**WASA-SED**

**User Manual**

Eva Nora Müller, Till Francke, George Mamede and Andreas Güntner

**30.1.2018**

**WASA-SED rev. 255**

Developed within the SESAM-Project:

Sediment Export of Semi-Arid Catchment: Monitoring and Modelling 2005-2008

SESAM II 2010-2014,

2015-2018

Institute of Earth and Environmental Science, University of Potsdam, Potsdam,

Deutsches Geoforschungszentrum Potsdam,

Germany

**Recent change: snow module (“WASA-SNOW” by Erwin Rottler)**

The respective documentation has not been included yet. It can be found in Rottler’s thesis (on request, to be published on https://publishup.uni-potsdam.de/opus4-ubp/home)

Updates of WASA-SED Manual (this file):

<https://github.com/TillF/WASA-SED>

Source-code (Fortran90) git-repository:

<https://github.com/TillF/WASA-SED>

Theoretical description of the WASA-SED model:

Mueller EN, Güntner A, Francke T, Mamede G (2010) Modelling sediment export, retention and reservoir sedimentation in drylands with the WASA-SED model. *Geosci Model Dev* 3:275–291. doi:10.5194/gmd-3-275-2010. <http://www.geosci-model-dev.net/3/275/2010/>

Information about the SESAM-Project:

<http://uni-potsdam.de/sesam/>

Contact:

Till Francke

Institute of Earth and Environmental Sciences

University of Potsdam

Karl-Liebknecht-Str. 24-25

14476 Potsdam, Germany

Email: till.francke@uni-potsdam.de

Copyrights and ownership:

For the original WASA code: Andreas Güntner, Geoforschungszentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany.

For all extensions of WASA-SED: SESAM-project team, University of Potsdam, 14476 Potsdam, Germany.

\* Creative Commons Attribution 4.0 International License

Disclaimer:

The WASA-SED program is large and complex and extensive knowledge of its design, purpose, and limitations is required in order to apply it properly. The WASA-SED and its source code is freely available under a CC4 licence (“use as you wish, don’t blame us, give credit,…”). See license.txt.

**Table of Content**

[Introduction 4](#__RefHeading__29_804869012)

[Program folders and structure 4](#__RefHeading__31_804869012)

[Hillslope module 5](#__RefHeading__33_804869012)

[River module 6](#__RefHeading__35_804869012)

[Reservoir module 7](#__RefHeading__37_804869012)

[Input Data 8](#__RefHeading__39_804869012)

[General parameter and control files 10](#__RefHeading__41_804869012)

[Input files for the hillslope module 13](#__RefHeading__43_804869012)

[Input files for the river module 24](#__RefHeading__45_804869012)

[Input files for the reservoir module 27](#__RefHeading__47_804869012)

[Input of climate data 36](#__RefHeading__49_804869012)

[Output Data 37](#__RefHeading__51_804869012)

[Output of the hillslope module 37](#__RefHeading__53_804869012)

[Output of the river module 38](#__RefHeading__55_804869012)

[Output of the reservoir module 39](#__RefHeading__57_804869012)

[Relevant Literature for the WASA-SED Model 46](#__RefHeading__59_804869012)

[Reference 47](#__RefHeading__61_804869012)

Introduction

The WASA-SED model simulates the runoff and erosion processes at the hillslope scale, the transport processes of suspended and bedload fluxes at the river scale and the retention and remobilisation processes of sediments in large reservoirs. The modelling tool enables the evaluation of management options both for sustainable land-use change scenarios to reduce erosion in the headwater catchments as well as adequate reservoir management options to lessen sedimentation in large reservoirs and reservoir networks. The model concept, its spatial discretisation and the numerical components of the hillslope, river and reservoir processes are summarised and current model applications are reviewed in Mueller *et al.* (2008). The hydrological routines of the model are based on the WASA model (Model for Water Availability in Semi-Arid environments), which was developed by Güntner (2002) and Güntner and Bronstert (2002, 2003) to enable the quantification of water availability in semi-arid regions. The WASA-SED model was developed within the joint Spanish-Brazilian-German research project SESAM (Sediment Export from Semi-Arid Catchments: Measurement and Modelling). The existing WASA model code has been extended to include sediment-transport routines for the three new conceptual levels of the WASA-SED model: the hillslope scale, river scale and the reservoir scale for the calculation of sedimentation. This documentation gives a short outline of the structure, computational routines and folder system of the WASA-SED code in Chapter 2, followed by a description of the input files for model parameterisation in Chapter 3 and output files for the hillslope, river and reservoir modules in Chapter 4.

Program folders and structure

The WASA-SED model is programmed in Fortran 90 and was tested with Compaq Visual Fortran (6.6.a) and gfortran 4.x compilers on Windows gfortran-4.3 under Linux. The WASA-SED code is organised as presented in Table 1**.** The main program is named wasa.f90 and calls the key subroutines as summarised in Table 2.

Table 1 Folder structure of WASA code

|  |  |
| --- | --- |
| **Folder Name** | **Content** |
| \General\ | Main program and utility routines of the WASA model |
| \Hillslope\ | Hillslope routines (Overland, sub-surface flow, evapotranspiration, sediment production etc.) |
| \River\ | River routines (Routing of water and sediment in the river network) |
| \Reservoir\ | Reservoir water and sediment modelling routines (Water balance, bed elevation change, management options) |
| \Input\ | Input data, contains parameter file: do.dat |
| \Input\Hillslope |
| \Input\River |
| \Input\Reservoir |
| \Input\Time\_series |
| \Output\ | Output files of model scenarios |

A complete example input-data set is part of the Subversion repository (see top of document). Model parameterisations are available e.g. for meso-scale catchments in dryland areas of Spain and Brazil (Bengue Catchment in Spain: Mamede 2008, Ribera Salada Catchment in Spain: Mueller *et al.* 2008, Mueller *et al.* submitted to CATENA, Isábena Catchment in Spain: Francke 2009).

The original WASA code version (Güntner 2002, Güntner and Bronstert 2004) was extended within the SESAM-Project to include sediment-transport processes at the hillslope scale using various USLE-derivative approaches, a spatially distributed, semi-process-based modelling approach for the modelling of water and sediment transport through the river network and a reservoir module that computes the transport of water and sediment as well as sedimentation processes in reservoirs.

Table 2 Main subroutines of the main program (wasa.f90)

|  |  |
| --- | --- |
| **Routine** | **Content** |
| readgen.f90 | Reads parameter file: do.dat |
| calcyear.f90 | Counter for time |
| calcday.f90 | Number of days per month |
| climo.f90 | Climate calculations |
| hymo\_all.f90 | Hydrological |
| routing.f90, routing\_new.f90 | Old river routing routine without sediment transport (unit hydrograph)  New river routine with Muskingum and sediment transport, calls reservoir routines |

The following sections give some information on the computational background and the functional structure of the corresponding routines for each of the three conceptual levels: hillslope, river and reservoir.

Hillslope module

The hillslope module comprises the modelling of the hydrological and sediment-transport processes. The hydrological modelling accounts for interception, evaporation, infiltration, surface and subsurface runoff, transpiration and ground water recharge. Details are given in Güntner (2002, Chapter 4). The main hydrological calculations are carried out in hymo\_all.f90 (for daily or hourly time steps). The subroutines that are called within hymo\_all.f90 are summarised in Table 3. The temporal sequence of hydrological process modelling is summarised in Güntner (p. 36-37).

Table 3 Main subroutines of hymo\_all.f90 (hydrological subroutines)

|  |  |  |  |
| --- | --- | --- | --- |
| **Routine** | **Content** | **Subroutine** | **Content of Subroutine** |
| readhymo.f90 | reads input data | soildistr.f90 | distribution functions for soil parameters |
| lake.f90 | water balance for small reservoirs | - | - |
| soilwat.f90 | soil water components (infiltration, percolation, runoff generation) | etp\_max.f90  etp\_soil.f90 sedi\_yield.f90 | maximal evapotranspiration  daily evapotranspiration  hillslope erosion |

Sediment generation on the hillslopes in the form of soil erosion by water is modelled with four erosion equations (USLE, Onstad-Foster, MUSLE and MUST after Williams, 1995). The following subroutines contain the main calculations for the water and sediment production for the hillslopes:

* hymo\_all.f90: general loop in daily or hourly timesteps
  1. Initialisation and reading of hillslope input data, preparation of output files
  2. For each timestep
* nested loop that contains the calculation for hydrological and sediment budgets for each sub-basin, landscape unit, terrain component, soil-vegetation component (soilwat.f90)
* aggregated runoff refers to the whole available area including reservoir areas; the corresponding reservoir areal fraction is substracted afterwards if reservoirs / small reservoirs are considered
* call module for small (diffuse, unlocated) reservoirs (lake.f90)
* write daily results into output files
* soilwat.f90: computes water and sediment balance for a terrain component in a given landscape unit of a given sub-basin

1. For each soil vegetation component (SVCs) in the terrain component:

* calculate hydrological variables (infiltration, surface runoff, subsurface runoff, evapotranspiration, etc.)

1. Re-distribute surface runoff, subsurface runoff among SVCs, allow re-infiltration and compute overall water balance for terrain component
2. Estimate runoff height and peak-runoff using Manning Equation
3. Call module for hillslope erosion (sedi\_yield.f90)

* sedi\_yield.f90: computes sediment production and sediment export for a TC
  1. No sediment export without surface runoff out of terrain component
  2. Otherwise, compute gross erosion for current terrain component using one of four erosion equations
  3. Distribute gross erosion among particle classes according to constitution of uppermost horizons in the current terrain component
  4. Completely mix the newly generated sediment with any sediment coming from upslope terrain components
  5. If necessary, limit sediment export by transport capacity.

River module

The river routing of the original WASA model (Güntner 2002) bases on daily linear response functions (Bronstert *et al.* 1999) similar to a triangular unit hydrograph. Its implementation does not support output in hourly resolution (only daily is produced) and sediment transport. It was extended to include a spatially semi-distributed, semi-process-based modelling approach for the modelling of water and sediment transport through the river network. The implemented water modelling approach is similar to the routing routines from the SWAT model (Soil Water Assessment Tool, Neitsch *et al.* 2002) model and the SWIM model (Soil Water Integrated Modelling, Krysanova *et al.* 2000). The new water routing is based on the Muskingum kinematic wave approximation. Suspended sediment transport and bedload is modelled using the transport capacity concept. The river module can be run with variable time steps. Transmission losses through riverbed infiltration and evaporation are accounted for. The main routing calculations as well as the initialisation and reading of the river input files are carried out in routing.f90. The following sub-routines are called from routing.f90:

* muskingum.f90: contains the flow calculation using the Muskingum method

1. Calculation of water volume in reach

2. Calculation of cross-section area of current flow, flow depth, wetted perimeter and hydraulic radius

3. Calculation of flow in reach with Manning Equation

4. Calculation of Muskingum coefficients

5. Calculation of discharge out of the reach and water storage in reach at end of time step

* routing\_coefficients.f90: contains the calculations for travel time and flow depth

1. Calculation of initial water storage for each river stretch

2. Calculation of channel dimensions

3. Calculation of flow and travel time at 100 % bankfull depth, 120 % bankfull depth and 10 % bankfull depth

* route\_sediments.f90: contains the calculation for suspended sediment-transport routing

1. Calculation of water volume and sediment mass in reach

2. Calculation of peak flow and peak velocity

3. Calculation of maximum sediment carrying capacity concentration

4. Comparison with current concentration

5. Calculation of net deposition and degradation

6. Calculation of sediment mass out of the reach and sediment storage in reach at end of time step

* bedload.f90: contains the calculation for bedload transport using 5 different formulas

1. Calculation of current width of the river
2. Bedload formulas after Meyer-Peter & Müller (1948), Schoklitsch (1950), Smart & Jaeggi (1983), Bagnold (1956) und Rickenmann (2001), see Mueller *et al.* 2008 relevant references

Reservoir module

The reservoir sedimentation routine was included into the WASA-SED model by Mamede (2008) to enable the calculation of non-uniform sediment transport along the longitudinal profile of a reservoir, of the reservoir bed changes caused by deposition/erosion processes and of reservoir management options.

In order to perform the simulation of sediment transport in reservoirs, four important processes have to be considered: (1) reservoir water balance, (2) hydraulic calculations in the reservoir, (3) sediment transport along the longitudinal profile of the reservoir and (4) reservoir bed elevation changes. For the calculation of sediment transport in the reservoir, four different equations for the calculation of total sediment load were selected from recent literature. The reservoir bed elevation changes are calculated through the sediment balance at each cross section, taking into account three conceptual sediment layers above the original bed material. The reservoir sedimentation module is composed by the following subroutines:

* reservoir.f90: contains the reservoir water balance

1. Calculation of reservoir level

2. Calculation of controlled and uncontrolled outflow

* semres.f90: contains the sediment balance for each cross section

1. Calculation of sediment deposition for each cross section

2. Calculation of sediment entrainment for each cross section

3. Calculation of sediment compaction for each cross section

4. Calculation of total load transport

5. Calculation of storage capacity reduction because of the accumulated sediment

6. Calculation of effluent grain size distribution

* sedbal.f90: contains a simplified sediment balance of the reservoir whenever its geometry is not provided (no cross-section)

1. Calculation of sediment deposition in the reservoir

2. Calculation of trapping efficiency

3. Calculation of storage capacity reduction because of the accumulated sediment

4. Calculation of effluent grain size distribution

* hydraul\_res.f90: contains the hydraulic calculations for each cross section in the reservoir

1. Calculation of mean velocity of current flow for each cross section

2. Calculation of hydraulic radius for each cross section

3. Calculation of slope of energy-grade line for each cross section

4. Calculation of top width for each cross section

5. Calculation of water depth for each cross section

* eq1\_wu.f90, eq2\_ashida.f90, eq3\_tsinghua.f90 and eq4\_ackers.f90: each sub-routine contains a specific sediment transport function, mentioned in Table 4

1. Calculation of fractional bed load transport for each cross section

2. Calculation of fractional suspended load transport for each cross section

* change\_sec.f90: contains the calculation of reservoir geometry changes

1. Calculation of bed elevation changes for each cross section.

* reservoir\_routing.f90: contains the calculation of level-pool reservoir routing

1. Calculation of water routing for reservoirs with uncontrolled overflow spillways

* vert\_dist.f90: contains the calculation of vertical distribution of sediment concentration in the reservoir

1. Calculation of sediment concentration at the reservoir outlets

* lake.f90: contains the water balance for networks of small reservoirs

1. Calculation of water level in the reservoirs

2. Calculation of controlled and uncontrolled outflow out the small reservoirs

* sedbal\_lake.f90: contains a simplified sediment balance for networks of small reservoirs

1. Calculation of sediment deposition in small reservoir

2. Calculation of trapping efficiency in small reservoirs

3. Calculation of storage capacity reduction because of the accumulated sediment in small reservoirs

4. Calculation of effluent grain size distribution in small reservoirs

* lake\_routing.f90: contains the calculation of level-pool routing for networks of small reservoirs

1. Calculation of water routing for small reservoirs

Input Data

The model runs as a Fortran console application for catchment from a few km² up to several 100,000 km²) on daily or hourly time steps. Climatic drivers are daily/hourly time series for precipitation, humidity, short-wave radiation and temperature. For model parameterisation, regional digital maps on soil associations, land-use and vegetation cover, a digital elevation model with a cell size of 100 metres (or smaller) and, optional, bathymetric surveys of the reservoirs are required. The soil, vegetation and terrain maps are processed with the LUMP tool (see above) to derive the spatial discretisation into soil-vegetation units, terrain components and landscape units. Table 4 summarises the input parameters for the climatic drivers and the hillslope, river and reservoir modules. The vegetation parameters may be derived with the comprehensive study of, for example, Breuer *et al.* (2003), the soil and erosion parameters with the data compilation of FAO (1993, 2001), Morgan (1995), Maidment (1993) and Antronico *et al.* (2005).

For a semi-automated discretisation of the model domain into landscape units and terrain components, the software tool LUMP (Landscape Unit Mapping Program) is available (Francke *et al.* 2008). LUMP incorporates an algorithm that delineates areas with similar hillslope characteristics by retrieving homogeneous catenas with regard to e.g. hillslope shape, flow length and slope (provided by a digital elevation model), and additional properties such as for soil and land-use and optionally for specific model parameters such as leaf area index, albedo or soil aggregate stability. The LUMP tool is linked with the WASA-SED parameterisation procedure through a databank management tool, which allows to process and store digital soil, vegetation and topographical data in a coherent way and facilitates the generation of the required input files for the model. LUMP and further WASA-SED pre-processing tools have been transferred to the package lumpR for the free software environment for statistical computing and graphics R which is available from https://github.com/tpilz/lumpR.

The input files for general purpose, the hillslope, river and reservoir routines are explained below with details on parameter type, units, data structure including examples parameterisation files.

Table 4: Summary of model input parameters

|  |  |
| --- | --- |
| **Type** | **Model input parameter** |
| Climate | Daily or hourly time series on rainfall [mm/day, mm/h]  Daily time series for average short-wave radiation [W/m2]  Daily time series for humidity [%]  Daily time series for temperature [°C] |
| Vegetation | Stomata resistance [s/m]  Minimum suction [hPa]  Maximum suction [hPa]  Height [m]  Root depth [m]  LAI [-]  Albedo [-]  Manning's n of hillslope[-]  USLE C [-] |
| Soil | No. of horizons\*  Residual water content [Vol. %]  Water content at permanent wilting point [Vol. %]  Usable field capacity [Vol. %]  Saturated water content [Vol. %]  Saturated hydraulic conductivity (mm/h)  Thickness [mm]  Suction at wetting front [mm]  Pore size index [-]  Bubble pressure [cm]  USLE K [-]\*\*  Particle size distribution\*\* |
| Terrain and river | Hydraulic conductivity of bedrock [mm/d]  Mean maximum depth of soil zone [mm]  Depth of river bed below terrain component [mm]  Initial depth of groundwater below surface [mm]  Storage coefficient for groundwater outflow [day]  Bankful depth of river [m]  Bankful width of river [m]  **Run to rise** ratio of river banks [-]  Bottom width of floodplain [m]  **Run to rise ratio** of floodplain side slopes [-]  River length [km]  River slope [m/m]  D­­­50 (median sediment particle size) of riverbed [m]  Manning’s n for riverbed and floodplains [-] |
| Reservoir | Longitudinal profile of reservoir [m]  Cross-section profiles of reservoir [m]  Stage-volume curves  Initial water storage and storage capacity volumes [m3]  Initial area of the reservoir [ha]  Maximal outflow through the bottom outlets [m3/s]  Manning’s roughness for reservoir bed  Depth of active layer [m] |

\* for each soil horizon, all following parameters in the column are required, \*\* of topmost horizon

General parameter and control files

Four parameter files control the data input and output and some internal settings:

**do.dat** [can be generated with The LUMP package, manual completing required]

The do.dat file is located in the folder WASA\Input and contains the main parameter specifications for the WASA-SED model. Figure 1 displays an example file for the do.dat. The first line of the do.dat contains the title. Line 2 and 3 specify the path for the location of WASA input and output folder. Relative paths are supported. The backslash “\” only works on Windows-platforms. The slash “/” is accepted on Windows and Unix/Linux systems. Make sure that both specified paths end with slash or backslash, respectively. Line 4 and 5 contain the start and the end year of the simulation, respectively. Line 6 and 7 contain the start and the end calendar month of the simulation, respectively. Optionally, the day of month for begin and end can be specified. Line 10 contains the number of sub-basins. The number in line 9 is given by the sum of the number of terrain components in each landscape-unit of each sub-basin (e.g. if the system has only two sub-basins, sub-basin A has 1 landscape unit with 3 terrain components, sub-basin B has 2 landscape units with 1 terrain component each, then the number of combinations is 5). Line 14 specifies if the reservoir module is switched on (.t.) or is switched off (.f.). The same issue for the calculations of networks of small reservoirs in line 15. Lines 16 – 19 allow customizing the way water and sediment is (re-)distributed within and among the TCs. Line 21 allows the setting of the simulation timestep (daily / hourly). This may become obsolete in future versions by setting the timestep directly in line 30. Line 24 allows specifying a correction factor for hydraulic conductivity to account for intra-daily rainfall intensities. Optionally, this factor can also be made a function of daily rainfall by specifying two more parameters (a and b) in the same line, so that kfkorr=kfkorr0\*(a\*1/daily\_precip+b+1). In line 31 the erosion and sediment-transport routines may be switched on and off. Specify the number of grain size classes you want to model in line 32. Their limits must be specified in part\_class.dat, if more than one class is desired. Line 33 lets you choose the hillslope erosion model to be used in WASA. Currently, this parameter is disregarded, further options can be chosen in erosion.ctl. Select the model for the river routing in line 34. Possible options are: (1) old WASA routing (daily resolution only, no sediment transport), (2) Muskingum and suspended sediment, (3) Muskingum and bedload transport. Choose the sediment model in the reservoir in line 35 among 4 sediment transport equations: (1) Wu et al. (2000); (2) Ashida & Michiue (1973); (3) Yang (1973, 1984); (4) Ackers & White (1973).

The optional lines 36 and 37 allow the saving/loading of state variables (i.e. groundwater, interception and soil storages) at the end/beginning of a model run (works only if svc.dat has been specified).

Line 36 may additionally contain a second logical variable (append\_output), allowing the model to append to existing output files (not yet implemented for all outputs). The consistence with the existing files is not checked! Default is .FALSE.

Line 37 may additionally contain a second logical variable (save\_states\_yearly), determining if the model states are saved (and overwritten) at the end of each simulation year. Default is .TRUE.

|  |  |
| --- | --- |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37 | Parameter specification for the WASA Model (SESAM-Project)  ..\WASA\Input\Case\_study\ *Location of model platform*  ..\WASA\Output\ *Specification of folder for simulation output*  1980 //tstart (start year of simulation)  1981 //tstop (end year of simulation)  1 15 //mstart (start month of simulation) *in this case: simulation from January, 15th 1980*  12 15 //mstop (end month of simulation) *until December, 31st (=defaults to end of month) 1981*  10 //no. of sub-basins  49 //no. of combinations of sub-basins, landscape units, terrain components  321 //total no. of landscape units in study area  515 //total no. of terrain components in study area  77 //total no. of soil components in study area  34 //total no. of vegetation units in study area  .f. //doreservoir: do reservoir calculations  .f. //doacudes:includes dam calculations  .t. //dolattc: do latflow between TCs  .f. //doalllattc: rout latflow completely to next downslope TC  .t. //dolatsc: do latflow within TCs (surface runoff)  .t. //dolatscsub: do latflow within TCs (subsurface runoff)  .f. //dotrans: do water transpositions betwen sub-basins  .f. //dohour: do hourly version (ignored, use “dt”)  0 //scenario: choose scenario (0:less rain (ECHAM), 1:no trend, 2:more rain (Hadley))  0 //krig: type of precipitation interpolation (0….)  15.0 //kfkorr: hydraulic conductivity factor (for daily model version) (kfkorr)  0.30 //intcf: interception capacity per unit LAI (mm)  0 //dointc: type of interception routine (simple bucket:0, modified bucket:1)  .f. //doscale: do scaling due to rainfall interpolation ?  .f. //domuncell: for muni/ezg-nocell-version, use rainfall input derived from cells ? (change kf\_calib.dat !)  1, //sensfactor: factor for sensitivity studies  24 //dt: time step in [hours]  .t. //dosediment  1 //No. of grain size classes  1 // type of sediment transport model at the hillslope  1 type of water / sediment model in the river: (1) old routing, (2) Muskingum & ss transport, (3) Muskingum & bedload modelling  1 //type of sediment model in the reservoir: choose sediment transport …  .t. //load state of storages from files (if present) at start (optional)  .f. //save state of storages to files after simulation period (optional) |

Figure 1 WASA parameter specification file: do.dat

**maxdim.dat**

*optional* [can be generated with the LUMP package]

The file maxdim.dat serves to optimise memory management and thus improves computational performance. It is, however, optional and if not encountered, default values are assumed.

|  |
| --- |
| contains maximum dimensions of spatial units  3 //maximum no. of landscape units in a sub-basins  3 //maximum no. of terrain components in a landscape unit  4 //maximum no. of soil vegetation components in a terrain component  6 //maximum no. of horizons in a soil  2 //maximum no. transpositions between sub-basins  0 //number of cross sections at the strategic reservoirs [optional]  0 //number of points (x,y) along the cross sections [optional] |

Example: In the given example, no more than 3 LU may occur in one sub-basin (line 2). Analogously, no LU may contain more than 3 TCs (line 3) and no TC more than 4 SVCs (line 4). The number of horizons in a soil is limited to 6 (line 5). No more than 2 transpositions between sub-basins may exist. The last two lines are optional and valid only for computation of sedimentation patterns in strategic reservoirs (assumed 200, if missing).

**part\_class.dat**

*optional* [can be generated with the LUMP package]

The file part\_class.dat is only necessary if sediment transport in multiple particle-size classes is to be modelled. If part\_class.dat is missing, sediment transport will be modelled for a single particle-size class only. Otherwise, the file defines the number and the properties of the particle sizes that will be modelled. Please note that class numbering has to be continuous, starting with 1. The particle size classes must be ordered from fine to coarse.

|  |
| --- |
| Particle size classes to be used in sediment modelling  class\_number upper\_limit[mm]  1 0.002  2 0.063  3 2.0 |

Class\_number continuous numbering of particle classes

Upper\_limit upper limit of particle size for the respective class [mm]

Example: The example file describes the 3 particle-size-classes clay, silt and sand (according to German classification) with clay particles up to 0.002 mm, silt (0.002 - 0.063 mm) and sand (0.063 - 2.0 mm).

**outfiles.dat**

*optional*

The file allows specifying, which output files are desired. Disabling unnecessary output files saves computation time and disk space. The contains two headerlines, each following line contains a keyword, which is the filename of a possible output file (case insensitive, without the extension .out). If a keyword for a certain output file is not contained in outfiles.dat the respective file is not created, any existing file of that name is deleted. Information on the content of output files can be found in the respective sections. If outfiles.dat is not found, WASA-SED creates a default set of output files.

|  |
| --- |
| This files describe which output files are generated  put any character before the files you don't want to be created  daily\_actetranspiration  #daily\_potetranspiration  #daily\_qhorton  daily\_qin\_m3s  daily\_qout\_m3s  daily\_rain  daily\_runoff  daily\_sediment\_production  daily\_subsurface\_runoff  daily\_theta  daily\_total\_overlandflow  daily\_water\_subbasin  routing\_response  sediment\_production  water\_subbasin  deep\_gw\_recharge  deep\_gw\_discharge  tc\_theta  river\_degradation  river\_deposition  river\_flow  river\_flow\_dailyaverage  river\_flowdepth  river\_sediment\_concentration  river\_sediment\_total  river\_sediment\_total\_dailyaverage  river\_storage  river\_sediment\_storage  river\_susp\_sediment\_storage  river\_velocity  river\_bedload  river\_infiltration  tc\_surfflow  tc\_sedout  lu\_sedout  actetranspiration  qhorton  subsurface\_runoff  total\_overlandflow  gw\_discharge  potetranspiration  gw\_loss  gw\_recharge  res\_watbal  res\_vollost  res\_cav  res\_hydraul  res\_bedchange  res\_sedbal  res\_longitudunal  res\_sedcomposition  lake\_inflow\_r  lake\_outflow\_r  lake\_retention\_r  lake\_volume\_r  lake\_sedinflow\_r  lake\_sedoutflow\_r  lake\_sedretention\_r  lake\_sedimentation\_r  lake\_watbal  lake\_sedbal  lake\_inflow  lake\_outflow  lake\_volume  lake\_retention  lake\_vollost  lake\_sedinflow  lake\_sedoutflow  lake\_sizedistoutflow |

Example: The output files daily\_actetranspiration.out and daily\_qhorton.out will be created. The creation of daily\_potetranspiration.dat is omitted.

Input files for the hillslope module

The input files for the hillslope module are located in the folder Input\[case\_study]\Hillslope and are summarised in Table 5.

Table 5 Input data files for the hillslope component

|  |  |
| --- | --- |
| **Parameter File** | **Content** |
| hymo.dat | Specification of the sub-basins |
| soter.dat | Specification of the landscape units |
| terrain.dat | Specification of the terrain components |
| svc.dat | Specifications of soil vegetation components, erosion parameters |
| soil\_vegetation.dat | Specification of soil-vegetation components |
| svc\_in\_tc.dat | Specification which SVCs are contained in each TC |
| soil.dat | Specification of the soil properties |
| horizon\_particles.dat | Particle size distributions of soil horizons |
| vegetation.dat | Specification of the vegetation properties |
| rainy\_season.dat (optional)  k\_seasons.dat (optional)  c\_seasons.dat (optional)  p\_seasons.dat (optional)  coarse\_seasons.dat (optional)  n\_seasons.dat (optional) | Specification of the start and end of rainy season  Seasonality of USLE factors K, C, P, coarse fraction and Manning’s n, resp. |
| scaling\_factor.dat (optional) | Scaling/calibration factors for hydraulic conductivity |
| calibration.dat (optional) | Calibration factors for hydraulic conductivity of soils |
| Transposition.dat (optional) | Specification of additional water fluxes between sub-basins |
| ../erosion.ctl (optional) | Options for the erosion module |
| gw\_storage.stat (optional)  intercept\_storage.stat (optional)  soil\_moisture.stat (optional) | Initialisation of storage content of ground water  Initialisation of storage content of interception  Initialisation of storage content of soil moisture |
| frac\_direct\_gw.dat (optional) | partitioning of groundwater into river and alluvia |
| beta\_fac\_lu.dat (optional)  sdr\_lu.dat (optional) | Correction factors for beta (USLE L-factor computation)  LU-wise specification of sediment delivery ratio |
| calib\_wind.dat (optional) | Calibration of wind speed (sensitive parameter for evapotranspiration) |

The spatial conceptualisation of the WASA model is explained in detail in Güntner (2002), and are only shortly summarised in this manual. The following spatial modelling units were identified (Güntner 2002, p. 33):

* *Sub-Basins*: ca. 50-1000 km3, topologically referenced, defined e.g. by the location of river gauging stations, or large reservoirs with a storage capacity of more than 50x106 m3 and the confluence of major rivers;
* *Landscape units (LUs)*: based on the LU concept (e.g. SOil and TERrain digital database, FAO, 1995), i.e. structure of the landscape according to geological, topographic and soil characteristics with similarity in major landform, general lithology, soil associations and toposequences, georeferenced;
* *Terrain components (TCs)*: fraction of area of a landscape unit with similarity in slope gradients, position within toposequence (highlands, slopes and valley bottoms), soil association;
* *Soil vegetation components (SVCs)*: fraction of area of a terrain component, characterised by specific combination of soil type, and vegetation/land-cover class
* *Soil profile:* descriptions of characteristic soil horizons.

The model domain is divided into sub-basins; each sub-basin has an individual Map-ID. This Map-ID has to be a unique number; the employed numbering scheme does not have to be continuous (i.e. with three sub-basins, they do not have to be named Map-ID 1, 2 and 3, but could be named e.g. 100, 500, 877). The following paragraphs explain each of the input files in turns.

**1) hymo.dat** [can be generated with the LUMP package]

|  |
| --- |
| Specification of the sub-basins and their total number, type & areal fraction of LU units  Subasin-ID [-], Area[km\*\*2], nbr[-], LU-IDs[-], areal fraction of LU[-]  49 10 4 19 87 90 135 0.357 0.147 0.214 0.282  50 15 2 19 87 0.827 0.173  1 40 3 19 103 87 0.612 0.143 0.245  44 37 3 19 87 18 0.646 0.097 0.257  10 5 3 19 18 87 0.483 0.173 0.344  4 22 3 159 19 18 0.107 0.793 0.100  15 13 2 87 138 0.740 0.260  39 25 5 87 18 142 56 31 0.351 0.146 0.142 0.237 0.124  3 31 3 87 18 136 0.416 0.471 0.113  29 20 4 56 122 31 7 0.091 0.652 0.131 0.126 |

Subasin-ID Map-ID of sub-basin

Area Area of each sub-basin in [km2] (including reservoir areas)

nbr Number of LU units in each sub-basin

LU-IDs List of LU-Ids which occur in this specific sub-basin

areal fraction Fraction of each LU unit within each sub-basin [-]

Example: In the do.dat, it was specified that 10 sub-basins are simulated with the WASA model. Accordingly, the file hymo.dat above contains the specification of 10 sub-basins, with the map IDs 49, 50, 1, … 29. The first sub-basin has a Map ID of 49 and an area of 10 km2. Within this sub-basin, four different landscape units can be identified with the LU-IDs 19, 87, 90 and 135. The first LU (ID 19) covers an area of 35.7 % (0.357) of the total area of the sub-basin, the second one 14.7 %, the third one 21.4 % and the last one 28.2 % (total 100 %).

Important: Any subbasin that is not listed in the file routing.dat will be ignored.

**2) soter.dat**[can be generated with the LUMP package]

|  |
| --- |
| Specification of LU units  LU-ID [-],No.\_of\_TC[-], TC1[-], TC2[-],TC3[-],kfsu[mm/d],length[m],meandep[mm],maxdep[mm],riverbed[mm],gwflag[0/1],gw\_dist[mm], frgw\_delay[day]  1 3 7 49 11 100 601 -1 -1 1500 0 0 1  2 1 2 100 1963.7 -1 -1 1500 0 0 1  … |

LU\_id ID of landscape units

Nb.\_of\_TC Number of terrain components

TC1 ID of a terrain component

TC2 ID of another terrain component

TC3 ID of a third terrain component

... more TC-IDs according to field 2

kfsu Hydraulic conductivity of bedrock [mm/d]

length Mean slope length in LU unit [m]

meandep Mean maximum depth of soil zone [mm]

maxdep Maximum depth of alluvial soil zone [mm]

riverbed Depth of river bed below terrain component [mm]

gw\_flag Flag for LU unit [0: no groundwater, 1: with groundwater]

gw\_dist Initial depth of groundwater below surface [mm] (ignored, unless gw\_flag=99)

frgw\_delay Storage coefficient for groundwater outflow [day]

Example: The landscape unit with ID 1 has 3 terrain components with the IDs 7, 49 and 11, a hydraulic conductivity of bedrock of 100 mm/d, a mean slope length of 601 m, etc.

The LU with ID 2 has only 1 terrain component with the ID-Number 2 (i.e. consisting only of one rather homogenous hillslope section, TC2 and TC3 are set to zero), a hydraulic conductivity of bedrock of 100 mm/d, a mean slope length of 1963.7 m, etc. The TCs within a LU can be listed in any order, their position in the toposequence is read from terrain.dat.

LU-ids not lister in hymo.dat are ignored.

Remarks concerning groundwater: In WASA-SED, the representation of groundwater is yet quite simplistic. The general groundwater regime is essentially controlled by the flag for groundwater (gw\_flag) in soter.dat. Currently, the three options for setting gw\_flag are gwflag=0, 1 or 99 (see Table below). This determines if the water that leaves the soil column is “lost” for the model (gwflag=0) or enters a linear storage (gwflag=1). Gw\_flag=99 is an experimental modelling option which usually should not be chosen.

Please note that the depth of the bedrock may be specified in two ways: In soil.dat, the bedrock is assumed beneath the deepest soil horizon, if the bedrock flag is set (bedrock=1). Otherwise (bedrock=0), its depth is taken from the meandep (maxdep for alluvial soils) specification given in soter.dat.

Please note that in the case of alluvial soils, for each option in Tables 1 or 2 below, maxdep as defined in soter.dat instead of meandep is used. maxdep usually should be set larger than meandep. The rationale behind this is that alluvial soils in the valley bottoms, in particular in crystalline bedrock environment, usually have larger soil depths (and thus higher water storage capacity) than average soils somewhere else (at the slopes) within the landscape unit.

IMPORTANT:

In any of the above options, riverbed is to be defined in soter.dat. In WASA, only soil horizons of the lowest terrain component which are located at depths above the riverbed are allowed to exfiltrate into the river by lateral flow. Soil horizons below riverbed cannot lose water to the river, but only due to evapotranspiration or percolation to groundwater/bedrock.

**I) Groundwater option Gw\_flag=0**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Modelling options** | **Groundwater regime, internal representation of processes** | **Gw flag (soter.dat)** | **Bed-rock (soil.dat)** | **Add. parameters (soter.dat)** |
| I) Groundwater below soil zone is ignored / not relevant for surface processes | Soil water balance is modelled within the zone above bedrock. Water percolation out of the deepest soil horizon leaves the model domain | 0 | Select option 1.1 or 1.2 | |
| I.1) No bedrock is taken into account | Water percolation out of the deepest soil horizon leaves the model domain. | 0 | Select option 1.1.1 or 1.1.2 | |
| I.1.1) Depth of soil zone is the sum of all horizons given in soil.dat | See 1.1) | 0 | 0 | meandep=-1  maxdep=-1  riverbed |
| I.1.2) Depth of soil zone is meandep (or the total profile depth given in soil.dat if this is larger than meandep) | See 1.1) | 0 | 0 | Meandep  Maxdep  riverbed |
| I.2) Bedrock is taken into account below deepest soil horizon | Hydraulic conductivity of bedrock may affect percolation rates out of the deepest soil horizon. A saturated zone (“groundwater”) above bedrock may consequently evolve due to saturation. Groundwater percolating into the bedrock leaves the model domain. | 0 | Select option 1.2.1 or 1.2.2 | |
| I.2.1) Bedrock is given in soil.dat | See 1.2) | 0 | 1 | Kfsu  riverbed |
| I.2.2) If bedrock is not given in soil.dat, bedrock is assumed to be in the depth defined by meandep (or below deepest horizon given in soil.dat if its depth is greater than meandep) | See 1.2) | 0 | 0 | Meandep  maxdep  kfsu  riverbed |

**II**) Groundwater option Gw\_flag=1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Modelling options** | **Groundwater regime, internal representation of processes** | **Gw flag (soter.dat)** | **Bed-rock (soil.dat)** | **Add. parameters (soter.dat)** |
| II) Groundwater below soil zone is taken into account | Soil water balance is modelled within the zone above bedrock. Water percolation out of the deepest soil horizon enters linear groundwater storage | 1 | Select option 2.1 or 2.2 | |
| II.1) No bedrock is taken into account | Water percolation out of the deepest soil horizon goes directly into the groundwater storage. | 1 | 0 | meandep=-1  maxdep=-1  frgw\_delay  riverbed |
| II.2) Bedrock is taken into account below deepest soil horizon | The hydraulic conductivity of the bedrock may affect percolation rates out of the deepest soil horizon. A saturated zone (“groundwater”) above bedrock may consequently evolve due to saturation. Percolation into the bedrock is added to linear groundwater storage. | 1 | Select option 2.2.1 or 2.2.2 | |
| II.2.1) Bedrock is given in soil.dat | See 2.2) | 1 | 1 | Kfsu  frgw\_delay  riverbed |
| II.2.2) If bedrock is not given in soil.dat, bedrock is assumed to be in the depth defined by meandep (or below deepest horizon given in soil.dat if the profile depth is greater than meandep) | See 2.2) | 1 | 0 | Meandep  maxdep  kfsu  frgw\_delay  riverbed |

**III) Groundwater option Gw\_flag=99**

Experimental option, not verified !

|  |  |  |  |
| --- | --- | --- | --- |
| **Modelling options** | **Groundwater regime, internal representation of processes** | **Gw flag (soter.dat)** | **Add. parameters (soter.dat)** |
| III) Groundwater in soil zone. The initial depth of the groundwater surface below soil surface is defined by gw\_dist in soter.dat. A separate deep groundwater storage or bedrock is ignored. | Permanent groundwater in soil zone is assumed. The groundwater level may vary in time as a function of input by percolation and drainage into river. | 99 | meandep  maxdep  riverbed  gw\_dist |

**3) terrain.dat** [can be generated with the LUMP package]

|  |
| --- |
| Specification of terrain components  TC-ID, fraction, slope [%], position [-]  1 0.65 12 1  2 1.00 2 2  … |

TC-ID ID of terrain component

fraction Fraction of terrain component in LU [-]

slope Slope of terrain component [%]

position Position of terrain component in LU (e.g. 1: highlands, 2: middle slopes, 3: lowland)

(beta\_fac) (optional) correction factor for beta (details below)

(SDR) (optional) TC-specific sediment delivery ratio (details below)

Example: The terrain component with ID 1 covers 65 % (0.65) of the corresponding LU. This terrain component has a slope of 12 % and is located at the hillslope top of the landscape unit (position 1). The terrain component with ID 2 covers 100 % (1.00) of the corresponding LU, has a slope of 2 % and is located at the second position within the landscape unit (position 2), i.e. downslope of another TC.

For erosion modelling, terrain.dat may contain a fifth column holding correction factors for beta (see explanation section beta\_fac\_lu.dat) on the TC-scale OR

A fifth AND sixth column holding beta\_fac and a sediment delivery ratio (SDR) for each TC. If either of these are given, the respective settings for the LUs are ignored.

SDRs are applied to raw erosion on TC-scale before transport capacity limitations. Normally, they should be used with USLE and without transport capacity limitation, otherwise deposition may be accounted for twice.

**4) svc.dat** [can be generated with the LUMP package] (optional, mandatory for sediment module and saving/loading of model states)

|  |
| --- |
| Specifications of soil vegetation components and erosion parameters  id soil\_id veg\_id musle\_k[(ton acre hr)/(acre ft-ton inch)] musle\_c[-] musle\_p[-] coarse\_fraction[%] manning\_n  11 13 21 0.13 1.0 1.0 0.8 0.011  … |

ID unique ID for the soil-vegetation component

Soil\_id ID of corresponding soil unit (as specified in soil.dat)

Veg\_id ID of corresponding vegetation component (as specified in vegetation.dat)

Musle\_k\* MUSLE erodibility factor [(ton acre hr)/(acre ft-ton inch)]

Musle\_c\* MUSLE crop factor

Musle\_p\* MUSLE protection factor

Coarse\_fraction \* fraction of soil fragments > 2 mm [%]

Manning\_n\* Manning’s n roughness coefficient

\*Each of these columns can be replicated 4 times to describe seasonal dynamics of the respective parameter. In that case, the corresponding seasonality file must be created (see rainy\_season.dat).

Example: The SVC with the ID 11 consists of the soil with ID 13 (as specified in soil.dat) and the vegetation/landuse with ID 21 (as specified in vegetation.dat), resulting in the MUSLE-factors K, C, P of 0.13, 1.0 and 1.0, respectively. It contains 0.8 % coarse particles and has a surface roughness coefficient of 0.011.

**5) svc\_in\_tc.dat** [can be generated with the LUMP package]

|  |
| --- |
| Specification of which SVCs are contained in each TC  TC-ID[-] SVC-ID[-] fraction[-]  11 12 1.0  12 13 0.2  12 14 0.8  … |

TC-ID ID of terrain component (as specified in terrain.dat)

SVC-ID ID of soil vegetation component (as specified in svc.dat)

Fraction fraction of TC that is covered by the current SVC

Note: The sum of “fraction” over a specific TC can be smaller than one as the sum over a TC plus “fraction\_rocky” needs to sum up to one (see also the description for file soil\_vegetation.dat). If this requirement is not fulfilled, WASA-SED will issue a warning and normalize the fraction to unity automatically.

Example: The TC with the ID 11 consists only of the SVC with the ID 12. The TC with the ID 12 is covered by the SCV 12 at 20 % of its area. The remaining 80 % of TC 12 consist of SVC 14.

**6) soil\_vegetation.dat** [can be generated with the LUMP package]

|  |
| --- |
| Specification of soil-vegetation components (links LU, terrain component, soil and vegetation properties)  For each block: first line Soil IDs, Second line Land use, third line fraction of SVCs in each terrain component  Subasin-ID[-],LU-ID[-],TC-ID[-],fraction\_rocky[-],nbrSVC[-],Soil-ID(30 values)[-],Vegetation-ID (30 values)[-],fraction (30 values)[-]  49 19 25 0.12 9 86 30 77 86 85 86 … 43 *in total max. 30 IDs\**  49 19 25 0.12 9 8002 8004 8005 8500 7203 9203 … 7203  49 19 25 0.12 9 0.017 0.031 0.019 0.022 0.043 0.598 … 0.025  49 19 26 0.000 2 27 27 0 0 0 0 … 0  49 19 26 0.000 2 8002 8004 0 0 0 0 … 0  49 19 26 0.000 2 0.024 0.042 0 0 0 0 … 0.000  … |

Subasin-ID ID of sub-basin (Map-ID), same ordering as in hymo.dat

LU-ID ID of corresponding LU (as determined in hymo.dat)

TC-ID ID of corresponding terrain component (as determined in soter.dat)

fraction\_rocky fraction of impermeable (rock) area in each terrain component [-]1

nbrSVC Number of soil-vegetation components (SVCs) in current TC of sub-basin

Soil-IDs(nbrSVC values) 1st row of each block: corresponding soil-IDs as defined in soil.dat

Vegetation-ID(nbrSVC values) 2nd row of each block: corresponding vegetation-ID as defined in vegetation.dat

fraction (nbrSVC values) Areal fraction of SVCs in current terrain component of current sub-basin [-]

(\*each Sub-basin, LU, Terrain Component Unit has a block of data in three lines)

1fraction\_rocky will probably become obsolete in future versions. If it is 0 for all TCs, the rocky fraction is determined from the fraction of soils that have with a coarse fraction of 1 in their topsoil (see soil.dat). Please note that fraction\_rocky and the fraction values are internally normalized to unity if the sum is greater than one. It is advisable, however, to respect this already during the pre-processing. The package lumpR is able to handle impervious areas.

Example: The combination sub-basin Map-ID of 49, the LU-ID of 19 and the terrain component-ID 25 has a fraction of 12 % (0.12) of impermeable rock area, and 9 different soil and landuse / vegetation classes. The sum of the fraction of the impermeable area and of the areal fractions of all SVCs must equal 1.0. The first row holds the 9 different soil-IDs (86, 30, 77, 86, etc.). The second row contains the landuse / vegetation classes for the same sub-basin – LU – terrain component combination (8002, 8004, 8005, etc.). The third line holds the areal fraction of each soil-vegetation specification within each LU-terrain combination. The next three lines contain the same block of data for sub-basin 49, LU 19 but for terrain component-ID 26.

The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs that was used in hymo.dat (due to computational reasons), in this case 49, 50, 1, 44, etc.; otherwise an error message occurs.

7) soil.dat [can be generated with the LUMP package]

|  |
| --- |
| Specification of soil parameters  Soil-ID[-],number(horizons)[-],res[Vol-],PWP[-],FK2.5[-],FK1.8[-],nFK[-],saturated[-],depth[mm],ks[mm/d],suction[mm],pore-size-index[-],bubblepressure[cm],coarse\_frag[-], shrinks[0/1] , bedrock[0/1] , alluvial[0/1] (*1 line)\**  1 3 0.073 0.102 0.184 0.270 0.168 0.472 200.0 504 9.037 72.9 0.3593 9.80 0.000 0 0.102 0.160 0.265 0.349 0.188 0.472 600.0 1096.288 125.5 0.2705 16.16 0.000 0 0.064 0.084 0.152 0.229 0.145 0.472 300.0 7709.267 46.1 0.3891 6.31 0.000 0 0 0 (*1 line)\**  2 4 0.070 0.094 0.164 0.240 0.146 0.452 250.0 6229.629 67.2 0.3816 9.07 0.001 0 0.075 0.102 0.176 0.253 0.151 0.453 250.0 5250.267 71.4 0.3655 9.56 0.001 0 0.076 0.106 0.184 0.262 0.156 0.458 500.0 5368.695 82.4 0.3558 10.96 0.000 0 0.066 0.087 0.155 0.232 0.145 0.462 500.0 8344.087 56.4 0.3903 7.67 0.225 0 0 1    3 3 0.075 0.104 0.191 0.278 0.174 0.396 100.0 1020.368 154.2 0.3666 20.89 0.000 0 0.089 0.126 0.215 0.297 0.170 0.434 400.0 1381.206 107.1 0.3192 14.18 0.000 0 0.070 0.097 0.181 0.270 0.173 0.434 500.0 2655.635 102.0 0.3741 13.87 0.000 0 0 0  … |

*\* the data must be all in one line*

Soil-ID ID of soil unit [-]

numb (*horizons*) number of horizons in soil profile [-]

res residual soil water content (*horizons*) [Vol. fraction]

PWP water content at permanent wilting point (at 15000 cm suction)) (*horizons*) [Vol. fraction]

FK2.5 field capacity (316 hPa / pF=2.6) (*horizons*) [Vol. fraction]

FK1.8 field capacity (63 hPa / pF=1.8) (*horizons*) [Vol. fraction]

nFK usable field capacity (*horizons*) [Vol. fraction]

saturated saturated water content (*horizons*) [Vol. fraction]

depth thickness of soil horizon (*horizons*) [mm]

ks saturated hydraulic conductivity (*horizons*) [mm/d]

suction suction at the wetting front (*horizons*) [mm]

pore-size-index pore-size index (*horizons*) [-]

bubblepressure bubbling pressure (=1/alpha of van Genuchten) (*horizons*) [cm]

coarse\_frag fraction of coarse fragments (*horizons*) [Vol. fraction]1

shrinks flag for soil structure (*horizons*) [0/1, currently not used, set to 0]

bedrock Does bedrock occur below deepest horizon or profile [0: no bedrock, 1: bedrock below deepest horizon]?

alluvial Is this soil an alluvial soil [0: no alluvial soil, 1: alluvial soil]?

1If set to 1 for a top horizon, these soils can contribute to fraction\_rocky of a TC (see soil\_vegatation.dat).

Example: The soil class with the ID 1 has 3 horizons in the soil profile. Consecutively within each row, first all horizon-specific attributes of horizon 1 are given, then those of horizon 2 and finally those of horizon 3. For example, the first horizon has a residual soil water content of 7.3 % (0.073), a water content at permanent wilting point of 10.2 % (0.102), a field capacity of 18.4 % (0.184), a field capacity [63 %] of 27.0 % (0.270), a usable field capacity of 16.8 % (0.168), a saturated water content of 47.2 % (0.472), a thickness of 200 mm, etc… The values for the second horizon start again with a residual soil water content of 10.2 % (0.102), a water content at permanent wilting point of 16.0 % (0.160) etc. The very last two parameters of each row are the flags for bedrock and alluvium for the entire soil column. In the first line of the file dump above, the data belonging to one horizon have the same colour. All data for each individual soil ID must be given continuously in one line.

8) **soil\_particles.dat** [can be generated with the LUMP package]

|  |
| --- |
| Particle size distribution of topmost horizons of soils  soil\_id part\_class\_id fraction[-]  1 1 0.3  1 2 0.4  1 3 0.3  2 1 0.1  2 2 0.2  2 3 0.7  … |

Soil\_id ID of Soil (as determined in soil.dat)

part\_class\_id ID of particle-size class (as determined in part\_class.dat)

fraction mass fraction of the respective particle class in the topmost horizon [-]

Example: The topmost horizon of soil 1 contains 30 % of particles falling into the particle-size-class 1. Furthermore, it consists of 40 % of particles out of class 2 and of 30 % of particles out of class 3.

9) vegetation.dat[can be generated the LUMP package]

|  |
| --- |
| Specification of vegetation parameters  Veg-ID, Stomata\_Resistance[s/m],minsuction[hPa],maxsuction[hPa],height[m],root-depth[m,]LAI [-],albedo[-]  9101 200 10000 30000 5 5.5 6 6 1.5 1.5 1.7 1.8 1 5.5 5.5 1.5 0.23 0.17 0.17 0.21  9102 175 10000 30000 3 3 3 3 1.25 1.25 1.25 1.25 0.4 4 4 0.8 0.25 0.18 0.18 0.23  … |

Veg-ID ID of landuse/vegetation

Stomata\_Resistance stomata resistance without water stress [s/m]

minsuction suction threshold for water stress effect on resistance (begin of stomata closure) [hPa]

maxsuction suction threshold for water stress effect on resistance (total closure of stomata – wilting point) [hPa]

height Average height of vegetation canopy [m] *4 values*

root depth Rooting depth of vegetation [m] *4 values*

LAI Leaf area index of vegetation cover [-] *4 values*

albedo Surface albedo [-] *4 values*

Example: The landuse/vegetation class with ID 9101 has a stomata resistance without water stress of 200 s/m, a minimal suction threshold of 10000 hPa and a maximal suction threshold for water stress effect on resistance of 30000 hPa. Furthermore, 4 values for vegetation height (5 m, 5.5 m, 6 m, 6 m), 4 values for root depth (1.5 m, 1.5 m, 1.7 m, 1.8 m), 4 values for leaf area index (1, 5.5, 5.5, 1.5) and 4 values for albedo (0.23, 0.17, 0.17, 0.21) are specified for this landuse/vegetation class. Do not use zero values here but very low ones instead! The four values for the four parameters (height, root depth, LAI, albedo) reflect the temporal changes of vegetation parameters as a function of seasonal changes (e.g. due to a rainy season). The first value of a set of four reflects the vegetation properties *before* the rainy season, the second value at the *beginning* of the rainy season, the third value at the *end*, and the fourth value *after* the rainy season. The exact date for these four points in time is given in the next file (rainy\_season.dat).

10) rainy\_season.dat (optional)

k\_seasons.dat (optional)

c\_seasons.dat (optional)

p\_seasons.dat (optional)

coarse\_seasons.dat (optional)

n\_seasons.dat (optional)

|  |
| --- |
| Specification of the rainy season (per year)  for the interpolation of temporal distribution of vegetation characteristics (Rootdepth,height,lai,albedo)  Subasin Veg\_id Year DOY1 DOY2 DOY3 DOY4  49 2 1980 10 40 175 205  49 -1 1980 20 40 175 205  50 -1 1980 10 40 175 205  -1 1981 5 35 150 180  -1 -1 -1 36 151 181  … |
|  |

Subasin-ID Map-ID of sub-basin

Year Simulation year(s), each individual year has to be listed in the file

*Veg\_id (optional column) option for vegetation-specific dynamics*

DOY1 – DOY4 day-of-year (1-365/366) for four days within the seasonal cycle, serving as support points for intraannual dynamics (e.g. start of transition phase, first day of rainy season, last day of (rainy) season, start of transition phase)

Temporal dynamics of LAI, root depth, C-factor, etc. can be specified as a piecewise linear cycle with four segments. The ordinates (y-values, e.g. minimum, maximum and transitional LAIs) are listed in vegetation.dat and svc.dat. They are time-invariant.

The respective abscissa (x-values as day-of-year, DOY) are listed in \*\_seasons.dat. They can be specified separately for each year, subbasin and (optionally) vegetation class.

Eg. rainy\_season.dat contains the points in time that serve as temporal nodes, between which the seasonal dynamics of LAI, vegetation height, root depth and albedo are linearly interpolated. The nodes are specified as julian days/DOYs in relation to the respective year. Negative values (previous) and values greater than 365/366 (next year) are allowed as long as they do not surpass the next adjacent node. Please make sure that all required rainy-seasons must be specified (i.e. for all subbasins, all simulation years), otherwise an error message occurs. If not specified otherwise, values for days BEFORE the first / AFTER the last specified node are extrapolated with constant value.

“-1” can be used as a wildcard for subbasins, vegetation classes and years. The file is interpreted top to bottom, i.e. if multiple matches are found, the uppermost is used. Thus, a fallback specification (“all other cases”) should go into the last line (see example).

A standard (legacy) rainy\_season.dat can be generated from rainfall data using the complementary program RainySeason.f. If rainy\_season.dat is missing, only the first value in vegetation.dat is used (i.e. no seasonality).

The optional files k\_seasons.dat, c\_seasons.dat, p\_seasons.dat, coarse\_seasons.dat, n\_seasons.dat work analogously for the USLE factors K, C, P, the coarse fraction and Manning’s n. If any of these files is found, four respective columns (instead of the default one) must be given in svc.dat.

Example: The example file above is for two specific simulation years: 1980 and 1981. For vegetation class 2 in sub-basin 49, the rainy season in 1980 started on the 40th day (09.02.1980), and stopped on the 175th day (28.06.1980) (line 4). For all other vegetation classes, it started ten days later (DOY 20) (line 5). For subbasin 50, the dynamics are identical for all vegetation classes (line 6).

In 1981, the same DOYs are used for all subbasins (line 7). All other subbasins, vegetation classes or years would use the values of the last line.

11) scaling\_factor.dat (optional)

|  |
| --- |
| Subasin-ID mean\_kf-calib-factor  1 10  2 4.5  … |

Subasin-ID Map-ID of sub-basin

mean\_kf-calib-factor scaling factor (**actually a divisor**)

This file is optional and is only read if doscale (in do.dat) is set to “.T.”. In this case, scaling\_factor.dat is expected in the subdirectory “Others/”.

Example: All values for saturated hydraulic conductivity during infiltration in subbasin 1 are modified by **dividing** them by 10. Maximum interception is adjusted by setting it to (0.340+0.647\*10).

12) calibration.dat (optional)

|  |
| --- |
| Soil-ID Ksat-calib-factor  -1 20  5 0.3  … |

Soil-ID ID of soil

Ksat-calib-factor calibration factor

This file is optional and is in the subdirectory “Others/”.

Example: All values for saturated hydraulic conductivity of ALL soils (wildcard “-1”) are increased by factor 20. For soil 5, the values are additionally multiplied with 0.3.

13) transposition.dat (optional)

|  |
| --- |
| Water transpositions via canals or pipes between sub-basins, in order of routing scheme  Start-Subasin-ID Flag(reservoir/river) Flow(m3/s) Loss(%) Destination-Subasin-ID Flag (reservoir/river), begin\_year  91 1 1.75 0.01 96 1 1965  67 2 2.4 0.1 31 1 1997  31 1 2 0.06 30 1 1993  30 1 2 0.02 29 2 1993 |

Start-Subasin-ID ID of subbasin (source of water abstraction)

Flag(reservoir/river) ?

Flow(m3/s) amount of re-routed water

Loss(%) transmission loss

Destination-Subasin-ID ID of subbasin (destination of water abstraction)

Flag (reservoir/river) ?

begin\_year start time of water abstraction

This file is optional and is only read if dotrans (in do.dat) is set to true. In this case, transposition.dat is expected in the subdirectory “Others/”. WARNING: The transposition of sediment has not yet been implemented.

14) erosion.ctl (optional)

|  |
| --- |
| #WASA-control file for erosion and sediment transport routines;  application\_scale 0 #0: apply equations on TC-scale; 1: apply on subbasin-scale  erosion\_equation 4 #erosion equation to be used: 1: USLE, 2: Onstad-Foster, 3: MUSLE, 4: MUST  ri\_05\_coeffs 1.911 0.807 #needed for USLE and OF: coefficients for estimation of maximum half-hour rainfall intensity (ri\_05) from daily rainfall data (R\_day): ri\_05=a\*R\_day^b  transport\_limit\_mode 2 #different modes how/if transport capacity of runoff is limited: 1: no transport capacity limit; 2: transport capacity according to Everaert (1991); 3: transport capacity computed from MUSLE with maximum erodibility  #river module  transp\_cap\_a 0.016111 empirical factor for computing suspended sediment transport capacity in river (a \* vel\_peak \*\* b)  transp\_cap\_b 1.807 empirical factor for computing suspended sediment transport capacity in river (a \* vel\_peak \*\* b) |

Application scale 0: apply equations on TC-scale; 1: apply on subbasin-scale

Erosion equation erosion equation to be used

1: USLE, 2: Onstad-Foster, 3: MUSLE, 4: MUST

ri\_05\_coeffs needed for USLE and OF: coefficients for estimation of maximum half-hour rainfall intensity (ri\_05) from daily/hourly rainfall data (R\_dt): ri\_05=a\*R\_dt^b.

transport\_limit\_mode different modes how/if transport capacity of runoff is limited:

1: no transport capacity limit; 2: transport capacity according to Everaert (1991); 3: transport capacity computed from MUSLE with maximum erodibility

transp\_cap\_a empirical factor for computing suspended sediment transport capacity in river (a \* vel\_peak \*\* b)

transp\_cap\_b empirical factor for computing suspended sediment transport capacity in river (a \* vel\_peak \*\* b)

This file and any of its entries are optional. If not present, default values are used (Application scale=0; Erosion equation=3, ri\_05\_coeffs = (a\_i30=1.1630; b\_i30=0.667981 for daily resolution; a\_i30=1; b\_i30=1 for hourly resolution); transport\_limit\_mode=2, transp\_cap\_a=0.016111, transp\_cap\_b=1.707).

15) gw\_storage.stat, intercept\_storage.stat, soil\_moisture.stat, interflow\_storage.stat

lake\_volume.stat, river\_storage.stat (optional)

|  |
| --- |
| ground water storage (for analysis or model re-start)  Subbasin LU volume\_[mm] area\_[m²]  1 11111 39.51 1013437.4  … |
| interception storage (for analysis or model re-start)  Subbasin LU TC SVC storage\_[mm] area\_[m²]  1 11111 5 16010 0.00 73491.9  … |
| soil moisture status (for analysis or model re-start)  Subbasin LU TC SVC horizon watercontent\_[mm] area\_[m²]  1 11111 5 16010 1 26.70 73491.9  … |
| interflow storage (for analysis or model re-start)  Subbasin LU TC horizon storage\_[m3]  1 1 3 1 0.000  ... |
| Lake volume status (for analysis or model re-start)  Subbasin reservoir\_size\_class volume[m^3]  1 1 0.00 |
| UHG routing: values of routed discharge per timestep of unit hydrograph  Subbasin [n\_h x timestep]  101 1.286 0.649 0.074 |
| Muskingum routing: river reach volume status (for analysis or model re-start)  Subbasin volume[m^3]  1 2033.808 |

subbasin subbasin ID

LU landscape unit ID

TC ID of terrain component

SVC ID of soil vegetation component

Horizon position of horizon (numbering from top)

Volume/ storage content [mm]

Storage/

Watercontent

Area [ignored, for external analysis only]

These files are optional. If not present, default values are used (currently, 100 % relative saturation for the soils, 0 for all others). These files are expected in the WASA-SED output directory. WASA overwrites them at the end of each simulation year. See also section “output files”. Any existing files at the start of the simulation will be renamed to “\*.\*\_start”.

The structure of river\_storage.stat depends on the routing option chosen (UHG or Muskingum, see examples above).

16) frac\_direct\_gw.dat (optional)

|  |
| --- |
| 0.7 |

This file contains a single value x that specifies the fraction of the groundwater (formed in the LUs) that is routed directly into the river. The remaining fraction 1-x enters the lowermost TC as subsurface flow. Low values of x tend to reduce periods of very low flow in ephemeral rivers. Default x is 1. frac\_direct\_gw.dat resides in the root of the WASA-SED input-directory as specified in do.dat.

17) beta\_fac\_lu.dat (optional)

|  |
| --- |
| specified correction factor for beta (rill/interrill ratio, used for the computation of L-factor, see Renard, 1997, pp.101  lu\_id beta\_factor  12111 2  21111 0.5  … |

Lu\_id landscape unit ID

beta\_factor factor for modification of beta

This file allows specifying a correction factor for beta for selected LUs. Beta describes the ratio of

rill/interrill erosion and is used for the computation of the L-factor (see Renard et al., 1997, pp.101, eq. 4-1 – 4-3). Default value (for non-specified LUs) is 1. Common values are 0.5 for a low (lower yield) and 2 for a high (higher yield) rill/interrill ratio. If this correction factor is already specified for the TC-scale in terrain.dat, the values in beta\_fac\_lu.dat are ignored.

A row with an lu\_id of -1 (wild card) will set all unset LUs to the specified value.

18) sdr\_lu.dat (optional)

|  |
| --- |
| Prespecified Sediment delivery ratio [0-1] for Landscape units  lu\_id sdr  11211 0.94  11311 0.94  … |

lu\_id landscape unit ID

sdr sediment delivery ratio [0...1]

This file allows specifying a sediment delivery ratio for selected LUs.

Default value (for non-specified LUs) is 1. Check!

If this correction factor is already specified for the TC-scale in terrain.dat, the values in sdr\_lu.dat are ignored. A row with an lu\_id of -1 will set all unset LUs to the specified value.

Warning: Using SDR should be used without a transport capacity limitation, otherwise, deposition is considered twice.

18) calib\_wind.dat (optional)

This file contains a single value which will be used as static wind speed value (in m/s) within the model. If this file is not given, a value of 1 m/s is used by default. As this is a very sensitive parameter, it can be used for calibration of evapotranspiration.

Input files for the river module

The input files for the river module are located in the folder Input\[case\_study]\River and are summarised in Table 6. Three options are available for the river routing: routing scheme 1 comprises the original river routing using time response functions, routing scheme 2 uses the Muskingum routing and suspended sediment transport and routing scheme 3 uses the Muskingum routing and bedload transport. Routing schemes 2 and 3 enable a spatially distributed representation of river stretch characteristics. Sediment-transport calculations are only possible for routing schemes 2 and 3. The flow calculations are carried out in routing order, i.e. the river stretches which are located most upstream are calculated first. The routing order is specified in routing.dat (see WASA documentation, Mueller and Güntner 2005). The key model input parameters for water and sediment routing are stored in an input file called river.dat that assigns each sub-basin with a specific map ID a corresponding river stretch. The input file response.dat contains the time response parameters that were used for the original version of the WASA code (routing scheme 1).

Table 6 Input data files for the river component

|  |  |
| --- | --- |
| **Parameter File** | **Content** |
| routing.dat | Specification of routing order (for all routing schemes) |
| river.dat | Specification of river parameters (for routing scheme 2 and 3) |
| response.dat | Specification of time response parameters (for routing scheme 1) |
| bedload.dat | Specification of bedload data (for routing scheme 3) |
| subbasin\_out.dat | (optional) pre-specification of outflow of selected sub-basins |
| subbasin\_outsed.dat | (optional) pre-specification of sediment output of selected sub-basins |

1) routing.dat

|  |
| --- |
| Specification of routing order (flow directions)  No., Subasin-ID(upstream), Subasin-ID(downstream)  1 4 10  2 15 10  3 39 10  4 10 50  5 1 50  6 44 50  7 50 49  8 49 3  9 3 29  10 29 999 |

No. Continuous numbering (calculation order, value is ignored)

Subasin-ID(upstream) Map-ID of sub-basin, which is located upstream of another sub-basin

Subasin-ID(downstream) Map-ID of sub-basin, which is located downstream of the previous sub-basin

Example: This file defines the order of the calculation of the subbasins. All sub-basins must be listed before their corresponding outlet basins, otherwise an error is issued. For example, sub-basin No. 4 is upstream of sub-basin No. 10. Sub-basins No. 15 and 39 are also upstream of No. 10. The runoff of sub-basin No. 10 flows into sub-basin No. 50 etc. The subbasin at the outlet of the entire drainage system must drain to a subbasin labelled 999 or 9999.

2) river.dat

|  |
| --- |
| Specification of river parameters  Subasin-ID, depth(m), width(m), side ratio (m/m), bottom width of floodplain (m), side ratio floodplains (m/m), channel slope(m/m), length(km), manningn (-), manningn\_floddplain (-) Ksat(mm/hr), erodibilityfactor(-),coverfactor(-), riverbedrock(-),baseflowalphafactor(days), msk\_x(-), Q\_spring(m3/s)  1 1 5 2 100 4 0.006 7.4 0.02 0.05 25 0.1 1 0 0.1 0.2 4 0.1 |

Subasin-ID Map-ID of sub-basin

depth Bankful depth of river reach [m]

width Bankful width of river reach [m]

side ratio Run to rise ratio of river banks (1/side channel slope) [m/m]

bottom width Bottom width of flood plain [m]

side ratio floodplains Run to rise ratio of floodplain side slopes (1/floodplain side slope) [m]

slope Slope of river reach [m/m]

length Length of river reach [km]

manningn Manning’s n of river reach [-]

manningn\_floodplain Manning’s n of floodplain reach [-]

Ksat Saturated hydraulic conductivity the river bed [mm/h]

erodibility factor River erodibility factor of river reach [-]

cover factor River vegetation cover factor of river reach [-]

riverbedrock Cover of solid rock in riverbed [-]

baseflow baseflow alpha factor for bank storage (days)

msk\_x Muskingum X weighting coefficient (-)

msk\_k Muskingum K storage time constant (hours)

Q\_Spring Initial conditions for headwater reaches (minimum discharge) [m3/s]

Example: The river stretch at the sub-basin with the Map-ID of 1 has a bankful depth of 1 m, a width of 5 metres, a site ratio of 2, a bottom width of the floodplain of 100 m, a side ratio on the floodplains of 4, a channel slope of 0.006 (or 0.6 %), a length of 7.4 km, a Manning’s n of 0.02 and a Manning’s n in the floodplain of 0.05, a Ksat of 25 mm/h, an erodibility factor of 0.1, a cover factor of 1, a riverbedrock factor of 0, a baseflowalphafactor of 0.1 days, a Muskingum X coefficient of 0.2, a Muskingum K factor of 4 hours and an initial condition of 0.1 m3/s. The dimensions of the trapezoidal channels including the floodplains are depicted in Figure 2. The height of the wedge at the channel bottom (enables smooth transition of low flows) is fixed to 0.1 m.



Figure 2 Trapezoidal channel dimension with floodplains

3) response.dat

|  |
| --- |
| Specification of routing parameter  Subasin-ID,lag time [d],retention[d]  49 0.5 2.0  50 1 1.5  1 4 7  … |

Subasin-ID Map-ID of sub-basin

lag time Lag time between runoff input to sub-basin and first runoff response at its outlet in [days]

retention Retention specifies the maximum retention time in the sub-basin in [days]

Reference is midday, partial coverage of days is considered. Autochtonous runoff (riverflow generated inside a subbasin, not entering from upstream) is routed slightly different with zero lag time (triangular like this: /\\_; tL\*=0, tR\*=tL+tR).

Example: The sub-basin with the Map-ID of 49 has a lag time of 0.5 days and a retention time of 2 days (i.e. its runoff will be delayed by 0.5 day, then stretched over another 2 days). The sub-basin with the Map-ID of 50 has a lag time of 1 day and a retention time of 1.5 days; etc.

For a detailed description of the routing process and the linear response function, see Güntner (2002), p. 48 and Bronstert *et al.* (1999). The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise an error message occurs.

4) bedload.dat

|  |
| --- |
| Specification of bedload modelling parameter D50  Subasin-ID, D50 (m)  49 0.048  50 0.048  1 0.048  … |

Subasin-ID Map-ID of sub-basin

D50 median sediment particle size in the riverbed in (m)

Example: The river stretch in the sub-basin with the Map-ID of 49 has a riverbed gradation with a D50 value of 0.048 m.

5) subbasin\_out.dat (optional)

|  |
| --- |
| pre-specified mean daily river flow [m3/s] for selected sub-basins (MAP-IDs)  Date Timestep Subbasin-ID.  0 0 4  1092005 1 0.5  2092005 1 0.3  3092005 1 0.2  … |

Date Date in the format ddmmyyyy

Timestep timestep (not interpreted in daily resolution, 1..24 for hourly resolution)

Subasin-ID Map-ID of sub-basin

This optional file allows specifying the water output of selected subbasins. If this file is not found in the folder Time\_series, all subbasins are treated regularly. Otherwise, any outflow that is specified in this file is used directly as an output of the respective subbasin – no computations are performed within this basin (evaporation, groundwater, river routing, etc.). WASA reads data from this file sequentially, starting from start of simulation and every calendar year (e.g. chunks of 365 days). The subsequent entries are assumed without gaps and not checked for completeness.

Example: Sub-basin 4 has pre-specified discharge of 0.5 m³/s for 1 Sep 2005.

6) subbasin\_outsed.dat (optional)

|  |
| --- |
| pre-specified daily sediment output [t] for selected sub-basins (MAP-IDs), mean PSD: 0.3 0.2 0.5  Date Timestep Subbasin-ID.  0 0 4  1092005 1 0.5  2092005 1 0.3  3092005 1 0.2  … |

mean PSD mean particle size distribution to be used for all records, consists of n\_sed\_classes fraction values that sum to 1

Date Date in the format ddmmyyyy

Timestep timestep (not interpreted in daily resolution, 1..24 for hourly resolution)

Subasin-ID Map-ID of sub-basin

This optional file allows specifying the sediment output of selected subbasins. If this file is not found in the folder Time\_series, all subbasins are treated regularly. Otherwise, any sediment output that is specified in this file is used directly as an output of the respective subbasin – no sediment related computations are performed within this basin. WASA reads data from this file sequentially, starting from start of simulation and every calendar year (e.g. chunks of 365 days). The subsequent entries are assumed without gaps and not checked for completeness.

Example: Sub-basin 4 has pre-specified sediment output of 0.5 t/d for 1 Sep 2005, distributed among 3 particle size classes with the fractions 0.3, 0.2 and 0.5.

Input files for the reservoir module

The input files for the reservoir module are located in the folder Input\[case\_study]\Reservoir and are summarised in Table 7. The files listed below are required according to the simulation option defined in the file *do.dat*. Reservoirs are considered in the model simulations if the option *doreservoir* is switched on. For simulations of reservoir water balance the file *reservoir.dat* (file 1) is required. Nevertheless, additional files can be given to improve the model results (files 2 to 6). For calculations of reservoir sediment balance, the options *doreservoir* and *dosediment* must be switched on. The reservoir sedimentation model consists of two modelling approaches, which may be applied according to reservoir size and data availability. For reservoirs with information about their geometric features (reservoir topography, stage-area and stage-volume curves) and physical properties of sediment deposits, such as deposition thickness, grain size distribution of sediment deposits and sediment densities, a detailed modelling approach to reservoir sedimentation may be applied (files 7 to 9 are required; and files 10 to 12 are used to improve model results). For reservoirs without those characteristics, a simplified modelling approach is used (file 8 is required). Networks of small reservoirs are considered in the model simulations if the option *doacudes* is switched on. For simulations of water and sediment routing through the reservoir networks the file 13 and 16 are required (files 14, 15 and 17 are used to improve model results).

Table 7 Input data files for the reservoir component

|  |  |
| --- | --- |
| **Parameter File** | **Content** |
| 1) reservoir.dat | Specification of reservoir parameters |
| 2) lateral\_inflow.dat (optional) | Specification of lateral inflow into the sub-basin’s reservoir |
| 3) operat\_rule.dat (optional) | Specification of reservoir operation rule |
| 4) operat\_bottom.dat (optional) | Specification of operation rule of reservoir bottom outlets |
| 5) cav.dat (optional) | Specification of stage-area and stage-volume curves of the sub-basin’s reservoir |
| 6) intake.dat (optional) | Specification of measured data on regulated outflow discharge through intake devices from the sub-basin’s reservoir. This file is a time series file and thus need to be in directory Time\_series! |
| 7) hydraul\_param.dat (optional) | Specification of hydraulic parameters of the sub-basin’s reservoir |
| 8) sed.dat | Specification of sedimentation parameters of the sub-basin’s reservoir |
| 9) cross\_sec\_”Map-ID”.dat (optional) | Specification of cross section geometry of the sub-basin’s reservoir (sub-basin with a specific Map-ID) |
| 10) original\_sec\_”Map-ID”.dat (optional) | Specification of original cross section geometry of the sub-basin’s reservoir (sub-basin with a specific Map-ID) |
| 11) sizedist\_”Map-ID”.dat (optional) | Specification of size distribution of original bed material along the cross sections of the sub-basin’s reservoir (sub-basin with a specific Map-ID) |
| 12) main\_channel.dat (optional) | Specification of main channel geometry of the sub-basin’s reservoir |
| 13) lake.dat | Specification of parameters for the reservoir size classes |
| 14) lake\_maxvol.dat (optional) | Specification of water storage capacity for the reservoir size classes |
| 15) lake\_year.dat (optional) | Specification of changes on the number of reservoirs in the size classes |
| 16) lake\_number.dat | Specification of total number of reservoirs in the size classes |
| 17) lake\_frarea.dat (optional) | Specification of runoff contributing area for the reservoir size classes |

1) reservoir.dat

|  |
| --- |
| Specification of reservoir parameters  Subasin-ID, minlevel[m], maxlevel[m], vol0([1000m\*\*3]; unknown=-999), storcap[1000m\*\*3], damflow[m\*\*3/s], damq\_frac[-], withdrawal[m\*\*3/s], damyear[YYYY], maxdamarea[ha], damdead[1000m\*\*3], damalert[1000m\*\*3], dama[-], damb[-], qoutlet[m\*\*3/s], fvol\_bottom[-], fvol\_over[-], damc[-], damd[-], elevbottom[m]  60 413.30 447.67 45213.92 91795.66 36.00 1.00 0.020 1980 718.67 4802.95 45213.92 20.935 0.716 146.84 1.00 0.80 300 1.5 430 |

Subasin-ID Map-ID of sub-basin

minlevel Initial minimum level in the sub-basin’s reservoir [m]. Value varies because of the sediment accumulation

maxlevel Maximum water level in the sub-basin’s reservoir [m]

vol0 Initial volume of the sub-basin’s reservoir [10³ m³]. Value varies because of the sediment accumulation

storcap Initial storage capacity in the sub-basin’s reservoir [10³ m³]. Value varies because of the sediment accumulation

damflow Target release through the barrage’s intake devices of the sub-basin’s reservoir [m³/s]. Contributes to *intake* in output file res\_\*\_watbal.out. Influenced by *damq\_frac* and further reduced if the reservoir’s actual storage volume is less than *damalert.*

damq\_frac Maximum fraction of *damflow* which is released from the sub-basin’s reservoir [-]

withdrawal Water withdrawal discharge to supply the water use sectors in the sub-basin’s reservoir [m³/s]. Outflow discharge through the dam is not considered

damyear Year of construction of the dam in the sub-basin

maxdamarea Initial maximum area of the sub-basin’s reservoir (ha). Value varies because of the sediment accumulation

damdead. Initial dead volume of the sub-basin’s reservoir [10³ m³]. Value varies because of the sediment accumulation. Influences actual values of *damflow* and *qoutlet*.

damalert. Initial alert volume of the sub-basin’s reservoir [10³ m³]. Value varies because of the sediment accumulation. Influences *damflow*. Should be set to volume at the height of the barrage’s intake devices.

dama, damb Parameters of the area-volume relationship in the sub-basin’s reservoir (area=dama.Voldamb) [-]. Values of reservoir area and volume are expressed in m² and m³, respectively. damb should be > 0 and <= 1.

qoutlet Maximum outflow discharge released through the bottom outlets in the sub-basin’s reservoir [m³/s]. Contributes to *qbottom* in output file res\_\*\_watbal.out. Set to zero if less than *damdead* or less than *fvol\_bottom*\**storcap.*

fvol\_bottom Fraction of storage capacity that indicates the minimum storage volume for sediment release through the bottom outlets of the sub-basin's reservoir [-]. Influences the actual value of *qoutlet*.

fvol\_over Fraction of storage capacity that indicates the minimum storage volume for water release through the spillway of the sub-basin's reservoir [-]

damc, damd Parameters of the spillway rating curve in the sub-basin’s reservoir (Qout=damc.Hvdamd) [-]. Values of water height over the spillway and overflow discharges are expressed in m and m³/s, respectively

elevbottom bottom outlet elevation of the sub-basin's reservoir [m]. Currently not used, fill in dummy values.

Example: At the outlet point of the sub-basin with the Map-ID 60, there is a reservoir with an initial minimum level of 413.30 m, a maximum water level of 447.67 m, an initial volume of 45,213,920 m³, an initial storage capacity of 91,795,660 m³, a target outflow discharge of 36 m³/s, a water withdrawal discharge to supply the water use sectors of 20 L/s, year of construction in 1980, an initial maximum area of 718.67 ha, an initial dead volume of 4,802,950 m³, an initial alert volume of 45,213,920 m³, an area-volume relationship with parameters *dama* and *damb* set to 20.935 and 0.716, respectively, an maximum outflow discharge through the bottom outlets of 146.84 m³, a percentage of storage capacity for the operation of bottom outlets of 100 % and a percentage of storage capacity for overflow discharge through radial gates of 80 %, a spillway rating curve with parameters *damc* and *damd* set to 300 and 1.5, respectively. Value of *vol0* set to -999 means that at the beginning of the simulation period the water volume is 20 % of the storage capacity (Güntner, 2002). Value of *damq\_frac* set to -999 means that the reservoir operation rule is affected by irrigation season. Thus, an additional file has to be provided, which gives the interannual variability of exploitation regime (see below the file *operat\_rule.dat*). Values of *damflow* may be replaced by measurements when providing the optional input file intake.dat (see file description). Value of *fvol\_bottom* set to -999 means that an additional file must be provided with detailed information about the sediment management technique selected to routing sediment through the sub-basin’s reservoir (see below the file *operat\_bottom.dat*). The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without outlet reservoirs must not be entered in the file.

2) lateral\_inflow.dat

|  |
| --- |
| Specification of lateral inflow into the sub-basin’s reservoir  Subasin-ID, reservoir\_down[-]  15 60 |

Subasin-ID Map-ID of sub-basin with generated runoff flowing directly into the reservoir of another sub-basin

Reservoir\_down Map-ID of sub-basin with an outlet reservoir that receives lateral inflow coming from another sub-basin.

Example: This optional file allows specifying lateral inflow into the sub-basin’s reservoir. If this file is not found in the folder reservoir, lateral inflow into the sub-basin’s reservoir is disregarded. The reservoir located at the outlet point of the sub-basin with the Map-ID 60 receives lateral inflow coming from the sub-basin with the Map-ID 15. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without generated runoff flowing directly into the reservoir of another sub-basin must not be entered in the file.

3) operat\_rule.dat (optional)

|  |
| --- |
| Specification of reservoir operation rule  Subasin-ID, dayexplot(4 values)[-], damq\_frac\_season(4 values)[m\*\*3/s]  60 59 120 212 335 0.50 0.72 0.38 0.17 |

Subasin-ID Map-ID of sub-basin

dayexplot Days of change in exploitation regime in the sub-basin's reservoir [-]. Four days of the year have to be provided

damq\_frac\_season Fraction of Q90 released from the sub-basin's reservoir in different seasons in the sub-basin's reservoir [-]

Example: This optional file allows specifying changes on the operation rule of the sub-basin’s reservoir. If this file is not found in the folder reservoir, a target value of controlled outflow discharge given in the file *reservoir.dat* is applied to the respective sub-basin’s reservoir. The reservoir located at the outlet point of the sub-basin with the Map-ID 60 changes its exploitation regime on those days of the year (59, 120, 212 and 335). Such values are followed by four corresponding values of fraction of Q90 released from the sub-basin's reservoir, according to the given intervals (0.50, 0.72, 0.38 and 0.17). It means that exemplarily between the 120th and the 212th of the year 38 % of Q90 can be released. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without outlet reservoirs or those without data on reservoir operation rule must not be entered in the file.

4) operat\_bottom.dat (optional)

|  |
| --- |
| Specification of operation rule of reservoir bottom outlets  Subasin-ID, operat\_start[-], operat\_stop[-], operat\_elev[m]  60 270 320 430 |

Subasin-ID Map-ID of sub-basin

operat\_start Target day of year to open the bottom outlets [-]

operat\_stop Target day of year to close the bottom outlets [-]

operat\_elev Target water depth of the sub-basin's reservoir during the period the bottom outlets remain open [m]

Example: This optional file allows specifying the operation rule of bottom outlets of the sub-basin’s reservoir. If this file is not found in the folder reservoir, a target value of controlled outflow discharge through the bottom outlets given in the file *reservoir.dat* is applied to the respective sub-basin’s reservoir. The bottom outlets of the reservoir located at the outlet point of the sub-basin with the Map-ID 60 are opened on 120th day and closed on 212th of the year. During that period, the reservoir water level should not surpass the elevation of 430 m in order to increase flow velocity and, consequently, sediment release. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without outlet reservoirs or those without data on operation rule of bottom outlets must not be entered in the file.

5) cav.dat (optional)

|  |
| --- |
| Specification of stage-area and stage-volume curves of the sub-basin’s reservoir  Subasin-ID, nbr. points, 1st row: elevation [m], 2nd row: reservoir area [1000m\*\*2], 3rd row: reservoir volume [1000m\*\*3]  60 36 413.30 415.00 416.00 417.00 … 447.00 447.67 448.00 in totalmax 200 IDs  60 36 0.00 54.82 96.10 142.89 … 6980.25 7186.73 7288.43 in totalmax 200 IDs  60 36 0.00 35.78 111.24 231.23 … 87049.73 91795.66 94184.06 in totalmax 200 IDs |

Subasin-ID Map-ID of sub-basin

Nbr. points Number of points from the stage-area and stage-volume curves of the sub-basin's reservoir

1st row: elevation 1st row of each sub-basin: water elevation from the stage-area and stage-volume curves of the sub-basin's reservoir [m]

2nd row: reservoir area 2nd row of each sub-basin: reservoir area for a given elevation at the stage-area and stage-volume curves of the sub-basin's reservoir [103 m2]

3rd row: reservoir volume 3rd row of each sub-basin: reservoir volume for a given elevation at the stage-area and stage-volume curves of the sub-basin's reservoir [103 m3]

Example: This optional file allows specifying the stage-area and stage-volume curves of the sub-basin’s reservoir. If this file is not found in the folder reservoir, an area-volume relationship given in the file *reservoir.dat* is applied to the respective sub-basin’s reservoir. The reservoir located at the outlet point of the sub-basin with the Map-ID 60 has 36 points at the stage-area and stage-volume curves. The first row holds 36 values of water elevation at the stage-area and stage-volume curves (413.30 m, 415.00 m, 416.00 m, 417.00, etc). The second row holds 36 values of reservoir area for the given values of elevation at the stage-area and stage-volume curves (0.00 m2, 54.82 10³m², 96.10 10³m², 142.89 10³m², etc). Finally, the third row holds 36 values of reservoir volume for the given values of elevation at the stage-area and stage-volume curves (0.00 10³m³, 35.78 10³m³, 111.14 10³m³, 231.23 10³m³, etc). The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without outlet reservoirs or those without data on stage-area and stage-volume curves must not be entered in the file.

6) intake.dat (optional)

|  |
| --- |
| Specification of controlled release through reservoir's intake devices in [m3/s]  Date doy 10 16  1012005 1 5 -999  2012005 2 5 0.1  … |

Date Date [ddmmyyyy]

Doy day of year. Not used but kept for historical reasons, fill in dummy values.

Sub-basin ID Measured data on regulated outflow discharge through intake devices of the reservoir’s barrage in a specific sub-basin [m³/s]

Example: This optional file allows specifying measured data on regulated outflow discharge of the sub-basin’s reservoir. If this file is not found in the folder Time\_series, either a target value of regulated outflow discharge is given in the file *reservoir.dat* or a reservoir operation rule is provided in the file *operat\_rule.dat* to the respective sub-basin’s reservoir. On January 1st 2005, a discharge of 5 m³/s was regulated through the intake devices of the barrage from the reservoir located at the outlet of the sub-basin 10. A regulated outflow discharge set to -999 for sub-basin 16 means that there is no measured data that day. In that case, the target value of regulated outflow discharge given in the file *reservoir.dat* (parameter *damflow*) is used. Time series of measured data on regulated outflow discharge of the sub-basin’s reservoir must be given for the whole simulation period. For those days without measurements, the value of regulated outflow discharge must be set to -999. Sub-basins without outlet reservoirs or those without measured data on regulated outflow discharge must not be entered.

7) hydraul\_param.dat (optional)

|  |
| --- |
| Specification of hydraulic parameters of the sub-basin’s reservoir  Subasin-ID, nbr. cross sec, 1st row: manning [s/m\*\*1/3], 2nd row: distance [-]  60 53 0.025 0.035 0.025 … 0.025 0.025 0.025 in totalmax 200 IDs  60 53 209.485 199.605 162.748 … 260.775 237.29 138.492 in totalmax 200 IDs |

Subasin-ID Map-ID of sub-basin

nbr cross sec Number of cross sections in the sub-basin’s reservoir

1st row: manning 1st row of each sub-basin: Manning's roughness for each cross section [m-1/3.s]

2nd row: distance 2nd row of each sub-basin: distance to the downstream cross section [m]

Example: This optional file allows specifying hydraulic parameters for the calculation of water routing through the sub-basin’s reservoir. If this file is not found in the folder reservoir, a simplified modelling approach for the calculation of sediment balance is assumed. The reservoir located at the outlet point of the sub-basin with the Map-ID 60 has 53 cross sections. The first row holds 53 values of Manning's roughness (0.025 m-1/3.s, 0.035 m-1/3.s, 0.025 m-1/3.s, etc). The second row holds 50 values of distance from a given cross section to the downstream cross section (209.485 m, 199.605 m, 162.748 m, etc). The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise an error message occurs. Sub-basins without outlet reservoirs or those without hydraulic data must not be entered in the file.

8) sed.dat

|  |
| --- |
| Specification of sedimentation parameters of the sub-basin’s reservoir  Subasin-ID, dry\_dens[ton/m\*\*3], factor\_actlay[-]  60 1.5 1 42 |

Subasin-ID Map-ID of sub-basin

dry\_dens Dry bulk density of the sediment deposited in the subbasin's reservoir [ton/m³]

factor\_actlay Calibration parameter for the determination of the active layer thickness [-]

Example: At the outlet point of the sub-basin with the Map-ID 60 there is a reservoir with a dry bulk density of 1.5 ton/m3. The calibration parameter for the determination of the active layer thickness at that reservoir is equal to 1. It means that the default value of active layer thickness (set to 0.03 mm, derived from the simulation for the Barasona reservoir in Spain) is multiplied by a factor of 1. For the calculation of sediment balance using the simplified modelling approach, the third column with values of *factor\_actlay* must not be entered in the file. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without outlet reservoirs must not be entered in the file.

9) cross\_sec\_*”Map-ID”*.dat (optional)

|  |
| --- |
| Specification of cross section geometry of the sub-basin’s reservoir  Subasin-ID, section-ID, nbpoints, x-axis [m], y-axis[m]  60 1 8 81.18 460 119.29 455 … 319.32 460 in totalmax 200 IDs  60 2 12 60.72 460 189.24 450 … 382.93 460 in totalmax 200 IDs  … |

Subasin-ID Map-ID of sub-basin

Section-ID Map-ID of cross-section

nbrpoints Number of points at the cross section of the sub-basin’s reservoir

x-axis Values at the x-axis for each point of the cross section in the sub-basin’s reservoir (from left to right, view from upstream side) [m]

y-axis Values at the y-axis for each point of the cross section in the sub-basin’s reservoir (from left to right, view from upstream side) [m]

Example: This optional file allows specifying detailed data on cross section geometry for the calculation of water routing through the sub-basin’s reservoir. If this file is not found in the folder reservoir, a simplified modelling approach for the calculation of sediment balance is assumed. The reservoir located at the outlet point of the sub-basin with the Map-ID 60 was divided into 53 cross sections. The first row holds eight points with values at the x-axis (81.18 m, 119.29 m, etc) and y-axis (460 m, 450 m, etc) at the most upstream cross section of the of the sub-basin’s reservoir. The second row holds 12 points with values at the x-axis (60.72 m, 189.24 m, etc) and y-axis (460 m, 450 m, etc) at the next downstream cross section of the sub-basin’s reservoir. All cross sections of the sub-basin’s reservoir must be entered in the file. The value at the y-axis should be given after the value at the x-axis for a same point at the cross section. Sub-basins with data on cross section geometry must be entered in different input files (e.g. *cross\_sec\_60.dat* referred to sub-basin with Map-ID 60). Sub-basins without outlet reservoirs or those without measured data on cross section geometry must not be entered.

10) original\_sec\_*”Map-ID”*.dat (optional)

|  |
| --- |
| Specification of original cross section geometry of the sub-basin’s reservoir  Subasin-ID, section-ID, nbpoints, y\_original[m]  60 1 8 460 455 450 … 455 460 in totalmax 200 IDs  60 2 12 460 450 449 … 455 460 in totalmax 200 IDs  … |

Subasin-ID Map-ID of sub-basin

Section-ID Map-ID of cross-section

nbrpoints Number of points at the cross section of the sub-basin’s reservoir

y\_original Values of original bed elevation for each point of the cross section in the sub-basin’s reservoir (from left to right, view from upstream side) [m]

Example: This optional file allows specifying detailed data on original cross section geometry for the calculation of water routing through the sub-basin’s reservoir. If this file is not found in the folder reservoir, there are two possibilities: sediment routing through the sub-basin’s reservoir is computed anyway, assuming that the original cross section geometry is the same as provided in the file *cross\_sec\_”Map-ID”.dat*; or a simplified modelling approach for the calculation of sediment balance is assumed (if the file *cross\_sec\_”Map-ID”.dat* is not given). The reservoir located at the outlet point of the sub-basin with the Map-ID 60 was divided into 53 cross sections. The first row holds eight values of original bed elevation for cross section 1 (460 m, 455 m, etc). The second row holds 12 values of original bed elevation for cross section 2 (460 m, 450 m, etc). All cross sections of the sub-basin’s reservoir must be entered in the file. Sub-basins with data on original cross section geometry must be entered in different input files (e.g. *original\_sec\_60.dat* referred to sub-basin with Map-ID 60). Sub-basins without outlet reservoirs or those without measured data on original cross section geometry must not be entered.

11) sizedist\_”Map-ID”.dat (optional)

|  |
| --- |
| Specification of size distribution of original bed material along the cross sections of the sub-basin’s reservoir  Subasin-ID, section-ID, frac\_actlay[-]  60 1 0 0 0 0.8848 0.1101 0.0049 0.0002 total number of sediment size classes  60 2 0.0307 0.0115 0.0012 0.7485 0.2044 0.0034 0.0003 total number of sediment size classes  … |

Subasin-ID Map-ID of sub-basin

Section-ID Map-ID of cross-section

y\_original Values of sediment fraction for different size classes of the cross section in the sub-basin’s reservoir [-]. The total number of sediment size classes is previously specified in the file *do.dat*.

Example: This optional file allows specifying detailed data on size distribution of original bed material for the calculation of water routing through the sub-basin’s reservoir. If this file is not found in the folder reservoir, there are two possibilities: sediment routing through the sub-basin’s reservoir is computed anyway, assuming that no sediment was deposited the sub-basin’s reservoir previously; or a simplified modelling approach for the calculation of sediment balance is assumed (if the file *cross\_sec\_”Map-ID”.dat* is not given). The reservoir located at the outlet point of the sub-basin with the Map-ID 60 was divided into 53 cross sections. The first row holds values of sediment fraction for seven sediment size classes of cross section 1 (0, 0, etc). The second row holds values of sediment fraction for seven sediment size classes of cross section 2 (0.0307, 0.0115, etc). All cross sections of the sub-basin’s reservoir must be entered in the file. Sub-basins with data on size distribution of original bed material must be entered in different input files (e.g. *sizedist\_sec\_60.dat* referred to sub-basin with Map-ID 60). Sub-basins without outlet reservoirs or those without measured data on size distribution of original bed material must not be entered.

12) main\_channel.dat (optional)

|  |
| --- |
| Specification of main channel geometry of the sub-basin’s reservoir  Subasin-ID, nbr. cross sec, 1st row: pt1 [-], 2nd row: pt2 [-]  60 53 8 10 15 … 40 65 70 in totalmax 200 IDs  60 53 15 17 25 … 60 80 90 in totalmax 200 IDs |

Subasin-ID Map-ID of sub-basin

nbr cross sec Number of cross sections in the sub-basin’s reservoir

1st row: manning 1st row of each sub-basin: Point of the cross section in the sub-basin’s reservoir that identifies the beginning of main channel (from left to right, view from upstream side) [-]

2nd row: distance 2nd row of each sub-basin: Point of the cross section in the sub-basin’s reservoir that identifies the end of main channel (from left to right, view from upstream side) [-]

Example: This optional file allows specifying the exact location of main channel in the cross sections of the sub-basin’s reservoir. This information is used to adjust bed profiles of cross sections, avoiding steeper slopes caused by erosion processes. If this file is not found in the folder reservoir, there are two possibilities: sediment routing through the sub-basin’s reservoir is computed anyway, disregarding the occurrence of steeper slopes; or a simplified modelling approach for the calculation of sediment balance is assumed (if the file *cross\_sec\_”Map-ID”.dat* is not given). The reservoir located at the outlet point of the sub-basin with the Map-ID 60 has 53 cross sections. The main channel of cross section 1 is located between the 8th and 15th points (cross section 2: located between the 10th and 17th points; etc). A value of -999 indicates unknown location of main channel for that cross section. Sub-basins without outlet reservoirs or those without data on location of main channel of cross sections must not be entered in the file.

13) lake.dat

|  |
| --- |
| Specification of parameters for the reservoir size classes  Reservoir\_class-ID, maxlake0[m\*\*3], lake\_vol0\_factor[-], lake\_change[-], alpha\_Molle[-], damk\_Molle[-], damc\_hrr[-], damd\_hrr[-]  1 5000 0.2 0.10 2.7 1500 7 1.5  2 25000 0.2 0 2.7 1500 14 1.5  3 50000 0.2 0 2.7 1500 21 1.5  4 100000 0.2 0 2.7 1500 28 1.5  5 250000 0.2 0 2.7 1500 35 1.5 |

Reservoir\_class-ID Map-ID of reservoir size class

maxlake0 Upper limit of reservoir size class in terms of volume [m³]

lake\_vol0\_factor Fraction of storage capacity that indicates the initial water volume in the reservoir size classes [-]

lake\_change Factor that indicates yearly variation in the number of reservoirs of the size classes [-]

alpha\_Molle, damk\_Molle Parameters of the area-volume relationship in the reservoir size classes (Area=alpha.k.(Vol/k)alpha/(alpha-1)) [-]. Values of reservoir area and volume are expressed in m² and m³, respectively

damc\_hrr, damd\_hrr Parameters of the spillway rating curve in the reservoir size classes (Qout=damc\_hrr.Hvdamd\_hrr) [-]. Values of water height over the spillway and overflow discharges are expressed in m and m³/s, respectively

Example: The study area has a network of small reservoirs, which are grouped into five size classes according to their storage capacity (changes on the number of size classes are not available yet). The water and sediment balances of small reservoirs are computed for one hypothetical representative reservoir of mean characteristics. The size class 1 has reservoirs with storage capacity up to 5,000 m³, an initial water volume of 20% of the storage capacity, an yearly increase of 10% in the number of reservoirs for the simulation period (*lake\_increase* set to zero means that the number of reservoirs remains constant), an area-volume relationship with parameters *alpha\_Molle* and *damk\_Molle* set to 2.7 and 1500, respectively, and a spillway rating curve with parameters *damc\_hrr* and *damd\_hrr* set to 7 and 1.5, respectively.

14) lake\_maxvol.dat (optional)

|  |
| --- |
| Specification of water storage capacity for the reservoir size classes  Sub-basin-ID, maxlake[m\*\*3] (five reservoir size classes)  60 2627.21 16591.52 0 0 0  … |

Subasin-ID Map-ID of sub-basin

maxlake Mean value of initial storage capacity of the hypothetical representative reservoirs of the size classes [m³]. Value varies because of the sediment accumulation

Example: This optional file allows specifying data on initial storage capacity of the hypothetical representative reservoirs of the size classes. If this file is not found in the folder reservoir, the initial storage capacity is computed as a geometrical mean of the lower and upper limit of the reservoir size classes (except for class 1, computed as 50% of its upper limit). The sub-basin with the Map-ID 60 has only two reservoir size classes with initial storage capacities of 2627.21 m³ and 16591.52 m³ (size classes 1 and 2, respectively). Therefore, there is no reservoir at the size classes 3 to 5 for that sub-basin. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without networks of small reservoirs must not be entered in the file.

15) lake\_year.dat (optional)

|  |
| --- |
| Specification of changes on the number of reservoirs in the size classes  Year, sub-basin-ID, acudfloatyear[-] (five reservoir size classes)  2005 15 32 34 17 20 11  2005 60 111 72 22 25 59  2006 15 34 36 18 21 12  2006 60 117 76 23 26 62  2007 15 35 37 19 22 12  2007 60 122 79 24 28 65  2008 15 37 39 20 23 13  2008 60 128 83 25 29 68 |

Year Year of simulation (yyyy)

subasin-ID Map-ID of sub-basin

acudfloatyear Total number of reservoirs in the sub-basin and size classes for all years of simulation [m³]

Example: This optional file allows specifying changes on the number of reservoirs in the size classes. If this file is not found in the folder reservoir, a yearly variation in the number of reservoirs for sub-basins and size classes given in the file *lake.dat* is assumed. In the year 2005, the sub-basin with the Map-ID 15 has 32 reservoirs of class 1, 34 of class 2, 17 of class 3, 20 of class 4, and 11 of class 5. The order of the sub-basins in the second column has to follow the same order of the sub-basin IDs for all years of simulation as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without networks of small reservoirs must not be entered in the file.

16) lake\_number.dat

|  |
| --- |
| Specification of total number of reservoirs in the size classes  Sub-basin-ID, acud[-] (five reservoir size classes)  60 15 8 0 0 0 |

Subasin-ID Map-ID of sub-basin

acud Total number of reservoirs in the size classes [-]

Example: The sub-basin with the Map-ID 60 has 15 and 8 reservoirs of the size classes 1 and 2, respectively. Therefore, there is no reservoir of size classes 3 to 5 for that sub-basin. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without networks of small reservoirs must not be entered in the file.

17) lake\_frarea.dat (optional)

|  |
| --- |
| Specification of runoff contributing area for the reservoir size classes  Sub-basin-ID, lakefrarea[-] (five reservoir size classes)  60 0.240 0.250 0 0 0 |

Subasin-ID Map-ID of sub-basin

maxlake Fraction of sub-basin area that represents the runoff contributing area for the reservoir size classes [-]

Example: This optional file allows specifying data on runoff contributing area for the reservoir size classes. If this file is not found in the folder reservoir, the runoff contributing area is equally divided into the five reservoir size classes (one-sixth to each class). Another sixth part is attributed to the area not-controlled by the reservoir network. The sub-basin with the Map-ID 60 has only two reservoir size classes with a runoff contributing area covering 24% and 25% of the sub-basin area (size classes 1 and 2, respectively). Therefore, there is no reservoir of size classes 3 to 5 for that sub-basin. The order of the sub-basins in the first column has to follow the same order of the sub-basin IDs as was used in hymo.dat (due to computational reasons); otherwise, an error message occurs. Sub-basins without networks of small reservoirs must not be entered in the file.

Input of climate data

The WASA model requires time series with a temporal resolution of one hour or one day for precipitation, short wave radiation, humidity and temperature. The input files are located in the folder Input\[case\_study]\Time\_series and are summarised below.

**temperature.dat**

|  |
| --- |
| Daily average temperature (in degree Celcius) for each subasin, ordered according to Map-IDs  Date No. of days, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID  0 0 49 50 1 44 10 4 15 39 3 29  01011980 1 15 15 15 15 15 15 15 15 15 15  02011980 2 15 15 15 15 15 15 15 15 15 15  03011980 3 15 15 15 15 15 15 15 15 15 15  … |

**rain\_daily.dat**

|  |
| --- |
| Daily average precipitation [mm/d] for each subasin, ordered according to Map-IDs  Date No. of days, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID  0 0 49 50 1 44 10 4 15 39 3 29  01011980 1 40 40 40 40 40 40 40 40 40 40  02011980 2 40 40 40 40 40 40 40 40 40 40  03011980 3 40 40 40 40 40 40 40 40 40 40  … |

**humidity.dat**

|  |
| --- |
| Daily average humidity [in %] for each subasin, ordered according to Map-IDs  Date No. of days, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID  0 0 49 50 1 44 10 4 15 39 3 29  01011980 1 75 75 75 75 75 75 75 75 75 75  02011980 2 75 75 75 75 75 75 75 75 75 75  03011980 3 75 75 75 75 75 75 75 75 75 75  … |

**radiation.dat**

|  |
| --- |
| Daily average shortwave radiation [in W/m2] for each subasin, ordered according to Map-IDs  Date No. of days, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID, Subasin-ID  0 0 49 50 1 44 10 4 15 39 3 29  01011980 1 260 260 260 260 260 260 260 260 260 260  02011980 2 260 260 260 260 260 260 260 260 260 260  03011980 3 260 260 260 260 260 260 260 260 260 260  … |

Date Continuous number of day month year

No. of days Continuous numbering

Subasin ID of sub-basin (Map-ID), same ordering at hymo.dat

Example: The four files are organised in the same manner. Here they are given for three days: 01.01.1980 until 03.01.1980. In the examples above, the time series are uniform for each sub-basin, however, it is possible to assign different time series to individual sub-basins.

**extraterrestrial\_radiation.dat**

|  |
| --- |
| Extra-terrestrial shortwave radiation as monthly mean daily value in [W/m2]  441  447  … |

This file specifies the extraterrestrial incoming shortwave radiation at the top of the atmosphere [W/m2]. The values are daily averages for each month from January until December (12 values).

Output Data

The location of the output folder is specified in the do.dat. By default, the output folder is set to WASA\Output. The parameter file **parameter.out** echoes the main parameter specification for the WASA model, as were given in the do.dat file.

Output of the hillslope module

The hillslope routine generates the following output files:

|  |  |
| --- | --- |
| **Output file** | **Content** |
| daily\_actetranspiration.out | daily actual evapotranspiration [mm/d] for all sub-basins (MAP-IDs) incl. river |
| daily\_potetranspiration.out | daily potential evapotranspiration [mm/d] for all sub-basins |
| daily\_qhorton.out | daily horton overland flow [m3] for all sub-basins |
| daily\_sediment\_production.out | daily sediment production [t] for all sub-basins and particle classes |
| daily\_subsurface\_runoff.out | daily total subsurface runoff [m3/d] for all sub-basins |
| daily\_theta.out | mean soil moisture in profile [mm] for all sub-basins |
| daily\_total\_overlandflow.out | total overland flow [m3] for all sub-basins |
| daily\_water\_subbasin.out water\_subbasin.out | daily water contribution into river [m3/s] for all sub-basins  sub-daily contribution to river [m3/s] for all sub-basins |
| sediment\_production.out | daily sediment production [t] for all sub-basins and particle classes |
| Daily\_gw\_loss.out | daily water loss from model domain due to deep seepage in LU without GW |
| deep\_gw\_discharge.out | total deep ground water discharge [m3] for all sub-basins |
| deep\_gw\_recharge.out | total deep ground water recharge [m3] for all sub-basins |
| actetranspiration.out | Subdaily actual evapotranspiration [mm] for all sub-basins incl. river |
| qhorton.out | subdaily horton overland flow [m3] for all sub-basins |
| subsurface\_runoff.out | subdaily total subsurface runoff [m3/d] for all sub-basins |
| total\_overlandflow.out | Subdaily total overland flow [m3] for all sub-basins |
| gw\_discharge.out | groundwater discharge [m\*\*3/timestep] for all sub-basins |
| potetranspiration.out | Subdaily potential evapotranspiration [mm/d] for all sub-basins |
| gw\_loss.out | model loss (deep seepage) [m\*\*3/timestep] for all sub-basins |
| gw\_recharge.out  storage.stats\_start  storage.stats  gw\_storage.stat  intercept\_storage.stat  soil\_moisture.stat | groundwater recharge [m\*\*3/timestep] for all sub-basins  Summary of storages (Groundwater, soil, interception) at start of simulation  Summary of storages (Groundwater, soil, interception) at end of simulation  Ground water storage  Interception storage  Soil moisture storage |

The output files daily\_water\_subbasin.out, sediment\_production.out and water\_subbasin.out include the effect of the distributed reservoirs. All other remaining basic hydrological output files contain the raw output of the hillslope module (no reservoir effects). All above-mentioned files have the same structure, as shown by the example daily\_actetranspiration.outbelow (the subdaily output files additionally contain the timestep number in the third column):

|  |
| --- |
| daily actual evapotranspiration [mm/d] for all sub-basins (MAP-IDs)  Year Day 57 15 20 60  1980 1 3.495 2.974 3.258 3.412  1980 2 3.504 3.076 3.424 3.436  … |

year year of simulation

day day of current year of simulation

[variable] respective variable for each sub-basin

Beware: “day” counts the number of days in the respective simulation year, i.e. if you start your simulation on May, 1, the number “1” refers to this day and the rest of the days in that year will be counted till 306.

**gw\_storage.stat, intercept\_storage.stat, soil\_moisture.stat and storage.stats:**

These files are written at the end of each simulation year, thus allowing recommencing an aborted WASA run starting from the last simulation timestep. Beware: all other output files are overwritten in this case. For file structure, see section “Input files”. storage.stats contains the overall summary of storages corresponding to the three files mentioned before.

Output of the river module

The river routine calculates the water and sediment discharge in each river stretch. Currently, the output comprises the water discharge and storage values for each timestep, and the linear response function, when river routing scheme 1 is selected. The following files are generated as daily time series, if enabled and depending on the selected routing scheme:

|  |  |
| --- | --- |
| **Output file** | **Content** |
| River\_flow.out | River discharge in m3/s |
| River\_storage.out | River storage volume in m3 |
| River\_velocity.out | Flow velocity in m/s |
| River\_flowdepth.out | Flow depth in m |
| River\_Flow\_dailyaverage.out | Daily averaged flow in m3/s |
| River\_Sediment\_total.out | Suspended sediment in tons/timestep |
| River\_Sediment\_Concentration.out | Suspended sediment conc. in g/l |
| River\_Sediment\_total\_dailyaverage.out | Daily averaged sediment flux in tons/h |
| River\_Degradation.out | Degradation of sediment in riverbed in tons/stretch |
| River\_Deposition.out | Deposition of sediment in riverbed in tons/stretch |
| River\_Bedload.out | Bedload rate for 5 formulas in kg/s |
| Routing\_response.out | Linear response function for routing scheme 1 |
| River\_Sediment\_storage.out  River\_Susp\_Sediment\_storage.out  River\_Infiltration.out | Deposited sediment stored in river reach in t  Suspended sediment stored in river reach in t  Infiltration of river stretches |

All above-mentioned files the same structure, as shown by the example River\_flow.outbelow:

**River\_flow.out**

|  |
| --- |
| Output files for river discharge q\_out (m3/s) (with MAP IDs as in hymo.dat)  Year Day dt 9 10 11  2009 1 1 6.313 1.797 8.922  2009 1 2 6.176 1.744 8.733  2009 1 3 4.001 1.029 5.878  … |

Subasin-ID Map-ID of all sub-basins in the second line of the file

Timestep Timestep as specified in the do.dat in [hours]

Time series: water discharge in river stretch in m3/s

Example: After each time step, e.g. hourly, the discharge is given for each sub-basin, e.g. Sub-basin No. 9 has a discharge of 6.313 m3/s, Sub-basin No. 10 of 1.797 m3/s and Sub-basin No. 11 of 8.922 m3/s after 1 hours.

Output of the reservoir module

The reservoir module simulates the water and sediment transport through the reservoirs located in the study area. Currently, the output comprises results on water balance, hydraulic calculations, sediment transport and bed elevation changes for all reservoirs located at the outlet point of the sub-basins. The results are printed for all outlet reservoirs separately, identified by the Map-ID of the sub-basin where it is located. Additional files are also printed for the reservoir size classes. The following files are generated:

|  |  |
| --- | --- |
| **Output file** | **Content** |
| 1) res\_”Map-ID”\_watbal.out | Water balance components of outlet reservoirs |
| 2) res\_”Map-ID”\_vollost.out | Dead volume, alert volume, and storage capacity of outlet reservoirs |
| 3) res\_”Map-ID”\_cav.out | Stage-area and stage-volume curves of outlet reservoirs |
| 4) res\_”Map-ID”\_hydraul.out | Hydraulic components of outlet reservoirs |
| 5) res\_”Map-ID”\_sec”ID”  \_bedchange.out | Bed elevation at cross sections (identified by a specific Section-ID) of outlet reservoirs |
| 6) res\_”Map-ID”\_sedbal.out | Sediment balance components of outlet reservoirs |
| 7) res\_”Map-ID”\_longitudinal.out | Longitudinal bed profile of outlet reservoirs |
| 8) res\_”Map-ID”\_sedcomposition.out | Effluent grain size distribution of outlet reservoirs |
| 9) lake\_inflow\_r.out | Water inflow discharges into the reservoir size classes¹ |
| 10) lake\_outflow\_r.out | Water outflow discharges from the reservoir size classes¹ |
| 11) lake\_retention\_r.out | Water retention in the reservoir size classes¹ |
| 12) lake\_volume\_r.out | Water volume of the reservoir size classes¹ |
| 13) lake\_sedinflow\_r.out | Sediment inflow discharges into the reservoir size classes¹ |
| 14) lake\_sedoutflow\_r.out | Sediment outflow discharges from the reservoir size classes¹ |
| 15) lake\_sedretention\_r.out | Sediment retention in the reservoir size classes¹ |
| 16) lake\_sedimentation\_r.out | Cumulative sediment deposition in the reservoir size classes¹ |
| 17) lake\_watbal.out | Water balance components of all upstream reservoirs² |
| 18) lake\_sedbal.out | Sediment balance components of all upstream reservoirs² |
| 19) lake\_inflow.out | Water inflow discharges into the reservoir size classes³ |
| 20) lake\_outflow.out | Water outflow discharges from the reservoir size classes³ |
| 21) lake\_volume.out | Water volume of the reservoir size classes³ |
| 22) lake\_retention.out | Water retention in the reservoir size classes³ |
| 23) lake\_vollost.out | Sediment retention in the reservoir size classes³ |
| 24) lake\_sedinflow.out | Sediment inflow discharges into the reservoir size classes³ |
| 25) lake\_sedoutflow.out | Sediment outflow discharges from the reservoir size classes³ |
| 26) lake\_sizedistoutflow.out | Effluent grain size distribution of the reservoir size classes4 |

1 - Results are displayed for the whole catchment after grouping them by reservoir size classes (one value for the whole catchment and each reservoir size class)

2 - Results are displayed for the whole catchment without distinguishing between size classes (one value for the whole catchment)

3 - Results are displayed for all sub-basins after grouping them by reservoir size classes (one value for each sub-basin and reservoir size class).

4 - Results are displayed for all sub-basins without distinguishing between size classes (one value for each sub-basin).

**1) res\_”Map-ID”\_watbal.out**

|  |
| --- |
| Subasin-ID, year, day, hour, inflow(m\*\*3/s), intake(m\*\*3/s), overflow(m\*\*3/s), qbottom(m\*\*3/s),  qout(m\*\*3/s), elevation(m), area(m\*\*2), volume(m\*\*3)  60 1980 1 1 55.04 6.12 0.00 0.00 6.12 440.86 5255332.50 49625572.00  60 1980 1 2 42.01 6.12 0.00 0.00 6.12 441.48 4580464.00 52922032.00  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

inflow Water inflow discharges into the sub-basin's reservoir [m3/s]

intake Water outflow discharges through water intake devices in the sub-basin's reservoir [m3/s]

qbottom Water outflow discharges through bottom outlets in the sub-basin's reservoir [m3/s]

overflow Water overflow discharges in the sub-basin's reservoir [m3/s]

qout Total outflow discharges in the sub-basin's reservoir [m3/s]

elevation Reservoir level in the sub-basin's reservoir [m]

area Reservoir area in the sub-basin's reservoir [m2]

volume Reservoir volume in the sub-basin's reservoir [m3]

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has a water inflow discharge of 55.04 m3/s, a water outflow discharge through the intake device of 6.12 m3/s, no water overflow discharge, no water outflow discharge through the bottom outlets, a total water outflow discharge of 6.12 m3/s, a water level of 440.86, a reservoir area of 5,255,332.50 m2 and a reservoir volume of 49,625,572.00 m3. Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60\_watbal.out* referred to sub-basin with Map-ID 60)

**2) res\_”Map-ID”\_vollost.out**

|  |
| --- |
| Subasin-ID, year, day, hour, deadvol(m\*\*3), alertvol(m\*\*3), storcap(m\*\*3)  60 1980 1 1 4795484.24 45171678.11 91744848.62  60 1980 1 2 4795457.23 45171322.04 91744690.30  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

deadvol Dead volume in the sub-basin's reservoir [m3]

alertvol Alert volume in the sub-basin's reservoir [m3]

storvap Storage capacity in the sub-basin's reservoir [m3]

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has a dead volume of 4,795,484.24 m3, an alert volume of 45,171,678.11 m3, and a alert volume of 91,744,848.62 m3. Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60\_watbal.out* referred to sub-basin with Map-ID 60).

**3) res\_”Map-ID”\_cav.out**

|  |
| --- |
| Subasin-ID, year, day, hour, 1st row: elev\_bat(m), 2nd row: area\_bat(m\*\*2), 3rd row:  vol\_bat(m\*\*3)  60 1980 1 1 413.34 415.00 416.00 … 447.00 447.67 448.00  60 1980 1 1 0.00 79176.34 122767.10 … 5872791.16 6020551.37 7288430.00  60 1980 1 1 0.00 35021.39 110657.75 … 86999642.73 91744848.62 94132893.50  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

1st row: elevation 1st row: bed elevation values of the stage-area and stage-volume curves after sediment erosion/deposition in the sub-basin's reservoir [m]

2nd row: res. area 2nd row: reservoir area values of the stage-area and stage-volume curves after sediment erosion/deposition in the sub-basin's reservoir [m2]

3rd row: res. volume 3rd row: reservoir volume of the stage-area and stage-volume curves after sediment erosion/deposition in the sub-basin's reservoir [m3]

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has 36 new points at the stage-area and stage-volume curves changed due to sediment erosion/deposition. The first row holds 36 values of water elevation at the stage-area-volume curve (413.34 m, 415.00 m, 416.00 m, etc). The second row holds 36 values of corresponding reservoir area (0.00 m2, 79,176.34 m2, 122,767.10 m2, etc). Finally, the third row holds 36 values of corresponding reservoir volume (0.00 m3, 35,021.39 m3, 110,657.75 m3, etc). Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60\_cav.out* referred to sub-basin with Map-ID 60).

**4) res\_”Map-ID”\_hydraul.out**

|  |
| --- |
| Subasin-ID, year, day, hour, section-ID, depth\_sec(m), watelev\_sec(m), area\_sec(m\*\*2), topwidth\_sec(m),  energslope\_sec(-), hydrad\_sec(m), meanvel\_sec(m/s), discharge\_sec(m\*\*3/s)  60 1980 1 1 1 1.325 448.635 34.717 40.183 0.192E-02 0.858863 1.585346 55.038498  60 1980 1 1 2 1.376 446.956 33.455 56.513 0.345E-02 0.585371 1.645158 55.038498  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

section-ID Map-ID of cross-section in the sub-basin's reservoir

depth\_sec Water depth of each cross section in the sub-basin's reservoir [m]

watelev\_sec Water elevation of each cross section in the sub-basin's reservoir [m]

area\_sec Wetted area of each cross section in the sub-basin's reservoir [m2]

topwidth\_sec Top width of each cross section in the sub-basin's reservoir [m]

energslope\_sec Slope of energy-grade line of each cross section in the sub-basin's reservoir [-]

hydrad\_sec Hydraulic radius of each cross section in the sub-basin's reservoir [m]

meanvel\_sec Mean velocity of each cross section in the sub-basin's reservoir [m/s]

discharge\_sec Discharge of each cross section in the sub-basin's reservoir [m3/s]

Example: After each time step, e.g. after one day, the most upstream cross section (section 1) of the reservoir of the sub-basin with the Map-ID 60 has a water depth of 1.325 m, a water elevation of 448.635 m, a wetted area of 34.717 m2, a top width of 40.183 m, a slope of energy-grade line of 0.00192, a hydraulic radius of 0.858863 m, a mean velocity of 1.585346 m/s and a discharge of 55.038498 m3/s. Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60\_hydraul.out* referred to sub-basin with Map-ID 60).

**5) res\_”Map-ID”\_sec”ID”\_bedchange.out**

|  |
| --- |
| Subasin-ID, section-ID, year, day, hour, nbr. points, y-axis(m)  60 1 1980 1 1 11 460.000000 451.000000 450.000000 … 450.000000 451.000000 460.000000  60 1 1980 1 2 11 460.000000 451.000000 450.000000 … 450.000000 451.000000 460.000000  … |

Subasin-ID Map-ID of sub-basin

section-ID Map-ID of cross-section in the sub-basin's reservoir

year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. points Number of points at the cross section in the sub-basin's reservoir

y-axis Bed elevation changes in the cross section of the reservoir (from left to right, seen from upstream) [m]

Example: After each time step, e.g. after one day, the most upstream cross section (section 1) of the reservoir of the sub-basin with the Map-ID 60 holds 11 values of bed elevation, changed because of either deposition or erosion processes (460.00 m, 451.00 m, 450.00 m, etc). Currently, the model generates an output file for each cross section of the sub-basin’s reservoir (e.g. *res\_60\_sec1\_bedchange.out* referred to cross section 1 and sub-basin with Map-ID 60).

**6) res\_”Map-ID”\_sedbal.out**

|  |
| --- |
| Subasin-ID, year, day, hour, sed\_input(ton/timestep), sed\_output(ton/timestep), sedimentation(ton/timestep), cum\_sedimentation(ton)  60 1980 1 1 78555.180 1799.437 76755.743 76755.743  60 1980 1 2 240.464 10.663 229.801 76985.544  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

sed\_input Sediment inflow discharges into the sub-basin's reservoir [ton/timestep]

sed\_output Sediment outflow discharges out the sub-basin's reservoir [ton/timestep]

sedimentation Sediment deposition rate in the sub-basin's reservoir [ton/timestep]

cum\_sedimentation Cumulative sediment deposition in the sub-basin's reservoir since dam construction [ton]

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has a sediment inflow discharge of 78,555.180 ton/timestep, a sediment outflow discharge of 1,799.437 ton/timestep, a sediment deposition rate of 76,755.743 ton/timestep and a cumulative sediment deposition of 76,755.743 ton/timestep. Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60 \_sedbal.out* referred to sub-basin with Map-ID 60).

**7) res\_”Map-ID”\_longitudinal.out**

|  |
| --- |
| Subasin-ID, year, day, hour, nbr. sections, minelev\_sec(m)  60 1980 1 1 12 447.309998 445.579987 445.239990 … 430.570007 418.160004 414.519989  60 1980 1 2 12 448.229315 445.615664 445.240689 … 430.591036 418.168831 414.525120  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. sections Number of cross sections in the sub-basin's reservoir

minelev\_sec Minimum elevation at the cross section of the sub-basin's reservoir [m]

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has 12 values of minimum bed elevation corresponding to the 12 cross sections. They are changed by either deposition or erosion processes (447.309998 m, 445,579987 m, 445.239990 m, etc). Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60 \_longitudinal.out* referred to sub-basin with Map-ID 60).

**8) res\_”Map-ID”\_sedcomposition.out**

|  |
| --- |
| Subasin-ID, year, day, hour, nbr. classes, sedcomp\_outflow(-)  60 1980 1 1 3 0.999 0.001 0.000  60 1980 1 2 3 0.999 0.001 0.000  … |

Subasin-ID Map-ID of sub-basin

year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. classes Number of sediment size classes considered in the simulation

sedcomp\_outflow Effluent size distribution downstream the sub-basin's reservoir [-].The total number of sediment size classes is previously specified in the file *do.dat*.

Example: After each time step, e.g. after one day, the reservoir of the sub-basin with the Map-ID 60 has the following effluent size distribution for the given sediment classes (e.g. three sediment classes): 0.999, 0.001, and 0.000. Currently, the model generates an output file for each reservoir considered in the simulation (e.g. *res\_60 \_sedcomposition.out* referred to sub-basin with Map-ID 60).

**9) lake\_ inflow\_r.out**

|  |
| --- |
| Year, day, hour, inflow\_r(m\*\*3/timestep)  1980 1 1 2224.611 1511.890 11.295 0.000 0.000  1980 2 1 2098.507 1457.613 10.831 0.000 0.000  … |

Year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. classes Number of sediment size classes considered in the simulation

inflow\_r Water inflow discharges into the reservoir size classes [m³/timestep]. Currently, the number of reservoir size classes can not be changed (total of five classes)

Example: After each time step, e.g. after one day, five values of water inflow discharges into the reservoir size classes are computed (5748.602 m³, 2409.138 m³, 31.014 m³, 0.000 m³ and 0.000 m³ within the timestep for the size classes 1 to 5, respectively). Results are displayed for the whole catchment after grouping them by reservoir size classes. The files 10 to 16 have the same structure, as shown by the file *lake\_ inflow\_r.out* (file 9).

**17) lake\_ watbal.out**

|  |
| --- |
| Year, day, hour, totallakeinflow(m\*\*3/timestep), totallakeoutflow(m\*\*3/timestep  ), totallakeprecip(m\*\*3/timestep), totallakeevap(m\*\*3/timestep), lakevol(m\*\*3)  1980 1 1 3747.793 0.000 0.000 53.854 38678.957  1980 2 1 3566.949 0.000 0.000 63.270 42182.633  … |

Year Year of simulation

day Day of simulation

hour Hour of simulation

totallakeinflow Total water inflow discharge into all upstream reservoirs of the catchment [m³/timestep]

totallakeoutflow Total water outflow discharge from all upstream reservoirs of the catchment [m³/timestep]

totallakeprecip Total rainfall over all upstream reservoirs of the catchment [m³/timestep]

totallakeevap Total evaporation from all upstream reservoirs of the catchment [m³/timestep]

lakevol Total water volume stored in all upstream reservoirs of the catchment [m³]

Example: After each time step, e.g. after one day, a total water inflow discharge into all upstream reservoir of 3747.793 m³/timestep, no water outflow discharge, no rainfall over the reservoir areas, a total evaporation of 53.854 m³/timestep, and a total water storage of 38678.957 m³ in all upstream reservoirs. Results are displayed for the whole catchment without distinguishing between size classes.

**18) lake\_ sedbal.out**

|  |
| --- |
| Year, day, hour, totalsedinflow(ton/timestep), totalsedoutflow(ton/timestep), t  otalsedimentation(ton/timestep), cumsedimentation(ton)  1980 1 1 200.000 0.000 200.000 200.000  1980 2 1 100.000 50.000 50.000 250.000  … |

Year Year of simulation

day Day of simulation

hour Hour of simulation

totalsedinflow Total sediment inflow discharge into all upstream reservoirs of the catchment [ton/timestep]

totalsedoutflow Total sediment outflow discharge from all upstream reservoirs of the catchment [ton/timestep]

totalsedimentation Total sediment deposition in all upstream reservoirs of the catchment [ton/timestep]

cumsedimentation Cumulative sediment deposition in all upstream reservoirs of the catchment [ton]

Example: After each time step, e.g. after one day, a total sediment inflow discharge into all upstream reservoir of 200 ton/timestep, no sediment outflow discharge, a total sediment deposition of 200 ton/timestep, and a cumulative sediment deposition of 200 ton in all upstream reservoirs. Results are displayed for the whole catchment without distinguishing between size classes.

**19) lake\_inflow.out**

|  |
| --- |
| Year, day, hour, reservoir\_class, lakeinflow(m\*\*3/timestep)  57 15 20 60  1980 1 1 1 384.741 587.248 38.144 17.718  1980 1 1 2 411.781 0.000 70.314 40.512  1980 1 1 3 0.000 0.000 0.000 11.295  1980 1 1 4 0.000 0.000 0.000 0.000  1980 1 1 5 0.000 0.000 0.000 0.000  … |

Year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. classes Number of sediment size classes considered in the simulation

lakeinflow Water inflow discharges into the reservoir size classes. Currently, the number of reservoir size classes can not be changed (total of five classes)

Example: After each time step, e.g. after one day, after one day, values of water inflow discharges into the reservoir size classes are computed for all sub-basins (e.g. for size class 1: 384.741 m³, 587.248 m³, 38.144 m³, and 17.718 m³ within the timestep, for sub-basins 57, 15, 20 and 60, respectively). Results are displayed for all sub-basins after grouping them by reservoir size classes. The files 20 to 25 have the same structure, as shown by the file *lake\_ inflow\_r.out* (file 9).

**26) lake\_sizedistoutflow.out**

|  |
| --- |
| Year, day, hour, sediment size class, lakesizedistoutflow(-)  57 15 20 60  1980 1 1 1 0.60 0.40 0.40 0.50  1980 1 1 2 0.30 0.30 0.40 0.40  1980 1 1 3 0.10 0.30 0.40 0.10  … |

Year Year of simulation

day Day of simulation

hour Hour of simulation

nbr. classes Number of sediment size classes considered in the simulation

lakeinflow Effluent size distribution at the sub-basin outlet after sediment routing through the reservoir cascade [-].The total number of sediment size classes is previously specified in the file *do.dat*.

Example: After each time step, e.g. after one day, the sediment outflow discharge at the sub-basin outlet has the following effluent size distribution for the given sediment classes (e.g. three sediment classes): fifth column displays the results of grain size distribution for the sub-basin with Map-ID 57 (0.60, 0.30 and 0.10, for sediment classes 1 to 3, respectively). Results are displayed for all sub-basins without distinguishing between size classes.

Relevant Literature for the WASA-SED Model

**For WASA-SED:**

Mueller, EN., Guentner, A., Francke, T., Mamede, GL. (2010): Modelling sediment export, retention and reservoir sedimentation in drylands with the WASA-SED Model. Geoscientific Model Development 3, 275-291.

Mamede, GL. (2008): Reservoir sedimentation in dryland catchments: Modelling and management. PhD thesis, Universität Potsdam, Germany. http://opus.kobv.de/ubp/volltexte/2008/1704/

**For WASA-SED parameterisations:**

Appel, K., 2006. Characterisation of badlands and modelling of soil erosion in the Isabena watershed, NE Spain. Unpublished MSc thesis. University of Potsdam, Germany.

Medeiros, PHA. (2009): Hydro-sedimentological processes and connectivity in a semiarid basin: modelling and validation in several scales. PhD thesis, Universidade Federal do Ceará, Brazil. http://www.teses.ufc.br/tde\_busca/arquivo.php?codArquivo=4425

Medeiros, PHA., Guentner, A., Francke, T., Mamede, GL., De Araújo, JC. (2010): Modelling spatio-temporal patterns of sediment yield and connectivity in a semi-arid catchment with the WASA-SED model. Hydrological Sciences Journal 55:4, 636-648. (1)

Mueller, EN., Francke, T., Batalla, RJ., Bronstert, A. (2009): Modelling the effects of land-use change on runoff and sediment yield for a meso-scale catchment in the Southern Pyrenees. Catena 79:3, 288-296. (1)

Mueller E. N., Batalla, R. J., Garcia, C., Bronstert, A., 2008. Modelling bedload rates from fine grain-size patches during small floods in a gravel-bed river. J. of Hydr. Eng. in press

Francke, T. (2009): Measurement and Modelling of Water and Sediment Fluxes in Meso-Scale Dryland Catchments. PhD thesis, Universität Potsdam, Germany. http://opus.kobv.de/ubp/volltexte/2009/3152/

**For the hydrological modules:**

Güntner, A., 2002. Large-scale hydrological modelling in the semi-arid North-East of Brazil. PIK-Report No. 77, Potsdam Institute for Climate Research, Germany.

Güntner, A. and Bronstert, A., 2004. Representation of landscape variability and lateral redistribution processes for large-scale hydrological modelling in semi-arid areas, Journal of Hydrology, 297: 136-161.

**For LUMP:**

Francke, T., Güntner, A., Bronstert, A., Mamede, G., Müller, E. N., 2008. Automated catena-based discretisation of landscapes for the derivation of hydrological modelling units, International Journal of Geographical Information Science, 22: 111-132.

**For LUMP package:**

Pilz, T (2015): https://github.com/tpilz/LUMP

Reference

Antronico, L., Coscarelli, R., Terranova, O., 2005. Surface erosion assessment in two Calabrian basins (southern Italy). In: R. J. Batalla and C. Garcia (Ed.), Geomorphological Processes and Human Impacts in River Basins, IAHS, pp. 16-22.

Appel, K., 2006. Characterisation of badlands and modelling of soil erosion in the Isabena watershed, NE Spain. Unpublished MSc thesis. University of Potsdam, Germany

Ashida, K. and Michiue, M. 1973. “Studies on bed load transport rate in alluvial streams”, *Trans. Japan Society of Civil Engineers*, Vol. 4.

Ackers, P. and White, W.R. 1973. “Sediment transport: a new approach and analysis”, Proc. ASCE, Journal of the Hydraulics Division, Vol. 99, HY11, pp. 2041-2060.

Breuer, L., Eckhardt, K., Frede, H.-G., 2003. Plant parameter values for models in temperate climates, Ecological Modelling, 169: 237-293.

Bronstert, A., Güntner, A., Jaeger, A., Krol, M., and Krywkow, J. 1999. Großräumige hydrologische Parameterisierung und Modellierung als Teil der integrierten Modellierung, pp. 31-40. In N. Fohrer and P. Döll, editors, *Modellierung des Wasser- und Stofftransports in großen Einzugsgebieten.* Kassel University Press, Kassel

Bronstert, A., Jaeger, A., Güntner, A., Hauschild, M., Döll, P., and Krol, M. 2000. Integrated modelling of water availability and water use in the semi-arid Northeast of Brazil, *Physics and Chemistry of the Earth* 25: 227-232

Francke, T., Parameterisation of the Esera/Isabena Catchment, Pre-Pyrenees, Spain. SESAM Working Report, http://brandenburg.geoecology.uni-potsdam.de/projekte/sesam/publications.php

Francke, T., Güntner, A., Bronstert, A., Mamede, G., Müller, E. N., 2008. Automated catena-based discretisation of landscapes for the derivation of hydrological modelling units. International Journal of Geographical Information Science 22: 111-132.

Francke, T., 2005. LUMP package, Manual, Auxiliary software tool to generate the input files for the hillslope module of the WASa model, SESAM working reports on http://brandenburg.geoecology.uni-potsdam.de/projekte/sesam/publications.php

FAO 1993. Global and national soils and terrain digital databases (SOTER). Procedures Manual. World Soil Resources Reports, No. 74., FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

FAO 2001. Global Soil and Terrain Database (WORLD-SOTER). FAO, AGL (Food and AgricultureOrganization of the United Nations, Land and Water Development Division), http://www.fao.org/ag/AGL/agll/soter.htm.

Güntner, A., 2002. Large-scale hydrological modelling in the semi-arid North-East of Brazil. PIK-Report No. 77. Potsdam Institute for Climate Research, Germany (http://www.pik-potsdam.de/pik\_web/ publications/pik\_reports/reports/reports/pr.77/pr77.pdf)

Güntner, A., Bronstert, A., 2002. Process-based modelling of large-scale water availability in a semi-arid environment: process representation and scaling issues. In G.H. Schmitz, editor, Schriftenreihe des Institutes für Abfallwirtschaft und Altlasten, Universität Dresden, Dresden, pp. 46

Güntner, A., Bronstert, A., 2003. Large-scale hydrological modeling of a semiarid environment: model development, validation and application, In T. Gaiser, M. Krol, H. Frischkorn, and J.C.Araujo, editors, *Global change and regional impacts.* Springer-Verlag, Berlin

Güntner, A., Bronstert, A., 2003. Large-scale hydrological modelling in the semiarid Northeast of Brazil: aspects of model sensitivity and uncertainty, In E. Servat, W. Najem, C. Leduc, and A. Shakeel, editors, *Hydrology of the Mediterranean and Semi-Arid Regions.* IAHS-Publication 278

Güntner, A., 2003. Auswirkung von Klimaänderungen auf die Wasserverfügbarkeit in Trockengebieten - Ergebnisse und Unsicherheiten am Beispiel Nordost-Brasiliens. In H.-B.Kleeberg, editor, Hydrologische Wissenschaften - Fachgemeinschaft in der ATV-DVWK, pp. 205-214

Güntner, A., Bronstert, A., 2004. Representation of landscape variability and lateral redistribution processes for large-scale hydrological modelling in semi-arid areas, Journal of Hydrology 297: 136-161

Güntner, A., Krol, M., Araujo, J.C., and Bronstert, A. 2004. Simple water balance modelling of surface reservoir systems in a large data-scarce semiarid region, *Hydrological Sciences Journal* 49: 901-918

IRTCES, 1985. Lecture notes of the training course on reservoir sedimentation. *International Research of Training Center on Erosion and Sedimentation*, Sediment Research Laboratory of Tsinghua University, Beijing, China.

Krysanova, V., Wechsung, F., Arnold, J., Srinivasan, R.., Williams, J., 2000. SWIM (Soil and Water Integrated Model), User Manual. PIK Report Nr. 69, pp 239.

Medeiros, PHA., Guentner, A., Francke, T., Mamede, GL., De Araújo, JC. (2010): Modelling spatio-temporal patterns of sediment yield and connectivity in a semi-arid catchment with the WASA-SED model. Hydrological Sciences Journal 55:4, 636-648. (1)

Maidment, D. R., 1993. Handbook of hydrology. MGraw-Hill, New York.

Mamede, G., 2008. Reservoir sedimentation in dryland catchments: Modelling and management. PhD thesis at the University of Potsdam, Germany, published on: urn:nbn:de:kobv:517-opus-17047.

Mamede, G.L., Bronstert, A., Araujo, J.C., Batalla, R. J., Güntner, A., Mueller, E. N., Francke, T. 2006. 1D Process-Based Modelling of Reservoir Sedimentation: a Case Study for the Barasona Reservoir in Spain. *Proceedings of the International Conference on Fluvial Hydraulics*, Lisbon, Vol. 2: 1585-1594.

Morgan, R.P.C., 1995. Soil erosion and conservation Longman Group, UK Limited.

Mueller, EN., Francke, T., Batalla, RJ., Bronstert, A. (2009): Modelling the effects of land-use change on runoff and sediment yield for a meso-scale catchment in the Southern Pyrenees. Catena 79:3, 288-296. (1)

Mueller, E. N., Batalla, R. J., Garcia, C., Bronstert, A., 2008. Modelling bedload rates from fine grain-size patches during small floods in a gravel-bed river. J. of Hydr. Eng. in press

Mueller, E. N., Güntner, A., Francke, T., Mamede, G., 2008. Modelling water availability, sediment export and reservoir sedimentation in drylands with the WASA-SED Model. submitted to Geoscientific Model Development

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., King, K.W., 2002. Soil and Water Assessment Tool. Theoretical Documentation, Version 2000. Published by Texas Water Resources Institute, TWRI Report TR-191

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C., 1997. Renard K, Foster G, Weesies G, McCool D, Yoder D 1997. Predicting soil loss by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *U.S. Dep. of Agriculture, Agriculture Handbook* **703**.

Williams, J., 1995. The EPIC Model. In: Singh, V. P. (Eds.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO., pp. 909-1000.

Wu, W., Wang, S.S.Y. and Jia, Y. 2000, “Nonuniform sediment transport in alluvial rivers”, *Journal of Hydraulic Research*, Vol. 38, No. 6, pp 427-434.

Yang, T.C. and Simoes, F.J.M. 2002 User’s Manual for GSTARS3 (Generalized Sediment Transport model for Alluvial River Simulation version 3.0). U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado