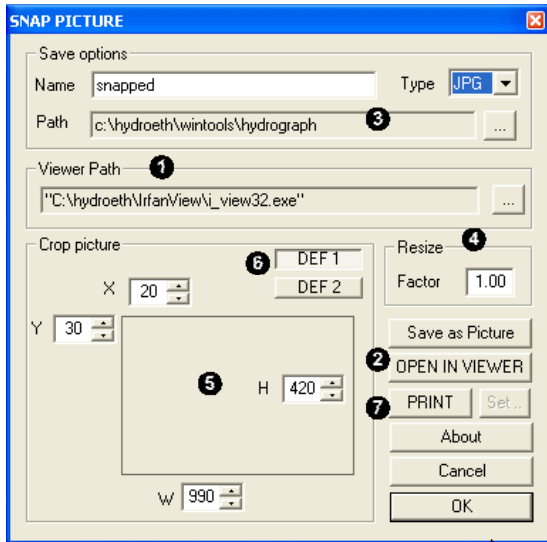
YYYY	MM	DD	P-uk	P-kor	P-SME	EPOT	EREA	EI	EB	RO	R1	R2	RGES
1983	1	1	0	0	0	0.259	0.085	0	0.085	0	0.05	12.6	12.65
1983	1	2	1.593	1.916	0	0.55	0.235	0.114	0.121	0	0	12.48	12.48
1983	1	3	5.714	6.484	1.641	0.003	0.003	0.002	0.001	0	0.1	12.37	12.47
1983	1	4	4.678	5.847	0.844	0.033	0.033	0.029	0.004	0	0.21	12.28	12.49
1983	1	5	17.804	21.259	7.491	0.147	0.147	0.142	0.004	0.06	1.62	12.19	13.87
1983	1	6	0	0	4.561	0.217	0.164	0.128	0.035	0	2.72	12.13	14.85
1983	1	7	4.324	5.088	0.517	0.234	0.227	0.214	0.013	0	2.34	12.07	14.42
1983	1	8	0.791	0.97	0	0.044	0.044	0.044	0	0	1.14	12.01	13.15
1983	1	9	0	0	0.001	0	0	0	0	0	0.39	11.94	12.33

*.mit file: Columns 15–25

S-SNO	SI	SSM	SUZ	SLZ	BIL	GLAC	RG1	RG2	RG3	DIFGA
0	0	6.83	0.17	1304.99	0	0	0.02	12.58	0	0
1.34	0.37	6.71	0.17	1292.51	0.08	0	0.02	12.46	0	0.53
5.95	0.42	6.79	1.12	1280.7	0.11	0	0.03	12.34	0	1.76
10.37	0.42	6.82	1.32	1269.39	0.01	0	0.06	12.22	0	1.42
20.9	0.5	6.87	8.41	1258.56	0.32	0	0.09	12.11	0	10.35
16.34	0.37	6.85	8.03	1248.36	0.27	0	0.14	11.99	0	4.84
20.52	0.42	6.85	4.6	1238.24	-0.22	0	0.2	11.88	0	0.72
21.49	0.42	6.85	2.01	1227.85	-0.23	0	0.25	11.76	0	0.01
21.5	0.42	6.85	0.47	1217.15	-0.09	0	0.29	11.65	0	0

G.5 Capturing and saving images

In connection with the freeware picture viewer Irfanview (<http://www.irfanview.com/>), HYDROGRAPH allows the capturing, viewing and printing of screenshots for the displayed hydrograph. To load a screenshot of the main dialog in the clipboard, click the [Snap picture] button. To subsequently edit the content of the clipboard, click the [Edit picture] button. A new dialog is prompted.



Usage:

At first use, link the SNAP PICTURE plug-in with Irfanview [Viewer Path] (1).

To export the content of the clipboard to Irfanview, click [OPEN IN VIEWER] (2).

To save the content of the clipboard as a file, select a path where the pictures will be stored and provide a name for the picture (3). Select then the type of the picture you want to save (choose between JPG, GIF, BMP, PCX, PNG, TIFF formatting). Then click the [Save as Picture] button (2).

To print the content of the clipboard to the default printer, click [PRINT] (7).

Editing options:

You may resize the picture stored in the clipboard by changing the resize factor field (4). Factors between 0.1 and 5 are recommended.

To cut undesired portions from the screenshot stored in the clipboard, you may specify the extent (in pixels) of the picture portion you would like to view in Irfanview or save as a picture (5). Select the X and Y pixels where the cropping of the picture has to start (e.g. X=20 pixels, Y=30 pixels) and the width (W) and height (H) of the portion of the picture you want to crop.

Example: Original Dimension of the Picture: 1014x680 pixels.

Start crop from X=20 and Y=30 pixels, for a width of 990 and height of 420 pixels.

The final picture will contain the pixel range X=[20, 1010] and Y=[30, 450].

The current settings of the crop option (5) are stored automatically in an initialisation file. Two different settings may be saved. The first default setting is loaded and updated when the [DEF 1] button is activated. The second default setting is loaded and updated when the [DEF 2] button is activated (6).

H WINGRID: Visualisation of grid raster files

H.1 Introduction

The management of digital representations of spatially distributed physiogeographical information is an important requirement for the development, parameterisation and initialisation of spatially distributed hydrological models such as PREVAH. The grid raster files involved in modelling and preprocessing are stored in a specific format (see below). While it may also be processed with commercial GIS software after conversion to a suitable import format, WINGRID is intended for quick display and rudimentary editing of PREVAH raster data.

H.2 Binary format

The PREVAH modelling system uses a straight-forward binary grid format. It is structured similarly to the widespread ASCII-format (see below). All values are stored in single precision (4 bytes in most computer systems, 6..7 digits precision). Records 1 to 6 correspond to the data of the ASCII format, followed by 6 additional records describing the grid statistics:

Records 1...6:

- Grid header with number of columns and rows
- Co-ordinates of the lower left corner
- Cell size
- NoData value

Records 7...12:

- Count of valid cells (without NoData-values)
- Minimum value of all valid grid cells
- Maximum value of all valid grid cells
- Sum of all valid grid cells
- Mean value of all valid grid cells
- Standard deviation of all valid grid cells

Following this header, all cells of the grid are listed from the top left cell to the lower right cell in a row by row order.

In order to exchange grids between different computer platforms and transfer grids to other software, e.g. with ArcInfo, an ASCII-format is required. The tool GRIDMATH (see particular documentation) is available for converting the various formats. ASCII-formats can be exchanged between different systems using e.g. ftp-programs with an automatic conversion of carriage returns/line feeds. To exchange binary data, they first have to be converted into ASCII-data, subsequently the exchange can be completed and then a re-converting on the target platform should be performed.

An ASCII-formatted file will look as follows when opened in a text editor:

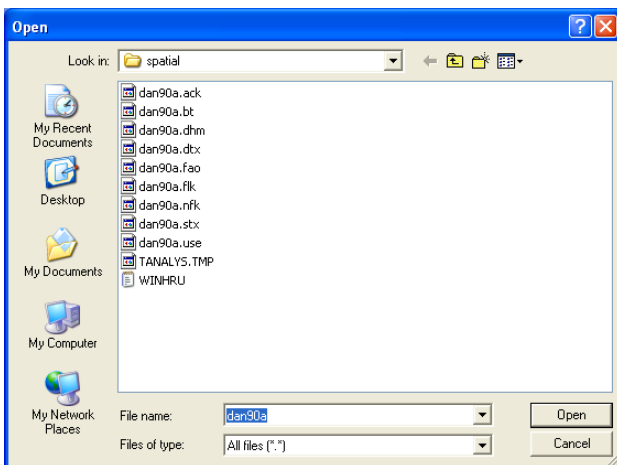
```
ncols      7
nrows     12
xllcorner 680500
yllcorner 222200
cellsize  2000
NoData_value -9999
-9999    -9999    -9999    -9999    -9999    -9999
-9999    -9999    -9999    -9999    -9999    -9999
-9999    -9999    586      559      595      601      585
584      -9999    -9999    -9999    -9999    -9999    -9999
-9999    449      -9999    -9999    454      511      551
-9999    561      529      509      498      487      499
521      523      523      534      -9999    -9999    -9999
-9999    -9999    -9999    -9999    -9999    -9999    -9999
-9999    -9999    -9999    -9999    -9999    345      234
567      453      456      478      789      576      482
123      -9999    1252    1211    876      564      825
-9999    -9999    234      1246    -9999    -9999    -9999
```

H.3 Basic features

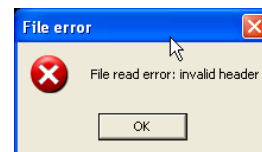
WINGRID is used for:

- Displaying grids in the binary format used by the PREVAH modelling system and ASCII grid format defined above.
- 2D and 3D visualisation.
- Editing grid cell values.
- Exporting binary grids to a standard ArcInfo ASCII grid format.
- Exporting binary grids to IDRISI raster format.
- Capturing and managing screenshots with the freeware picture viewer Irfanview.

H.4 Start-up



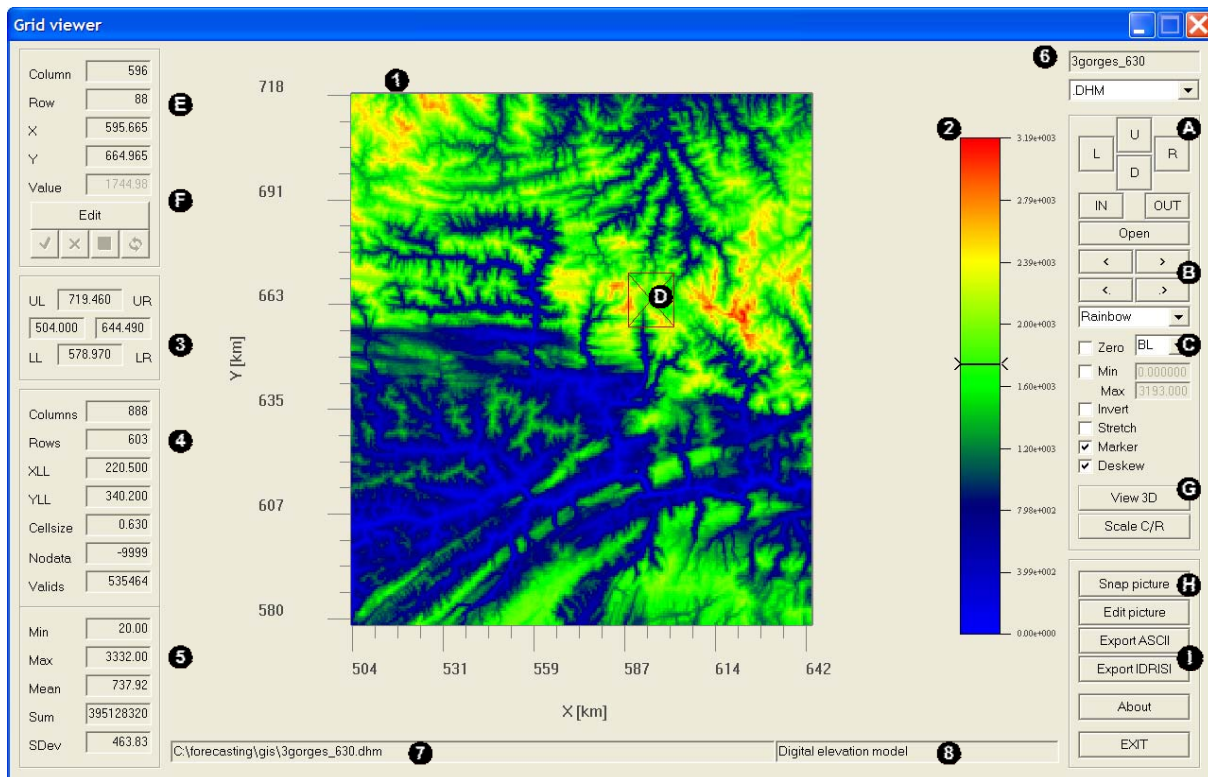
After launching WINGRID, a file open dialog is prompted automatically. Choose a grid to display and click [Open]. If the selected file does not meet the format requirements, a warning shows the particular file error, e.g.:



A void grid is displayed. By clicking [Open], the file open dialog is displayed again and you may choose another file.

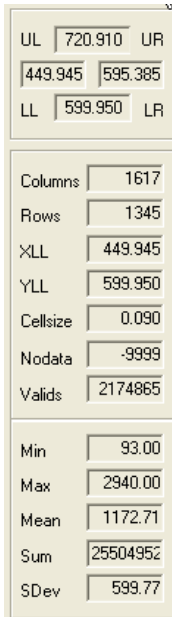
H.5 Main dialog

The following screenshot shows the main dialog of WINGRID.



- Legend:*
- ① Plotting area
 - ② Palette / legend
 - ③ Grid domain, co-ordinates in kilometres
 - ④ Grid properties
 - ⑤ Basic grid statistics
 - ⑥ File name and list box of recognised grids with same file root name
 - ⑦ Path of the current file
 - ⑧ Description of the current file (only for recognised grid extensions)
 - Ⓐ Navigation buttons
 - Ⓑ File-change buttons
 - Ⓒ Visualisation options
 - Ⓓ Point selection marker
 - Ⓔ Location and value of the marked grid cell
 - Ⓕ Grid editor
 - Ⓖ View options
 - Ⓗ Capture screenshot
 - Ⓘ Export grid

H.6 Grid info and standard visualisation options



In the left part of the main dialog, information on the displayed grid is shown.

- ③ The grid domain is defined by the lowest y co-ordinate (in the example 599.950 km), highest y co-ordinate (720.910 km), leftmost x co-ordinate (449.945 km) and rightmost x co-ordinate (595.385 km). These co-ordinates are obtained from the grid settings.
- ④ Grid settings include: Number of rows, number of columns, lower left corner x co-ordinate (449.945 km), lower left corner y co-ordinate (599.950 km), cell size (0.090 km), NoData value (voids, -9999) and the number of valid grid cells (i.e. all cells excluding NoData cells). For combining grids with PREVAH-tools (such as GRIDMATH), it is imperative that all grids are stored in the same format, resolution and extent (same number of columns and rows, co-ordinates, cell spacing and No-Data value).
- ⑤ For all valid grid elements in the displayed domain, basic grid statistics are shown: Minimum (Min), maximum (Max), average (Mean), summation (Sum) and standard deviation (SDev).



In the upper right part of the main dialog, the name and extension of the current file are displayed (⑥). The path (⑦) and description (⑧) of the current file are shown in the bar located in the lowermost part of the dialog (see main dialog window). In the dropdown list box, a list of other recognised extensions may be available. These are grid types that have the same file root name as the currently displayed file (in the example dan90a) located in the current directory (⑦). The example shows that besides the file dan90a.dhm, WINGRID also recognised the files dan90a.ack, dan90a.btm, dan90a.flk, dan90a.nfk and dan90a.use. Extensions which are not recognised are not listed in this box; a list of recognised grid extensions with their corresponding description is provided in the Appendix.

- Ⓐ To navigate within the displayed grid, the following options are provided (Ⓐ).



To zoom in, simply click the [IN] button. To focus the zoom on a particular area of the grid you may first move the marker (Ⓔ, see further below) by double-clicking on the part of the grid you want to zoom in. After zooming in, it is possible to move the focus left click [L], right [R], up [U] or down [D]. To zoom out, click the [OUT] button.



- Ⓑ Several options are available to change to another grid file:
 - Click [Open] and select a grid from your file system.
 - Select an extension from the list-box ⑥.
 - Switch to the previous [<.] or next [.>] grid with same file root name, but different extension.
 - Switch to the previous [<] or next [>] grid with same extension, but different file root name.



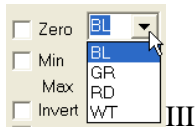
Ⓒ

Some visualisation options are controlled by the main dialog (ⒸI):

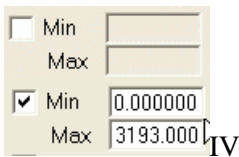
1. Change the colours of the palette (ⒸII). Six standard colour ramps are implemented (ⒸII): Blue-Cyan, Blue-White, Greyscale, Rainbow (Default), Red-Green and Red-White. The orientation of the ramp may be inverted by activating the [Invert] check-box.
2. Stretch the data to full palette scale by activating the [Stretch] check-box. Data minimum and maximum values are then used for palette minimum and maximum.
3. Change the background colour of NoData values (ⒸIII). First activate the [Zero] check-box, then choose a colour. Select BL for black, GR for green, RD for red and WT for white.
4. If you want to assign a specific minimum and maximum to the palette, activate the [Min/Max] option (ⒸIV) and enter the desired values for the minimum and maximum. All values outside the specified range will be displayed with the minimum (below range) or maximum (above range) colour, respectively.
5. Deskew the grid visualisation. If the option deskew is checked (default), the aspect-ratio of the grid is preserved and the scaling is fitted so that the resolution of the horizontal axis is identical with the vertical axis. If deskew is not checked, the grid is fitted to the full Plotting Area and the aspect-ratio is broken (different resolution in x and y directions)



II

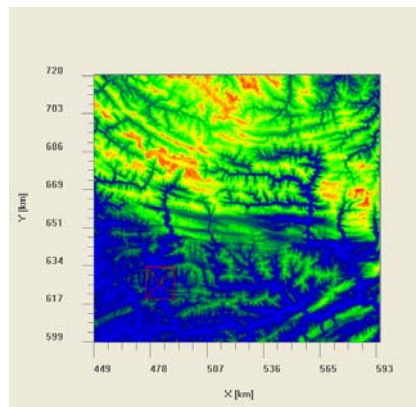


III

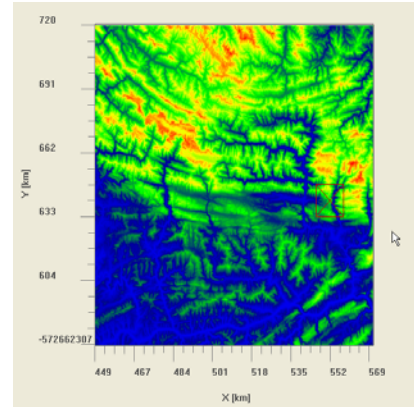


IV

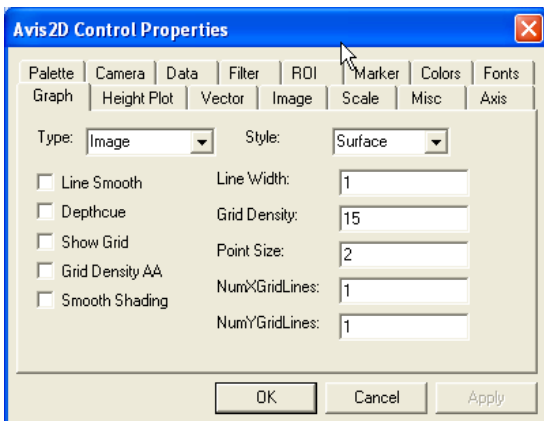
Deskew checked



Deskew unchecked



H.7 Additional visualisation options

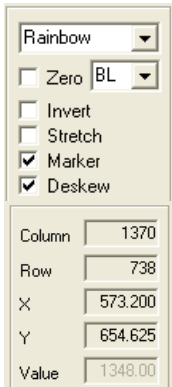


With a right-button click on the Plotting Area, the Array Visualiser Properties Dialog is accessed.



This allows the controlling of several additional plotting options. The consultation of the Compaq Array Visualiser documentation is advisable for understanding the meaning of all the available features. You may also take some time to try all the options to understand how they work.

H.8 Grid cell options

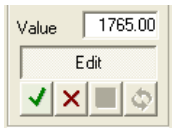


Ⓔ

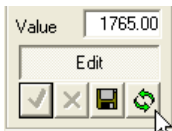
A red marker, Ⓔ on the main Grid Viewer dialog above, is activated by default. To move the marker, simply double-click a cell within the displayed domain. The selected cell may be used to control the zoom-in operation (see above). Uncheck the marker box to deactivate the marker.

In the upper left area, the attributes of the selected grid cell are displayed (Ⓔ). The attributes consist of the column, row, x co-ordinate (in km), y co-ordinate (in km) and value of the selected grid cell.

The value of the grid cell may be edited by activating the edit mode (click [Edit], Ⓔ) and entering the new value for the grid cell in the value field. To accept the changes applied, click the OK button [✓]. To discard them, click the cancel button [✗].

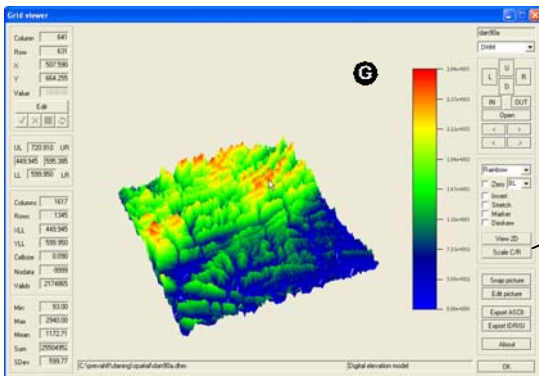


After accepting changes, you may still choose whether to store the changed grid (click the save button [floppy disk]) or to restore the original grid (click the reload button, [refresh]).



This edit operation may prove very useful to amend a digital elevation model when the digitally derived river network differs considerably from reality. Such errors are common in flat parts of a landscape and if the resolution is too low.

H.9 3D-Visualisation



The grids may also be displayed as 3-dimensional surfaces. To switch to 3D-view, click the [View 3D] button.



To adjust the scale of the z-axis, access the Array Visualiser Properties Dialog and edit the option [Scale]. To return to the 2D visualisation click the same button.

H.10 Axis Co-ordinates

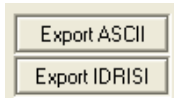
The x and y axis labels may be displayed in kilometric co-ordinates (default) or column and row numbers, respectively. To switch to column/row labels click the button [Scale C/R]. To change back to kilometric co-ordinates click the same button again (now named [Scale [km]]), see below).



H.11 Capturing and saving images

In connection with the freeware picture viewer Irfanview, WINGRID allows capturing, viewing and printing of screenshots of the displayed grid. This has already been described in Section G.5.

H.12 Export grids to other GIS formats



WINGRID allows the conversion of binary grids into two standard GIS formats:

- ArcInfo ASCII grid format
- IDRISI raster format

To export the grids, click the appropriate button and provide a filename in the appearing file save dialog.

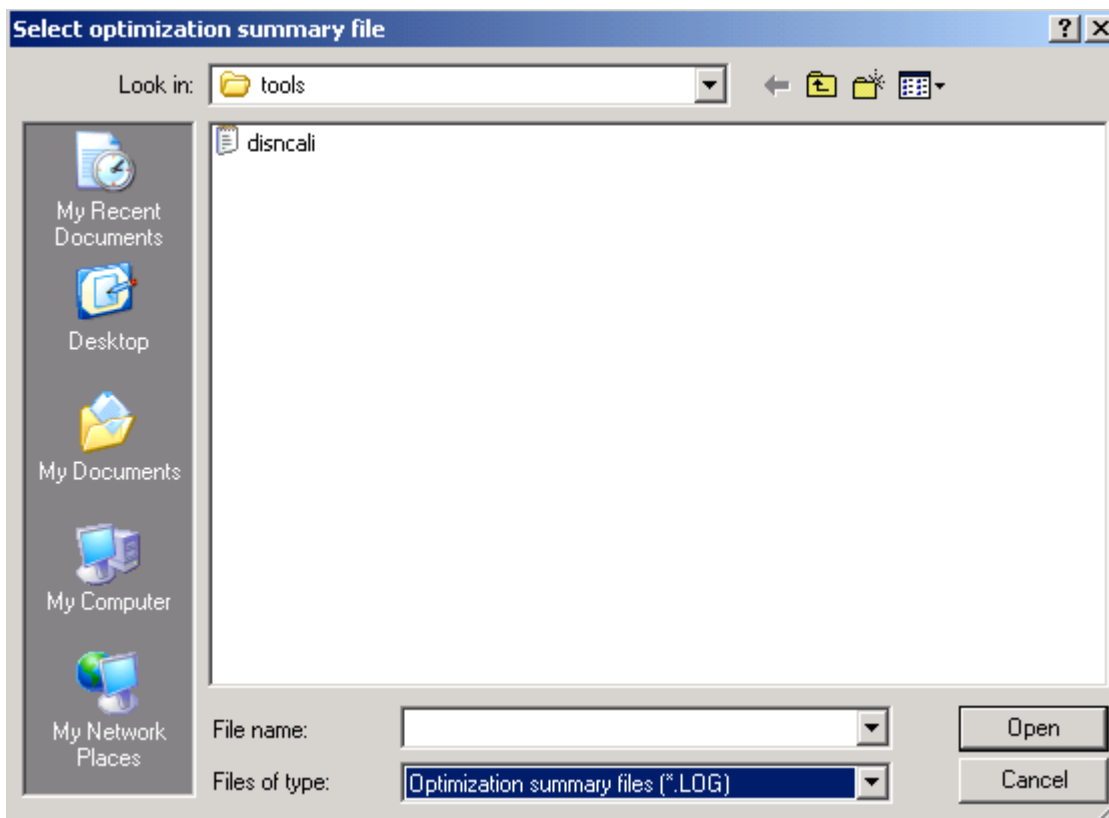
I VIEWOPTIM

I.1 Program description

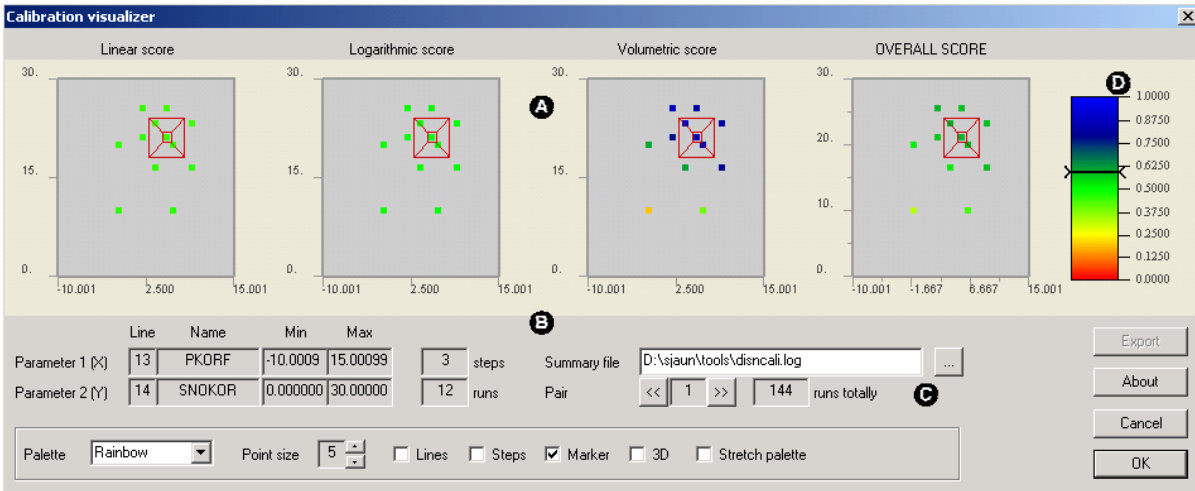
During an automatic calibration of WINPREVAH, the intermediate results are written to a summary file. This output may be visualised with the program VIEWOPTIM. It shows the gradual pair-wise optimisation process of the parameters and offers different settings to adjust the plotting to specific needs.

I.2 Start-up

VIEWOPTIM is started by double-clicking the corresponding icon in the program launcher or the file viewoptim.exe. The following file-open dialog will be displayed:



Select a data directory and choose the summary file to display.



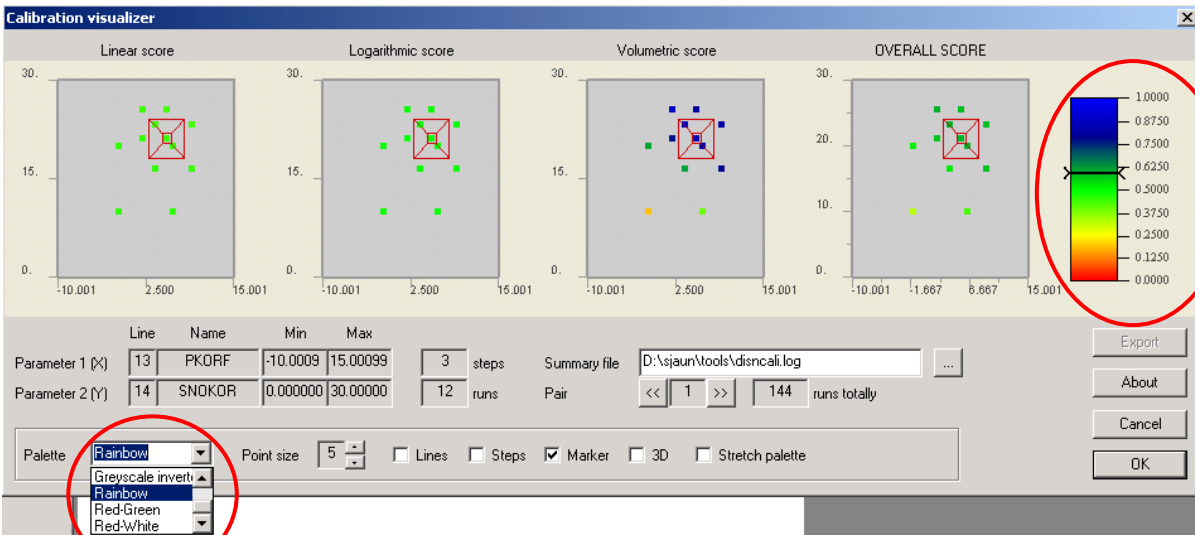
- Legend:**
- A** Plotting area
 - B** File and parameter display
 - C** View options
 - D** Colour palette

Plotting area

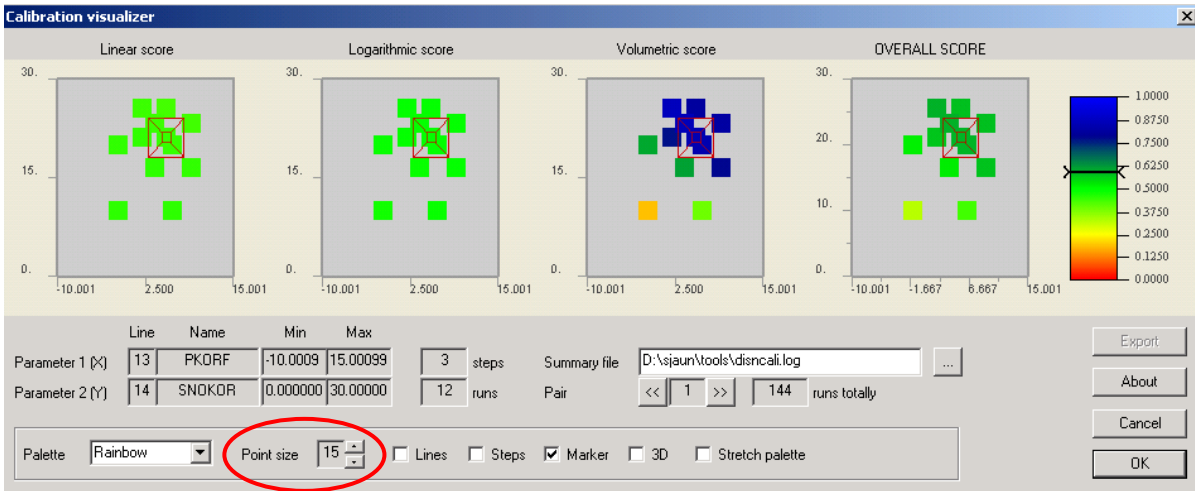
The plotting area is divided into 4 sections which show the course of different scores during calibration. The scores are from left to right: Linear score, logarithmic score, volumetric score, and the overall score, which combines the three preceding scores.

View options

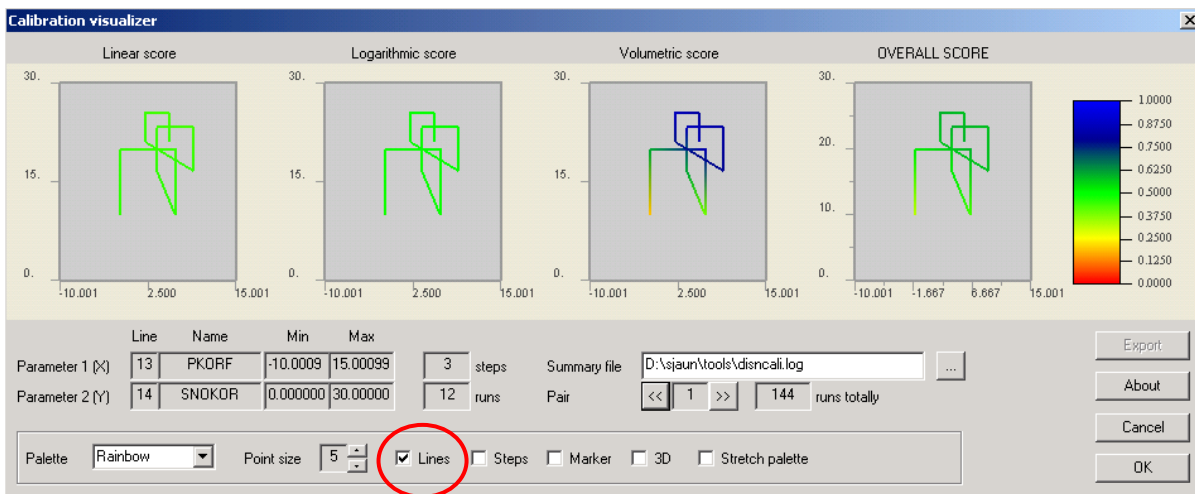
As an initial setting, the data marker is placed at the end-point of the calibration process.



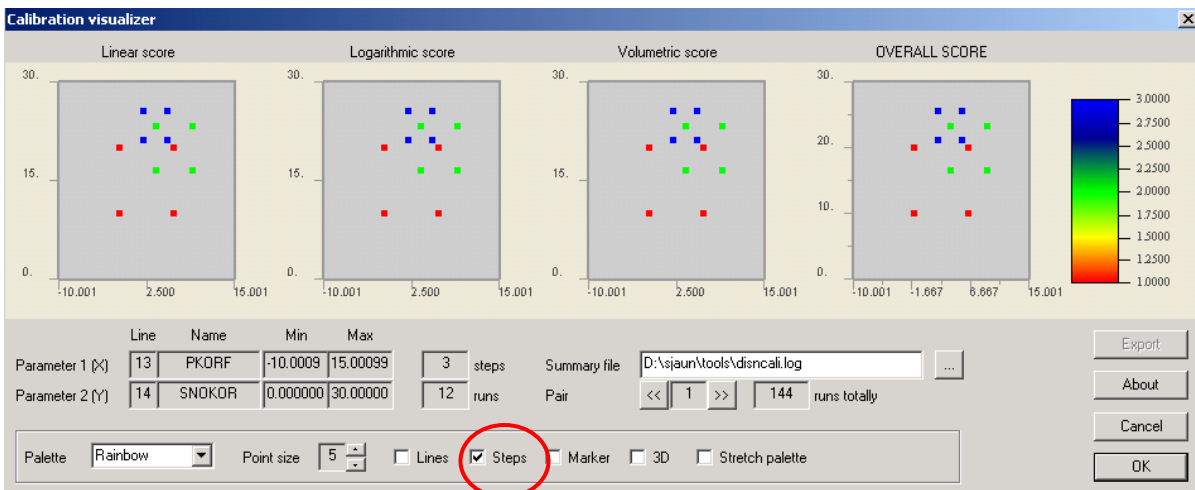
Different types of colour palettes may be chosen. On the right side of the main window, the corresponding colour palette is shown with the assigned values.



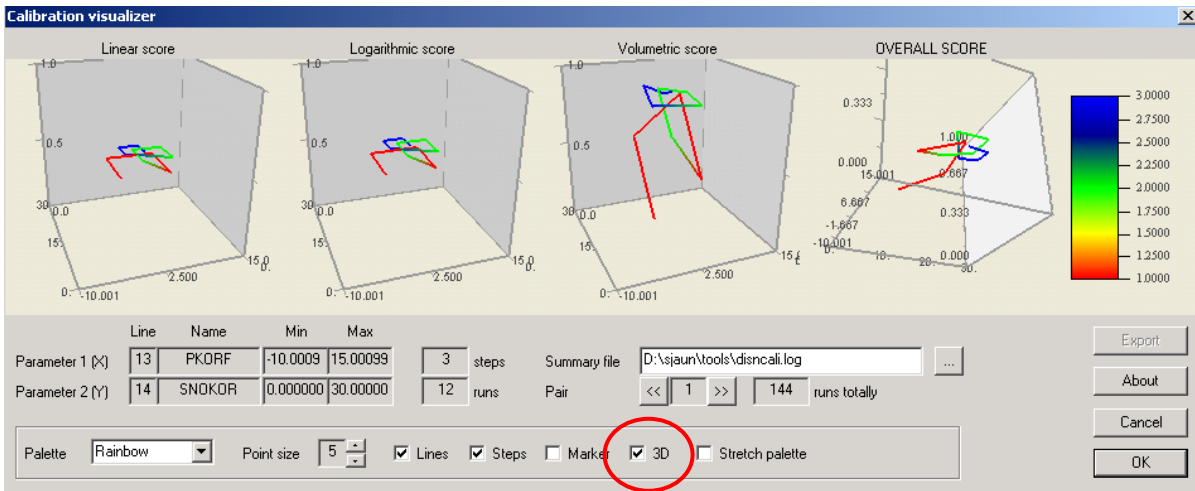
The point size may be varied from 1 to 20, the initial value is 5.



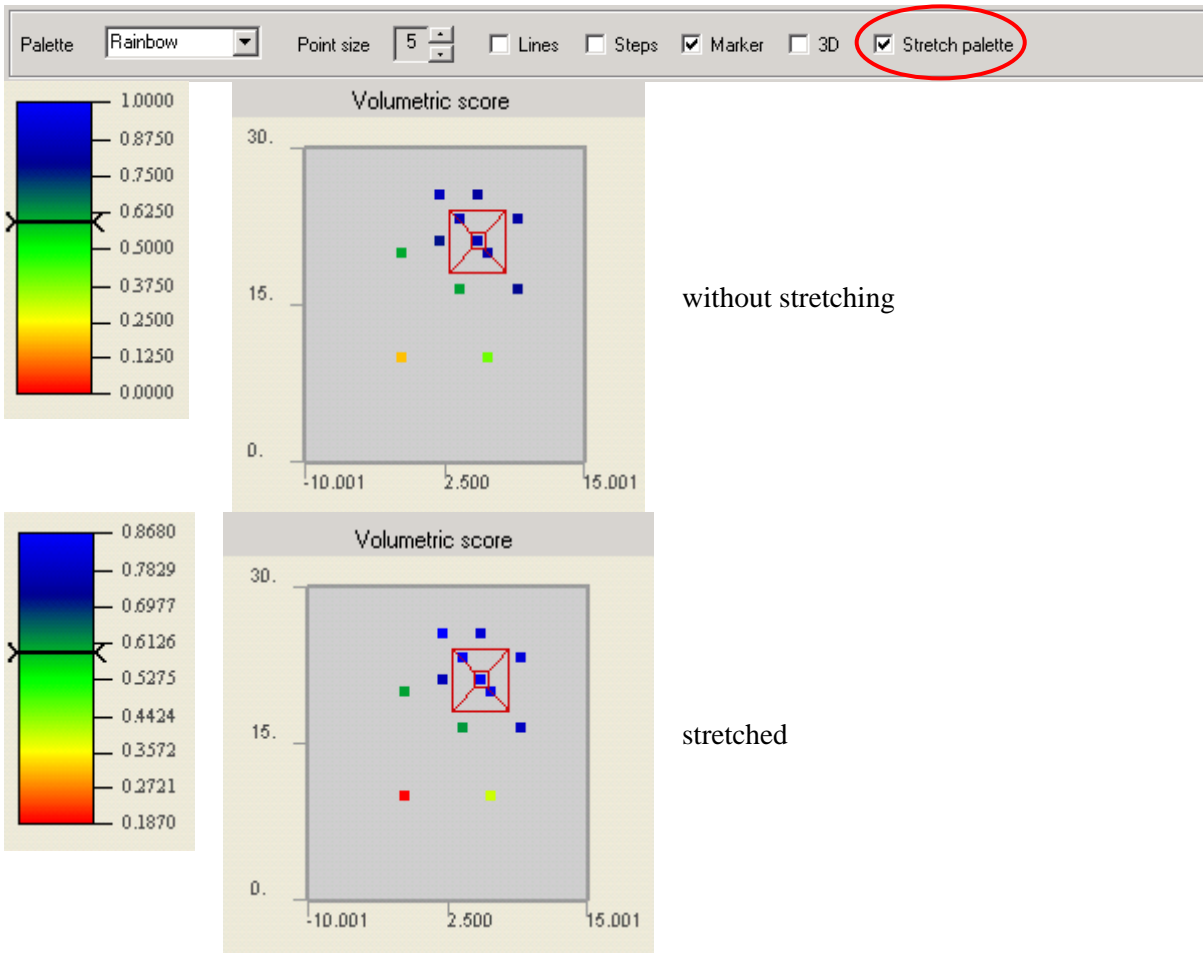
It is possible to connect the optimisation steps (points) with a line, which gives a better impression of the optimisation process.



The steps may be coloured individually in a separate colour.



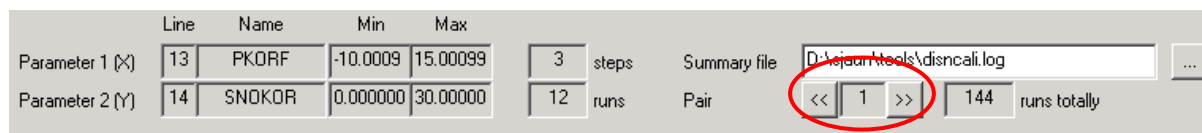
The 3D-plot is especially useful in combination with other settings like step colouring or lines; the 3D-plots may be turned with help of the mouse to change the perspective.



The Stretch palette option adjusts the colour palette to the actual data range.

Parameter pairs

The parameter optimisation is always completed for two parameters simultaneously. The display of parameter pairs in VIEWOPTIM depends on the respective settings that were used during the calibration with PREVAH.



Use the arrow buttons ([<<] / [>>]) to switch between the different parameter pairs.

Values which PREVAH protocols during calibration

The automatic calibration of WINPREVAH generates an optimisation summary file which shows the pair-wise optimisation process of the parameters. This output can be visualised using VIEWOPTIM as described above.

Log file of a calibration as interpreted by VIEWOPTIM

ITER	STEP	RUN	LINE1	LINE2	PAR1	PAR2	ALIN	ALOG	ADST	ATOT
1	1	1	13	14	-.1667E+01	0.1000E+02	0.452	0.475	0.187	0.322
1	1	2	13	14	-.1667E+01	0.2000E+02	0.449	0.482	0.603	0.516
1	1	3	13	14	0.6667E+01	0.1000E+02	0.452	0.481	0.393	0.436
1	1	4	13	14	0.6667E+01	0.2000E+02	0.444	0.486	0.841	0.589
1	2	1	13	14	0.3889E+01	0.1667E+02	0.450	0.484	0.611	0.520
1	2	2	13	14	0.3889E+01	0.2333E+02	0.441	0.486	0.859	0.593
1	2	3	13	14	0.9444E+01	0.1667E+02	0.446	0.486	0.781	0.573
1	2	4	13	14	0.9444E+01	0.2333E+02	0.434	0.488	0.814	0.578
1	3	1	13	14	0.2037E+01	0.2111E+02	0.446	0.485	0.769	0.569
1	3	2	13	14	0.2037E+01	0.2556E+02	0.438	0.486	0.868	0.594
1	3	3	13	14	0.5741E+01	0.2111E+02	0.443	0.486	0.847	0.590
1	3	4	13	14	0.5741E+01	0.2556E+02	0.433	0.487	0.807	0.576
2	1	1	15	16	-.3333E+00	0.5000E+00	0.443	0.488	0.861	0.595
2	1	2	15	16	-.3333E+00	0.1000E+01	0.444	0.489	0.879	0.601
2	1	3	15	16	0.3333E+00	0.5000E+00	0.436	0.484	0.843	0.586
...
10	1	4	38	39	0.2833E+01	0.2167E-03	0.442	0.495	0.983	0.630
10	2	1	38	39	0.2444E+01	0.1889E-03	0.442	0.495	0.977	0.628
10	2	2	38	39	0.2444E+01	0.2444E-03	0.442	0.495	0.981	0.629
10	2	3	38	39	0.3222E+01	0.1889E-03	0.442	0.496	0.985	0.630
10	2	4	38	39	0.3222E+01	0.2444E-03	0.443	0.496	0.987	0.631

In more detail, a log file (*.log), written by the automatic calibration routine, serves as input for VIEWOPTIM. The file's contents are as follows: The first column shows the iteration number. For every parameter pair, an iteration takes place. Each iteration consists of several steps (second column), the number of steps may differ between each iteration completed. The steps again consist of several model runs (third column). The number of runs may vary from iteration to iteration, but not between the steps and iteration. Columns four and five identify the two parameters that constitute the parameter pair through their respective line number in the PREVAH control file. PAR1 and PAR2 show the actual parameter values for every run. ALIN represents the linear, ALOG the logarithmic efficiency score, ADST is the volume score and ATOT the combined overall score.

A short version of this file (*.best) logs only the best run (i.e. the one with the highest total score, see Chapter 6.3.2 in Part II of the PREVAH documentation) of each step within an iteration.

Table: Best file (.best), as a summary to the optimisation logging file (*.log)*

Syntax

ITER	STEP	RUN	LINE1	LINE2	PAR1	PAR2	ALIN	ALOG	ADST	ATOT
1	1	4	13	14	0.6667E+01	0.2000E+02	0.444	0.486	0.841	0.589
1	2	2	13	14	0.3889E+01	0.2333E+02	0.441	0.486	0.859	0.593
1	3	2	13	14	0.2037E+01	0.2556E+02	0.438	0.486	0.868	0.594
2	1	2	15	16	-.3333E+00	0.1000E+01	0.444	0.489	0.879	0.601
...
10	1	4	38	39	0.2833E+01	0.2167E-03	0.442	0.495	0.983	0.630
10	2	4	38	39	0.3222E+01	0.2444E-03	0.443	0.496	0.987	0.631

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Appendix

Topographical analysis output.

Box to be Checked	Extension	Explanation
[Curvature]	.cur	Curvature
[Flow Correction]	.ack	Corrected flow accumulation
[Flow Correction]	.dhk	Corrected elevation model
[Flow Correction]	.flk	Corrected flow direction
[Flow Correction]	.nuk	Corrected river order
[Flow Correction]	.ork	Corrected river number
[Flow Correction]	.sin	Sinks
[Flow Separation]	.m##	Mouths of ## order
[Flow Times]	.dep	Stream depth
[Flow Times]	.fzt	Flow times
[Flow Times]	.wit	Stream width
[Horizont]	.hor	Horizon
[Plancurvature]	.plc	Plancurvature
[Profilcurvature]	.prc	Profilcurvature
[River Network]	.lin	Stream network
[River Order]	.num	River number
[River Order]	.ord	River order
Default	.acc	Flow accumulation
Default	.dhm	Digital elevation model
Default	.exp	Aspect
Default	.fld	Flow direction
Default	.slp	Slope

Recognised grid extensions.

ABB	Soil-topographic index	LN5	5th order streams
ABK	Soil-topographic index, classified	LNK	Routing network
ACC	Flow accumulation	M01	1st order stream pour point
ACK	Flow accumulation, corrected	M02	2nd order stream pour point
ART	Soil type	M03	3rd order stream pour point
ATB	Hydraulic-topographic index	M04	4th order stream pour point
ATK	H.-topographic index, classified	M05	5th order stream pour point
AZM	Help grid for aspect averaging	MEZ	Meteo zones
BIN	Binary grid (generic)	NAS	Nutrients content
BOS	Soil moisture storage	NFK	Soil water storage, classified
BT	Soil depth, classified	NUK	Stream numbering, corrected
BTK	Soil depth [m]	NUM	Stream numbering
DEP	Stream depth	ORD	Stream order
DHK	DEM with filled sinks	ORK	Stream order, corrected
DHM	Digital elevation model	PAT	Soil type, classified
E01	1st order catchments	PFC	Soil water storage capacity [%]
E02	2nd order catchments	PHK	Altitude, classified
E03	3rd order catchments	PRC	Precipitation
E04	4th order catchments	PUR	Pour points
E05	5th order catchments	PUS	Land use, classified
ETP	Potential evapotranspiration	RGS	Total runoff
ETR	Actual evapotranspiration	SCS	Snow storage
EXK	Aspect, classified	SID	Cell IDs
EXP	Aspect [°]	SIN	Sinks
EZG	Catchment	SKE	Portion of stones, classified
FLD	Flow direction	SLK	Slope, classified
FLK	Flow direction, corrected	SLP	Slope [°]
FZS	Flow time sums	SWA	Melt water runoff
FZT	Flow times	TRP	Transpiration
GEO	Geotopes	USE	Land use
GLM	Glacier morphology	WIT	Stream width
GWL	Glacier equilibrium line altitude	ZS1	1 st order streams flow time sums
HGL	Hydrogeology	ZS2	2 nd order streams flow time sums
HRU	HRU codes	ZS3	3 rd order streams flow time sums
IDH	Identifier of the HRUs	ZS4	4 th order streams flow time sums
INS	Interception storage	ZS5	5 th order streams flow time sums
K	Hydraulic conductivity, classified		
KMS	Hydraulic conductivity [m s ⁻¹]		
KWT	Hydraulic conductivity [mm h ⁻¹]		
LIN	Stream network		
LN1	1 st order streams		
LN2	2 nd order streams		
LN3	3 rd order streams		
LN4	4 th order streams		



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