CATMO-OMS

An overview

Hanoi, December 2013

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1. Introduction

CATMO stands for CATchment MOdel, it was originally developed at the Lehr- und Forschungsgebiet Wasser-Energie-Wirtschaft (Institute of Water and Energy Resources Management) at Rheinisch-Westphälische Technische Hochschule Aachen (Technical University Aachen), Germany. Numerous deductions of the original version are available, there are commercial deductions and freeware versions around. The software is being used by governmental institutions, universities and water resources consultants mainly throughout Germany.

2. Description

CATMO-OMS (CATchment Model for Object Modeling System) has been designed in order to allow hydrologic simulations for natural as well as urban areas. It allows for carrying out short, middle and long term simulations. CATMO-OMS is a conceptual deterministic non-linear distributed hydrologic model. It allows for a continuous simulation of the water balance of catchments.

CATMO-OMS encompasses the main components of the hydrological cycle for natural catchments, such as interception, surface runoff, interflow, soil water accounting (vadose zone), groundwater water accounting, streamflow. It also includes components of the hydrological cycle of settlement areas (urban areas) and their hydrologic modeling, e.g. runoff in sewers, storage sewers as well as reservoir simulation. It must be emphasized that no hydraulic computations are carried out in CATMO-OMS. The model structure of CATMO-OMS is depicted in Fig. 2-1. For detailed modeling of hydraulic effects hydraulic models must be applied.

Fig. 2-1 might leave the impression that there is a loop implemented at “Groundwater – Capillary Rise – Soil Moisture“. In fact, there is no loop implemented – to cut this apparent loop for each time step “Capillary Rise” draws on Groundwater states of the previous time step.

During the model setup the catchment is subdivided into subcatchments according to the streamflow network, land use patterns and topographical data as well as other objectives in each modeling project. These subcatchments are classified as being on the hydrological mesoscale (from a few hectars up to several tens of km^2). The simulation time steps may vary according to the modeling purpose from 10 minutes to one day. The model can be applied from the lowlands up to high mountainous areas. Fig. 2-2 depicts the model set-up/abstraction.

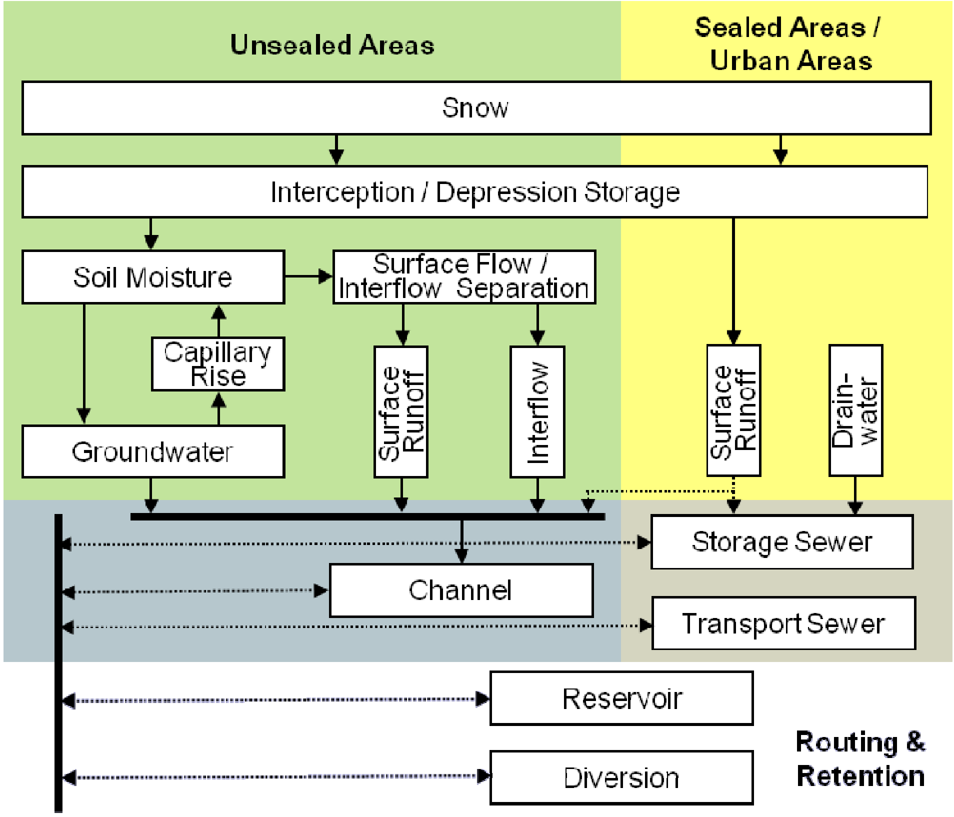

Fig. 2-1: Model structure of CATMO-OMS

There are four different system elements defined in CATMO-OMS:

- **Catchments** (**cmt**) allow for the simulation of either sealed and/or unsealed areas. The model structure of catchments is depicted on green and yellow background in the figure "Model structure of CATMO-OMS" in this section. In addition it comprises lateral runoff modules for channels and storage sewers.
- **Diversion elements** (**div**) allow for the hydrologic simulation of diversion elements (e.g. weirs).
- **Reservoir elements** (**res**) allow for the simulation of reservoir processes.
- **Transport sewers elements** (**sew**) allow for the hydrologic simulation of transport sewer processes.

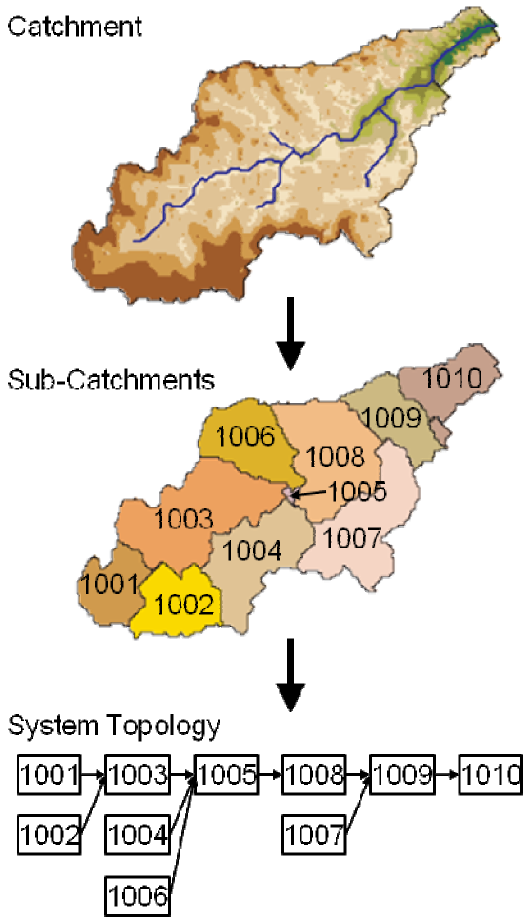

Fig. 2-2: Catchments, sub-catchments and system topology in CATMO-OMS

The main basics of the simulation algorithms implemented in CATMO-OMS are presented in Annex A. CATMO was originally coded in FORTRAN and has been completely recoded in JAVA (CATMO-OMS). The codes are provided by means of the GNU Lesser General Public License 2.1 (see Annex C). A description of the input formats is provided in Annex B.

3. Areas of Application

CATMO-OMS has been designed to be applied as a tool for planning and monitoring of water resource systems. Characteristic values for water resources management of rivers and creaks as well as catchments may be verified and determined using the software.

Among others CATMO-OMS can be used for:

- Design and verification of flood protection schemes
- Optimization of operation rules and rule curves of reservoirs

- Determination of characteristics for water resources design (e.g. duration curves, yearly means, basics for statistical analysis)
- Determination of groundwater recharge, scenario analysis of land use data and land management data
- Integrative modeling of natural catchments and settlement areas (sewers) as well as reservoirs
- Evaluation of climate scenarios on catchment scale and catchment states (e.g. land use)
- Realtime forecasting of floods
- Realtime management of reservoirs and flood protection schemes

4. Data Requirements

The following parameter data are required as CATMO_OMS input (please refer to Annex B for an example of input data):

- Catchment and subcatchment areas
- Land use data (e.g. interception (LAI), rooting depths) from land use maps
- Soil characteristics (kf value, total porosity, field capacity, wilting point) from soil maps
- Retention constants
- Time area functions of subcatchments (either as external input or as idealized model parameters)
- Lenghs and slopes of channels (streams, creaks)
- Characteristic channel cross sections including hydraulic roughness coeffients
- Urban hydrological data, e.g. areas connected to the sewer system, proportion of sealed areas, sewer system and sewer volumes, flow times, characteristics of hydraulic retention works (height-volume curve, height-discharge curve)
- Reservoir characteristics (height-volume curve, height-discharge curve)

Per system element up to eight time series input variables may be defined in CATMO-OMS. These comprise:

- Precipitation (precip)
- Potential evapotranspiration (pot_eva)
- Temperature (temp)
- Wind speed (wind_speed)
- External inflow (inflow)
- Surface water abstraction (surf_abstr)
- Groundwater abstraction (gw_abstr)
- Observed gauge runoff (obs_runoff)

For catchments precipitation, potential evapotranspiration, temperature and wind speed are mandatory input time series, all other time series input to the other elements are optional. Tab. 4-1 provides an overview on possible time series assignments for the different element types, wherein "x" denotes mandatory input and "(x)" denotes optional input.

Tab. 4-1: Possible time series assignments to elements

Element type	**precip [mm/h]**	**pot_eva [mm/h]**	**temp [^{0}C]**	**wind_speed [m/s]**	**inflow [m^3/s]**	**surf_abstr [m^3/s]**	**gw_abstr [m^3/s]**	**obs_runoff [m^3/s]**
cmt	x	x	X	X	(x)	(x)	(x)	(x)
div					(x)	(x)		(x)
res					(x)	(x)		(x)
sew					(x)	(x)		(x)

The simulation input data for CATMO-OMS are distributed into ten files:

- Parameter data file: This file contains the main parameter data (Annex B.2).
- Time area data file: This file contains the time area function data (Annex B.3).
- Channel data file: This file contains all data related to channels including geometric cross section data (Annex B.4).
- Diversion data file. This file contains possible diversion elements and their charcteristics (Annex B.5).
- Reservoir data file: This file contains the defined reservoir characteristcs (Annex B.6).

- Sewer data file: The sewer file contains all sewer characteristics (Annex B.7). This includes storage and transport sewers.
- Sequence data file: The network of flows among the system elements is defined in this file (Annex B.8)..
- Time series input file: This is the file which contains the input time series data (Annex B.9).
- Time series system element assignment file: This file contains the data how the data from the time series input file (e..g. precipitation) is distributed (which time series data are used as input for the different system elements) to the different system elements (Annex B.10).
- Time series output definition file: In this file it is defined which variables of which system elements are saved into a file for further analysis (Annex B.11).

Remark: For non-head catchments routing will be computed on the basis on available input datay according to the following ranking: 1.Kalinin-Miljukov, 2. storage sewer, 3. no routing.

5. Data Analysis

A plethora of variables are available to be analyzed for system elements after the simulation. The variables for the required elements need to be defined prior to the simulation in a simulation output file. For information on how to run OMS models please refer to the OMS manual. Tab. 5-1 provides an overview on available output variables for the different element types.

Tab. 5-1: Available output variables for element types

Variable	Element type	Unit	Description
cr	cmt	mm/h	Capillary rise in catchment
div_runoff	div; res; sew	m^3/s	Diversion runoff at node in system
drain_runoff	cmt	m^3/s	Base runoff from sewage in catchment
eva_soil	cmt	mm/h	Evapotranspiration from soil in catchment
evp_intc_sa	cmt	mm/h	Evaporation from interception in catchment (sealed area)
evp_intc_ua	cmt	mm/h	Evaporation from interception in catchment (unsealed area)
gw_abstr	cmt	m^3/s	Groundwater abstraction in catchment
gw_abstr_max	cmt	m^3/s	Maximum possible groundwater abstraction in catchment
gw_h	cmt	m	Groundwater height in catchment

Variable	Element type	Unit	Description
gw_leak	cmt	m^3/s	Groundwater leakage
gw_runoff	cmt	m^3/s	Runoff from groundwater in catchment
gw_td	cmt	m	Groundwater table depth in catchment
h_snow	cmt	mm	Snow height of catchment
i_sa	cmt	mm	Interception content in catchment (sealed area)
i_ua	cmt	mm	Interception content in catchment (unsealed area)
inflow	cmt; div; res; sew	m^3/s	Water inflow to entry node of element / catchment
inf	cmt	mm/h	Infiltration into the soil in catchment
intf_ua_runoff	cmt	m^3/s	Runoff from interflow in catchment (unsealed area)
obs_runoff	cmt; div; res; sew	m^3/s	Gauge runoff
perc	cmt	mm/h	Percolation into groundwater in catchment
pevp	cmt	mm/h	Pot. evapotranspiration in catchment
pr_gr	cmt	mm/h	Precipitation on catchment ground (sealed area)
pr_eff	cmt	mm/h	Runoff effective precipitation in catchment
pr_eff_surf	cmt	mm/h	Runoff effective precipitation on catchment (surface runoff)
pr_eff_intf	cmt	mm/h	Runoff effective precipitation for interflow runoff on catchment
pr_eff_intf_ua	cmt	mm/h	Runoff effective precipitation for interflow runoff on catchment (unsealed area)
pr_eff_surf_sa	cmt	mm/h	Runoff effective precipitation for surface runoff on catchment (sealed area)
pr_eff_surf_ua	cmt	mm/h	Runoff effective precipitation for surface runoff on catchment (unsealed area)
pr_in	cmt	mm/h	Precipitation on catchment
pr_s	cmt	mm/h	Precipitation on catchment ground (soil)
res_h	res	m asl	Reservoir water stage
res_vol	res	$1000\ m^3$	Reservoir volume
roh_snow	cmt	kg/m^3	Snow density of catchment
runoff	cmt; div; res; sew	m^3/s	Runoff at node in system
sm	cmt	mm	Soil moisture in catchment
surf_abstr	cmt; div; res; sew	m^3/s	Water abstraction at exit node of element / catchment
surf_sa_runoff	cmt	m^3/s	Runoff from surface in catchment (sealed area)
surf_ua_runoff	cmt	m^3/s	Runoff from surface in catchment (unsealed area)
surface_runoff	cmt	m^3/s	Runoff from surface in catchment
temp	cmt	°C	Surface air temperature in catchment
wind	cmt	m/s	Surface wind speed in catchment

6. Prerequisites and Known Issues

The following software needs to be installed in the following order to be able to use CATMO-OMS:

- JDK (Java Development Kit) version 7 and above. It requires JDK and not only JRE (Java Runtime Environment).
  http://www.oracle.com/technetwork/java/javase/downloads/index.html
- NetBeams IDE (Integrated Develpment Environment) for JAVA version 7.1.2 and above.
  https://netbeans.org/downloads/
- OMS (Object Modeling System) version 3.2 and above.
  http://www.javaforge.com/project/oms
- A docbook reader/editor is necessary to access the model documentation. XMLMind is a commercial docbook editor which is working well with docbook. The company offers 30 days trial versions of its product.
  http://www.xmlmind.com/xmleditor/
- A GIS is required for spatial data analysis and generation of input data. In particular GRASS and jgrasstools can be of special use in this context. Both are are available as open source software.
  http://grass.osgeo.org/ or http://code.google.com/p/jgrasstools/

Known issues:

OMS input is based on comma-separated value files (*.csv) which can be easily edited e.g. with MS Excel. However, there is a bug within the access routines from OMS. One way to pass around this bug is to delete tailing commas (“,”) with a text editor which are not required as input but are automatically generated by MS Excel when the CSV file is streamed to the hard disk. Please also refer to example file time area data file (Annex B.4, property “external_taf”) and channel data file (Annex B.5, property “iriver”) provided in Annex B.

OMS allows for model documentation (model description and model data). Up to the publication of this report only absolute paths were working in this conext. If you install the CATMO-OMS project under a different path than “d:\NA_Model\CATMO” you need to change the paths in the “@Documentation” annotated meta data fields within the “catmo2013” package.

Model documentation for CATMO-OMS is only implemented for the data contained in the “Parameter Data File”. All other parameter data, (e.g. time area data, channel data, sequence data) are currently omitted in this process (not documented).

7. CATMO-OMS Codes

The “Source” directory of CATMO-OMS contains five subdirectories which belong to five Java packages:

- catmo2013: This directory contains all of the CATMO-OMS modules (main modules) – 16 files. For a description of the simulation modules please refer to Annex A.
- input: This directory contains classes for data input and data handling for the main modules – 27 files.
- model: This directory contains the CATMO-OMS model – one file.
- msc: This directory contains miscellaneous classes – two files.
- sequence: This directory contains all classes linked to set up and test of a directed graph for e.g. determining sequences and loops for element processing – five files.

Annex A: Modules

A.1 Capillary Rise

The capillary rise component simulates capillary rise from groundwater into the root zone of the unsaturated soil zone. The component is compliant with the soil moisture component, but should be run before the soil moisture accounting since the water fluxes are here upward directed whereas in the latter case they are downward directed. This will be of special importance when different soil layers are being simulated separately. A definition sketch of the processes is depicted below.

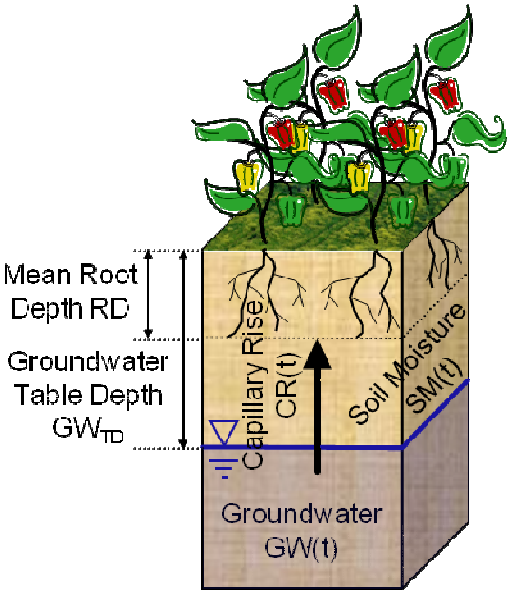

Fig. A.1-1: Relevant variables in the context of capillary rise

The differential equation for soil moisture SM in a soil column taking capillary rise into account reads as follows.

$$\frac{dSM(t)}{dt} = CR(t) \qquad \text{(Eq. A.1-1)}$$

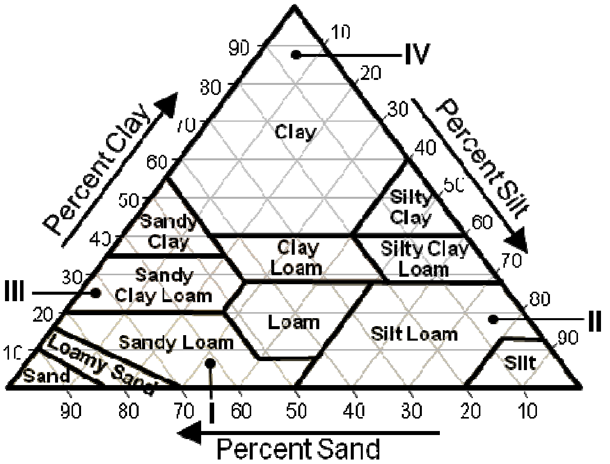

Fig. A.1-2: Texture triangle (Raes et al., 2012)

The potential capillary rise PCR in [mm/h] is determined according to Raes et al. (2012) by:

$$PCR = \exp\left(\frac{\ln(z - RD) - b}{a}\right) / 24$$ (Eq. A.1-2)

where a and b are determined according to soil class and hydraulic conductivities k_f in [mm/d] of the soils as shown in the table hereafter.

Tab. A.1-1: Determination of parameters values a and b in dependence of soil class and hydraulic conductivity (Raes et al., 2012)

Soil Class	Range of k_f in [mm/d]	a	b
I Sandy Soils: Sand, Loamy Sand, Sandy Loam	200 to 2000	$-0.3112 - 10^{-5} \times k_f$ (Eq. A.1-3 a)	$-1.4936 + 0.2416 \times \ln k_f$ (Eq. A.1-4 a)
II Loamy Soils: Loam, Silt Loam, Silt	100 to 750	$-0.4986 + 9 \times 10^{-5} \times k_f$ (Eq. A.1-3 b)	$-2.1320 + 0.4778 \times \ln k_f$ (Eq. A.1-4 b)
III Sandy Clayey Soils: Sandy Clay,Sandy Clay Loam	5 to 150	$-0.5677 – 4 \times 10^{-5} \times k_f$ (Eq. A.1-3 c)	$-3.7189 + 0.5922 \times \ln k_f$ (Eq. A.1-4 c)
IV Silty Clayey Soils: Silty Clay Loam, Silty Clay, Clay	1 to 150	$-0.6366 + 8 \times 10^{-4} \times kf$ (Eq. A.1-3 d)	$-1.9165 + 0.7063 \times \ln k_f$ (Eq. A.1-4 d)

Capillary rise CR from groundwater is dependent on soil moisture. In natural environments soil moisture can only vary between the permanent wilting point (PWP) and the total porosity (also called total pore volume, TPV). Capillary rise will only take place when the soil moisture is below field capacity (FC) and is zero otherwise. It will linearly decrease from the permanant wilting point (PWP) to zero at soil moisture SM = SM_CR0 ≤ SMFC. Assuming a linear relationship between these points results in piecewise linear functions for infiltration, evaporation and percolation as a function of soil moisture which is depicted in the graph hereafter.

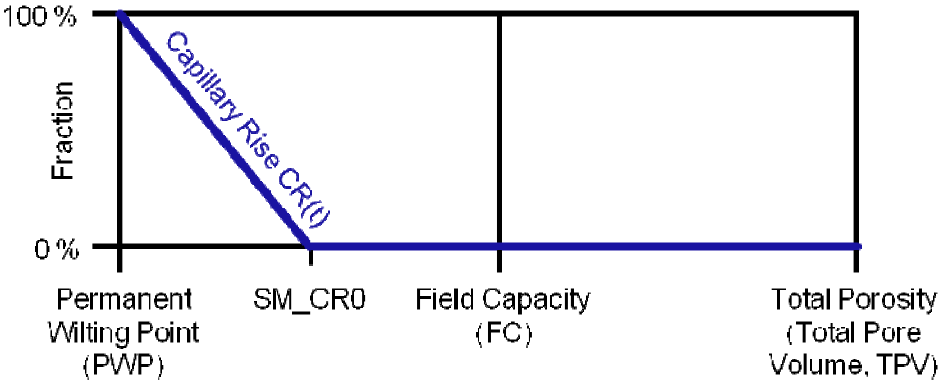

Fig. A.1-3: Piecewise linear function for capillary rise

Capillary rise:

$$CR(t) = \begin{cases} PCR \times \left(1 - \frac{1}{SM\_CR0} \times SM(t)\right) & , SM \leq SM\_CR0 \leq SMFC \\ 0 & , SM > SM\_CR0 \end{cases}$$

(Eq. A.1-5)

Where in (Eq. A.1-1) to (Eq. A.1-5) denote:

CR	capillary rise in [mm/h],
GW_{TD}	groundwater table depth in [m].
k_f	hydraulic conductivity in [mm/d],
PCR	potential capillary rise in [mm/h],
RD	mean root depth in [m],
SM(t)	soil moisture in [mm],
SM_CR0	soil moisture below field capacity where capillary rise CR is zero in [mm],

SMFC	soil moisture at field capacity in [mm].

Substituting equation (Eq. A.1-5) into equation (Eq. A.1-1) results in the following two different cases.

Case 1: SM(t) ≤ SM_CR0

$$\frac{\mathrm{SM(t)}}{\mathrm{dt}} + \mathrm{SM(t)} \times \frac{\mathrm{PCR}}{\mathrm{SM\_CR0}} = \mathrm{PCR} \qquad \text{(Eq. A.1-6 a)}$$

Case 2: SM(t) > SM_CR0

$$\frac{\mathrm{SM(t)}}{\mathrm{dt}} = 0 \qquad \text{(Eq. A.1-6 b)}$$

(Eq. A.1-6 b) states that there is no change of SM(t) over time for this case, (Eq. A.1-6 a) represents a inhomogeneous linear differential equation of the kind:

$$\frac{\mathrm{dSM(t)}}{\mathrm{dt}} + \mathrm{C1} \times \mathrm{SM(t)} = \mathrm{C2} \qquad \text{(Eq. A.1-7)}$$

Taking the boundary condition SM(t = 0) = SM0 into account a solution for (Eq. A.1-7) is given by the following function:

$$\mathrm{SM(t)} = \frac{\mathrm{C2}}{\mathrm{C1}} + \left(\mathrm{SM0} - \frac{\mathrm{C2}}{\mathrm{C1}}\right) \times e^{-\mathrm{C1} \times t} \qquad \text{(Eq. A.1-8)}$$

In order to reduce the volume error the mean soil moisture $\overline{\mathrm{SM}}$ for a time interval [0,t*] is used for determining the corresponding capillary rise by equation (Eq. A.1-5). The mean soil moisture $\overline{\mathrm{SM}}$ for a time interval [0,t*] is determined by:

$$\overline{\mathrm{SM}} = \frac{1}{t^*} \times \int_0^{t^*} \mathrm{SM(t)\,dt} = \frac{1}{t^*} \times \left[\frac{\mathrm{C2}}{\mathrm{C1}} \times t^* + \left(\mathrm{SM0} - \frac{\mathrm{C2}}{\mathrm{C1}}\right) \times \frac{1}{\mathrm{C1}} \times \left(1 - e^{-\mathrm{C1} \times t^*}\right)\right] \qquad \text{(Eq. A.1-9)}$$

The implemented algorithm first determines whether field capacity (SM_CR0) will be reached during the simulation time step Δt. It then determines the "volume" of water in [mm] that was gained by capillary rise in the soil column for the time interval [0,t_{max}] with t_{max} ≤ Δt by using the mean soil moisture for this interval as provided in (Eq. A.1-9). The last step will be repeated for a possible second interval [t_{max},Δt]. Dividing the sums of the capillary risen "volumes" of water for these two intervals [0,t_{max}] and [t_{max},Δt] by Δt will then provide the "mean" capillary rise rate in [mm/h] for this time step. The resulting soil moisture SM at the end of time step Δt forms the boundary condition SM0 for the next time step.

A.2 Dispatcher

Hydrologic processes can be divided into “runoff generation” and “runoff concentration” processes. For the runoff concentration processes runoffs from catchments / system elements need to be summed up at the input nodes into other catchments / system elements as the system is composed of a tree-like network as depicted in the following figure.

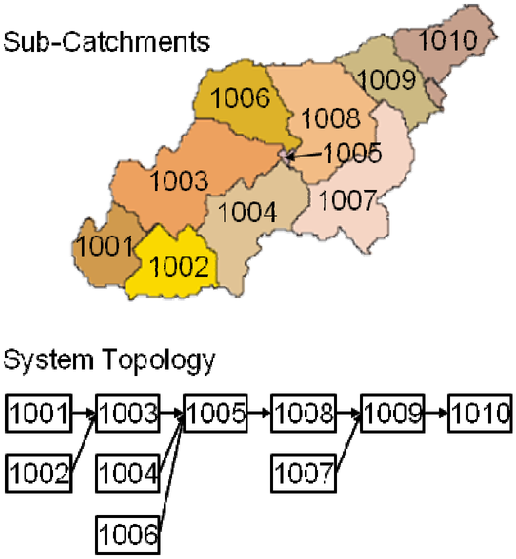

Fig. A.2-1: Sub-catchments and system topology

The dispatcher fulfills several purposes:

- It determines nonrelated components within the defined network, the network must consist of a single component.
- It determines loops within the defined network, loops are not allowed.
- It determines the sequence in which the catchments / elements are assessed during the run modus.

During run modus the runoffs from catchments (surface runoff, interflow, groundwater flow, drainwater flow) are summed up for each catchment. Other “runoff concentration” modules / elements (channel runoff, reservoir, sewer flow, divertion) are called in the sequence as has been determined on the basis of the defined network. The results are then assigned to the following network node and summed to other inflows of that node. External inflows or extractions are treated the same way.

A.3 Diversion

A diversion within the hydrologic flow cascade allows to divert parts of the runoff to other elements. This branching reflects the effects of anthropogenic activities in catchments. A schematic view on a diversion element is depicted in the following figure.

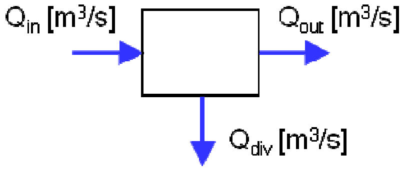

Fig. A.3-1: Diversion element

Three kinds of diversion elements are implemented:

- The throughflow runoff capacity Q_{out}^{max} in [m^3/s] is limited. Starting from a defined inflow Q_{in}^{min} in [m^3/s] a constant fraction of the surplus inflow will be diverted to Q_{div} in [m^3/s]. Above the given maximum throughflow capacity Q_{out}^{max} all surplus inflow will be diverted to Q_{div}. This represents a sewer diversion element with a throttle attached to it.
- The throughflow runoff capacity Q_{out} in [m^3/s] is not limited. Starting from a defined inflow Q_{in}^{min} in [m^3/s] a constant fraction of the surplus inflow will be diverted to Q_{div} in [m^3/s]. This represents a simple weir model.
- The runoff of the diversion Q_{div} in [m^3/s] is determined by a given function $Q_{div} = f(Q_{in})$. This represents a more complex diversion model where results of hydraulic calculations are utilized to simulate a diversion (e.g. side weir). The function is defined as a table of Q_{in} and Q_{div} tuples which are interpreted as piecewise linear sections.

A.4 Drainwater

Drainwater Q_{drain} in [m^3/s] is assumed to be a constant runoff from urban areas (greywater) into the sewage system / channels of the particular catchment. It is determined the following way:

$$Q_{drain} = q_{drain} \times A_{sealed} \qquad \text{(Eq. A.4-1)}$$

where:

A_{sealed}	sealed area of urban catchment in [km^2],
q_{drain}	specific sealed area runoff (greywater) in [$m^3/km^2/s$],
Q_{drain}	drainwater discharge from element during time interval [$t,t+\Delta t$] in [m^3/s].

A.5 Groundwater

The groundwater component simulates the groundwater processes in a subcatchment. Groundwater is treated as a single unconfined groundwater layer. The process is simulated as a linear reservoir. The modeling approach is depicted in the following figure.

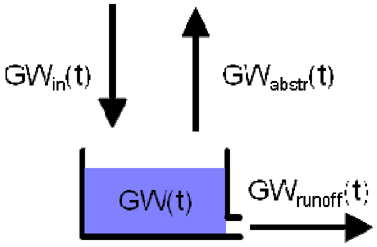

Fig. A.5-1: Fluxes into and out of the groundwater reservoir

The formulations hereafter are given for the time step t+Δt.

Inflow GW_{in} in [m^3/s] to the groundwater reservoir results from soil water percolation. Groundwater abstraction GW_{abstr} in [m^3/s] from the groundwater may result from e.g. abstracting water from wells, capillary rise or percolation into a deep groundwater reservoir. GW_{runoff} in [m^3/s] is the runoff from the linear reservoir. The governing equation for the groundwater reservoir is:

$$\frac{dGW(t)}{dt} = GW_{in} - GW_{abstr} - GW(t)_{runoff} \qquad \text{(Eq. A.5-1)}$$

Replacing $GW(t)_{runoff} = 1/k \times GW(t)$ (linear reservoir) into (Eq. A.5-1) and doing unit conversions results in the following inhomogeneous linear differential equation for the groundwater reservoir:

$$\frac{dGW(t)}{dt} + \frac{1}{k \times 3600} \times GW(t) = GW_{in} - GW_{abstr} \qquad \text{(Eq. A.5-2)}$$

The solution of this differential equation at the end of time step t+Δt is:

$$GW(t+\Delta t) = \left(GW_{in} - GW_{abstr}\right) \times k \times 3600 \times \left(1 - e^{-\Delta t / k}\right) + GW0 \times e^{-\Delta t / k}$$

(Eq. A.5-3)

The flow GW_{in} into the groundwater reservoir is:

$$GW_{in} = Perc \times A \times \frac{1}{3.6} \qquad \text{(Eq. A.5-4)}$$

The startup volume GW0 in [m^3] of the groundwater reservoir at the beginning of the time step is determined by:

$$GW0 = GW0_{height} \times A \times \frac{\Phi}{100} \times 10^6 \qquad \text{(Eq. A.5-5)}$$

Where in (Eq. A.5-1) to (Eq. A.5-5) denote:

A	subcatchment area in [km^2],
GW(t)	groundwater volume at time t in [m^3],
GW0	groundwater volume at the beginning of time interval [t,t+Δt] in [m^3],
$GW0_{height}$	groundwater height at the beginning of time interval [t,t+Δt] in [m],
Gw_{abstr}	groundwater abstraction during time interval [t,t+Δt] in [m^3/s],
GW_{in}	groundwater inflow during time interval [t,t+Δt] in [m^3],
$GW(t)_{runoff}$	runoff (base flow) from the groundwater reservoir at time t in [m^3/s],
k	retention constant of groundwater reservoir in [h],
Perc	percolation from soil (inflow) into the groundwater reservoir during time interval [t,t+Δt] in [mm/h],
Φ	porosity of groundwater medium within [0, 100] in [%],
Δt	time step length in [h].

If the groundwater reservoir runs empty during the interval [t, t+Δt], groundwater abstraction is reduced to $GW_{abstr\ red}$. The maximum constant groundwater abstraction is determined for running the reservoir empty at the end of the time interval [t, t+Δt]. The reduced groundwater abstraction rate in [m^3/s] amounts to:

$$GW_{abstr\ red} = GW_{in} + \frac{e^{-\Delta t/k}}{k \times 3600} \times \frac{GW0}{1 - e^{-\Delta t/k}} \qquad \text{(Eq. A.5-6)}$$

In order to reduce the volume error for determining the groundwater runoff $GW(t)_{runoff}$ the mean groundwater volume $\overline{GW}$ in [m^3] is determined for the time interval [t,t+Δt] which then is used for determining the groundwater runoff GW_{runoff} in [m^3/s]. The mean groundwater volume $\overline{GW}$ for the time interval [t,t+Δt] is determined by:

$$\overline{\mathrm{GW}} = \frac{1}{\Delta t} \times \int_{0}^{\Delta t} \mathrm{GW(t)\ dt}$$

$$= \frac{1}{\Delta t} \times \left[\left(\mathrm{GW}_{\mathrm{in}} - \mathrm{GW}_{\mathrm{abstr}}\right) \times k \times 3600 \times \left(\Delta t - k \times \left(1 - e^{-\Delta t / k}\right)\right) + \mathrm{GW0} \times k \times \left(1 - e^{-\Delta t / k}\right)\right]$$

(Eq. A.5-7)

Groundwater runoff then results to:

$$\mathrm{GW}_{\mathrm{runoff}} = \frac{1}{k \times 3600} \times \overline{\mathrm{GW}}$$

(Eq. A.5-8)

The groundwater height $\mathrm{GW(t+\Delta t)}_{\mathrm{height}}$ in [m] at the end of time interval [t,t+Δt] is determined according to (Eq. A.5-5) which forms the boundary condition for the next time step:

$$\mathrm{GW(t+\Delta t)}_{\mathrm{height}} = \mathrm{GW(t+\Delta t)} \times \frac{100}{\Phi \times A \times 10^{6}}$$

(Eq. A.5-9)

A.6 Interception

The interception component simulates the interception processes. Interception can take place on the vegetation cover or depression storage in puddles and in land formations (e.g. rills, furrows) as well as anthropogenic structures (e.g. roads, rooftops). The interception storage has a maximum storage capacity I_Cap in [mm], which is described by a function of leaf area indices (LAI) for different kinds of vegetation covers according to the approach of Dickinson (1984):

$$I\_Cap = 0.2 \times LAI \qquad \text{(Eq. A.6-1)}$$

LAI can be varied on a monthly basis within the component. The process is modeled as a "bucket model". The modeling approach is depicted in the following figure.

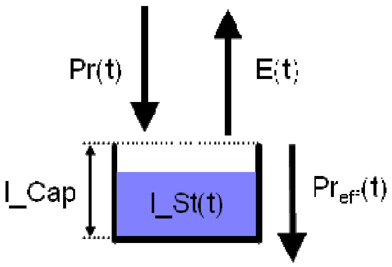

Fig. A.6-1: Modeling approach for interception

The interception storage I_St(t) in [mm] is bound by the interception storage capacity I_Cap in [mm]. It is filled up by gross precipitation Pr(t) in [mm/h] and is emptied by evaporation E(t) in [mm/h] and effective precipitation Pr(t)$_{eff}$ "overflow" in [mm/h]. The interception storage capacity I_Cap in [mm] may vary monthly. Three different cases are distinguished:

- No change
- Growth of interception storage and/or creation of effective precipitation
- Depletion of interception storage

The formulations hereafter are given for time step t+Δt.

No change ($Pr(t+\Delta t) = E(t+\Delta t)_{pot}$):

The interception storage I_St remains unchanged during the time step, there is no effective precipitation Pr_{eff}. The values for evaporation, difference of potential evaporation, effective precipitation and interception storage amount to:

$$E(t+\Delta t) = E(t+\Delta t)_{pot} \tag{Eq. A.6-2}$$

$$E(t+\Delta t)_{pot\ diff} = 0 \tag{Eq. A.6-3}$$

$$Pr(t+\Delta t)_{eff} = 0 \tag{Eq. A.6-4}$$

$$I\_St(t+\Delta t) = I\_St(t) \tag{Eq. A.6-5}$$

Growth of interception storage and/or creation of effective precipitation ($Pr(t+\Delta t) > E(t+\Delta t)_{pot}$):

If the interception storage I_St has not reached full interception capacity I_Cap at the beginning of the time step it continues to grow. For the time it grows no effective precipitation Pr_{eff} is generated. When interception storage I_St has reached the maximum volume I_Cap, effective precipitation is generated. The time to fill the interception storage to maximum capacity is determined by:

$$t^* = \frac{I\_Cap - I\_St(t)}{Pr(t+\Delta t) - E(t+\Delta t)_{pot}} \tag{Eq. A.6-6}$$

The values for evaporation, difference of potential evaporation, effective precipitation and interception storage then amount to:

$$E(t+\Delta t) = E(t+\Delta t)_{pot} \tag{Eq. A.6-7}$$

$$E(t+\Delta t)_{pot\ diff} = 0 \tag{Eq. A.6-8}$$

$$Pr(t+\Delta t)_{eff} = \begin{cases} \left(Pr(t+\Delta t) - E(t+\Delta t)_{pot}\right) \times \frac{(\Delta t - t^*)}{\Delta t} & , t^* \le \Delta t \\ 0 & , t^* > \Delta t \end{cases} \tag{Eq. A.6-9}$$

$$I\_St(t+\Delta t) = \begin{cases} I\_Cap & , t^* \le \Delta t \\ I\_St(t) + \left(Pr(t+\Delta t) - E(t+\Delta t)_{pot}\right) \times \Delta t & , t^* > \Delta t \end{cases} \tag{Eq. A.6-10}$$

Depletion of interception storage ($Pr(t+\Delta t) < E(t+\Delta t)_{pot}$):

Evaporation E from the interception storage I_St will take place according to the potential evaporation E_{pot} rate as long as the interception storage I_St has not been emptied during the time step. There is no effective precipitation Pr_{eff} generated. The time to empty the interception storage I_St is calculated by:

$$t^{**} = \frac{I\_St(t)}{E(t+\Delta t)_{pot} - Pr(t+\Delta t)}$$

(Eq. A.6-11)

The values for evaporation, difference of potential evaporation, effective precipitation and interception storage then amount to:

$$E(t+\Delta t) = \begin{cases} Pr(t+\Delta t) - \left(Pr(t+\Delta t) - E(t+\Delta t)_{pot}\right) \times \frac{t^{**}}{\Delta t} & , t^{**} \leq \Delta t \\ E(t+\Delta t)_{pot} & , t^{**} > \Delta t \end{cases}$$

(Eq. A.6-12)

$E(t+\Delta t)_{pot\ diff} = E(t+\Delta t)_{pot} - E(t+\Delta t)$ (Eq. A.6-13)

$Pr(t+\Delta t)_{eff} = 0$ (Eq. A.6-14)

$$I\_St(t+\Delta t) = \begin{cases} 0 & , t^{**} \leq \Delta t \\ I\_St(t) + \left(Pr(t+\Delta t) - E(t+\Delta t)_{pot}\right) \times \Delta t & , t^{**} > \Delta t \end{cases}$$

(Eq. A.6-15)

Where in (Eq. A.6-1) to (Eq. A.6-15) denote:

$E(t+\Delta t)$	evaporation from interception storage during time interval [t,t+Δt] in [mm/h],
$E(t+\Delta t)_{pot}$	potential evaporation during time interval [t,t+Δt] in [mm/h],
$E(t+\Delta t)_{pot\ dif}$	potential evaporation which was not covered by interception storage during time interval [t,t+Δt] in [mm/h],
I_Cap	interception storage capacity in [mm],
I_St(t)	interception storage content at the beginning of time interval [t,t+Δt] in [mm],
I_St(t+Δt)	interception storage content at time interval [t,t+Δt] in [mm],

LAI	leaf area index in [m^2/m^2],
$Pr(t+\Delta t)$	precipitation during time interval [$t,t+\Delta t$] in [mm/h],
$Pr(t+\Delta t)_{eff}$	effective precipitation during time interval [$t,t+\Delta t$] in [mm/h],
t^*, t^{**}	auxiliary time variables for determining the time when the interception reservoir is full (t^*) or empty (t^{**}) under the given conditions in [h],
Δt	simulation time step duration in [h].

$I\_St(t+\Delta t)$ is saved as boundary condition for the next time step.

Ludwig and Bremicker (2006) provide a selection of LAI values on a monthly basis for the Neckar catchment in southern Germany, a LAI value of 10 [m^2/m^2] for sealed areas is referred to in this publication. Scurlock, Asner and Gower (2001) report on an analysis of world-wide gathered LAI data which are depicted in the table hereafter.

Tab. A.6-1: LAI data (Scurlock, Asner and Gower, 2001)

Biome / land cover class	Number of observations	Mean	Standard deviation	Min	Max
Forest / BoDBL	53	2.58	0.73	0.6	4.0
Forest / BoENL	86	2.65	1.31	0.48	6.21
Crops	83	3.62	2.06	0.2	8.7
Desert	6	1.31	0.85	0.59	2.84
Grassland	25	1.71	1.19	0.29	5.0
Plantation	77	8.72	4.32	1.55	18.0
Shrub	5	2.08	1.58	0.4	4.5
Forest / BoTeDNL	17	4.63	2.37	0.5	8.5
Forest / TeDBL	184	5.06	1.60	1.1	8.8
Forest / TeEBL	57	5.70	2.43	0.8	11.6
Forest / TeENL	199	5.47	3.37	0.002	15.0
Forest / TrDBL	18	3.92	2.53	0.6	8.9
Forest / TrEBL	60	4.78	1.70	1.48	8.0
Tundra	11	1.88	1.47	0.18	5.3
Wetlands	6	6.34	2.29	2.5	8.4

The biome / land cover classes referred to are listed in the following table.

Tab. A.6-2: Biome / land cover classes (Scurlock, Asner and Gower, 2001)

Biome / land cover class	Acronym or terminology used
Tundra, circumpolar and alpine	Tundra
Deserts	Desert
Wetlands, temperate and tropical	Wetland
Grasslands, temperate and tropical	Grassland
Crops, temperate and tropical	Crops
Shrubland, heath or Mediterranean-type vegetation	Shrub
Plantations (managed forests); temperate deciduous broadleaf, temperate evergreen needleleaf, and tropical deciduous broadleaf	Plantation
Forest, boreal deciduous broadleaf	Forest / BoDBL
Forest, boreal evergreen needleleaf	Forest / BoENL
Forest, boreal/temperate deciduous needleleaf	Forest / BoTeDNL
Forest, temperate deciduous broadleaf	Forest / TeDBL
Forest, temperate evergreen needleleaf	Forest / TeENL
Forest, temperate evergreen broadleaf	Forest / TeEBL
Forest, tropical deciduous broadleaf	Forest / TrDBL
Forest, tropical evergreen broadleaf	Forest / TrEBL

A.7 Kalinin

The Kalinin simulation component simulates the flood wave routing in canals / rivers according to the Kalinin-Miljukov method. The method is described hereafter.

Theoretical background:

The method is based on the assumption of a linear relationship between runoff and volume of a river section. Kalinin and Miljukov derived a mathematical description of the unsteady flow conditions in rivers and canals based on steady flow flow relationships between stage, width of water table, runoff and mean bed slope by subtle assumptions for the geometry and by simplifying transformations of the basic equations. The general approach of the Kalinin-Miljukov method is presented hereafter followed by the description of the algorithms implemented in the component.

The Kalinin-Miljukov method is based on determining characteristic intervals L for a river / canal section for which changes in runoff volumes are the same for steady and unsteady flow. The characteristic interval L results from the hysteresis curve of the unsteady flow depicted below.

The unsteady flow stages which result for the same runoff Q possess a defined temporal relationship to the corresponding steady flow stages. The unsteady flow (rising as well as falling limb of the hydrograph) precedes the steady flow by Δt as depicted in the following figure.

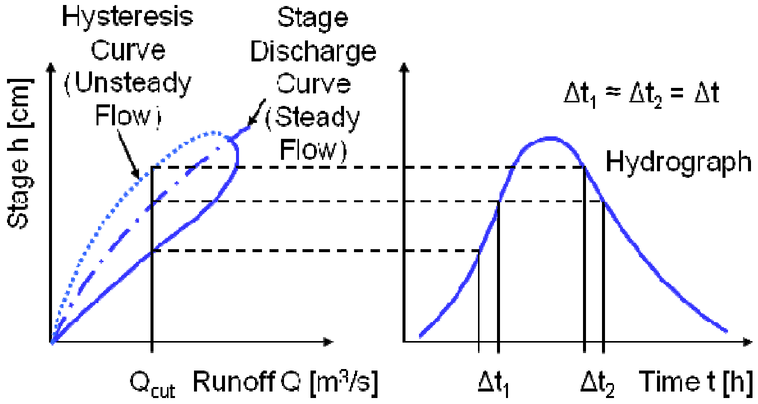

Fig. A.7-1: Stage-runoff-relationship for steady and unsteady flow

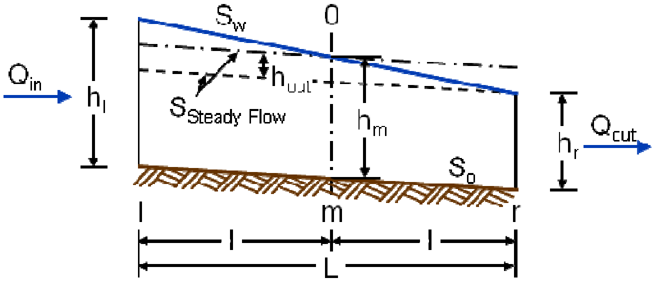

Fig. A.7-2: Characteristic length according to Kalinin-Miljukov

A unique volume runoff relationship is therefore only given if the runoffs are assigned to stages which occur Δt later. As depicted in the preceding figure the unsteady runoff Q_{out} at a given time is not assigned to location "r" of the characteristic interval L, instead it is assigned to location “m” which is located upstream at a distance l from “r”. Therefore the stage of the unsteady flow at location “m” will reach location “r” after Δt. Δt can also be interpreted as distance l. The volumes of the steady and unsteady flows are therefore the same for the characteristic interval L. Taking this into consideration the total length L_{total} of the river / canal section is subdivided into reservoirs of length L for determining the flood wave transformation:

$$n = L_{total} / L \qquad \text{(Eq. A.7-1)}$$

where

L	characteristic interval in [m],
L_{total}	total length of river / canal section in [m],
n	number of linear reservoirs in river / canal section.

This results in a series of linear reservoirs as depicted hereafter.

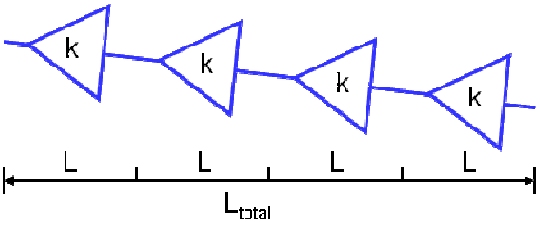

Fig. A.7-3: Series of linear reservoirs

Under the assumption that the energy slope is parallel to the bed slope and bed roughness is constant in the section the characteristic interval L results to:

$$L = 2 \times l = \frac{Q_{st}}{S_{st}} \times \frac{dh_{st}}{dQ_{st}} \approx \frac{Q_{max} + Q_{min}}{2 \times S_{st}} \times \frac{h_{max} - h_{min}}{Q_{max} - Q_{min}} \qquad \text{(Eq. A.7-2)}$$

dh_{st} / dQ_{st} denotes the slope of the stage-runoff relationship which in general is not constant. As an approximation the mean value of the runoff interval may be used instead. The retention constant k is determined by:

$$k = B \times L \times \frac{\mathrm{dh}_{\mathrm{st}}}{\mathrm{dQ}_{\mathrm{st}}} \approx B \times L \times \frac{h_{\mathrm{max}} - h_{\mathrm{min}}}{Q_{\mathrm{max}} - Q_{\mathrm{min}}}$$

(Eq. A.7-3)

where

B	width of water table in [m],
h_{st}	stage for steady flow Qst in [m],
h_{min}	minimum stage for steady flow during a particular time period in [m],
h_{max}	maximum stage for steady flow during a particular time period in [m],
l	half of the characteristic interval L in [m],
L	characteristic interval in [m],
Q_{st}	runoff for steady flow in [m^3/s],
Q_{min}	minimum runoff for steady flow during particular time period in [m^3/s],
Q_{max}	maximum runoff for steady flow during particular time period in [m^3/s],
S_{st}	slope of energy line for steady flow in [-].

Based on the continuity equation

$$\frac{\mathrm{dV}}{\mathrm{dt}} = Q_{\mathrm{in}} - Q_{\mathrm{out}}$$

(Eq. A.7-4)

and an unique volume-runoff relationship

$$Q_{out} = k \times V$$

(Eq. A.7-5)

and the assumption of a prismatic channel (river / canal cross section does not vary for the particular river / canal section) the following equation of the Kalinin-Miljukov method for one reservoir is derived:

$$\mathrm{Q(t+\Delta t)}_{\mathrm{out}} = \mathrm{Q(t)}_{\mathrm{out}} + c_1 \times \left(\mathrm{Q(t)}_{\mathrm{in}} - \mathrm{Q(t)}_{\mathrm{out}}\right) + c_2 \times \left(\mathrm{Q(t+\Delta t)}_{\mathrm{in}} - \mathrm{Q(t)}_{\mathrm{in}}\right)$$

(Eq. A.7-6)

where

c_1, c_2	$c_1 = 1 - e^{-\Delta t / k}$	(Eq. A.7-6 a) in [-] and
	$c_2 = 1 - \frac{k}{\Delta t} \times c_1$	(Eq. A.7-6 b) in [-],
k	retention constant of linear reservoir(s) in [h],	
$Q(t)_{in}$	runoff entering river / canal section at time t in [m^3/s],	
$Q(t+\Delta t)_{in}$	runoff entering river / canal section during time interval [t,t+Δt] in [m^3/s],	
$Q(t)_{out}$	runoff from river / canal section at time t in [m^3/s],	
$Q(t+\Delta t)_{out}$	runoff from river / canal section during time interval [t,t+Δt] in [m^3/s],	
Δt	simulation time step duration in [h].	

Implemented algorithm:

The implemented Kalinin-Miljukov Method is based on prismatic river / canal sections of length L_{total} in [m] with bed slope S_0 in [-] and cross sections as depicted hereafter.

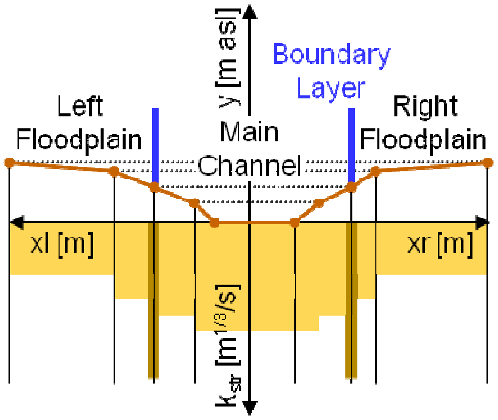

Fig. A.7-4: Cross section and hydraulic roughness values

Each height h (y value in [m asl]) is attributed with one x to the left value (xl in [m]), one x to the right value (xr in [m]), one Strickler roughness value for the left polygon section (kl_{str} in [$m^{1/3}$/s]), one Strickler roughness value for the right polygon section (kr_{str} in [$m^{1/3}$/s]), one Strickler roughness value for the boundary layer separating the left floodplain from the main channel (kbl_{str} in [$m^{1/3}$/s], 0 if not present) and one

Strickler roughness value for boundary layer separating the right floodplain from the main channel (kbr_{str} in [$m^{1/3}$/s], 0 if not present).

The function Q = f(h) is determined piecewise (h_i,Q_i) on the basis of these geometry data and a user defined maximum step size interval Δh_{max} according to Manning-Strickler's (Eq. A.7-7) flow law for open channel steady flow and Bernoulli's formula (Eq. A.7-8) for conduit flow (e.g. single field bridges, pipe flow). In parallel, the corresponding width of the water table B_i in [m] is determined for each h_i in [m]. The calculation is separately carried out for the main channel as well as the left and right side of the floodplain.

$$Q = k_{\mathrm{str}} \times \sqrt{S_0} \times R^{2/3} \times A = k_{\mathrm{str}} \times \sqrt{S_0} \times A^{5/3} \times C$$ (Eq. A.7-7)

$$Q = f_{\mathrm{eff}} \times \sqrt{2 \times g \times h_p} \times A$$ (Eq. A.7-8)

where

A	area of open channel cross section (dependant on h) and / or conduit flow in [m^2],
C	contour length of wetted cross section (dependant on h) in [m],
f_{eff}	proportion of effective flow (without friction losses) in [-], feff is set to 1.0 in the component,
g	gravity constant (g = 9.81) in [m/s^2],
h_p	hydraulic head for pressure flow (dependant on h) in [m],
k_{str}	Strickler roughness value (dependant on h, kstr is determined as weighted mean value) in [$m^{1/3}$/s],
Q	runoff in [m^3/s],
R	hydraulic radius (R = A / C , dependant on h) in [m],
S_0	bed slope in [-].

The characteristic interval L in [m] and the retention constant k in [s] are averaged over a user defined number of "iriver" intervals from Q_{min} in [m^3/s] to Q_{max} [m^3/s] according to (Eq. A.7-2) and (Eq. A.7-3) as follows:

$$L = \frac{1}{\mathrm{iriver}} \times \sum_{\mathrm{i=1}}^{\mathrm{iriver}} \frac{Q_i}{S_0} \times \frac{h_{\mathrm{i+1}} - h_i}{Q_{\mathrm{i+1}} - Q_i}$$ (Eq. A.7-9)

$$k = \frac{1}{\text{iriver}} \times \sum_{i=1}^{\text{iriver}} L \times B_i \times \frac{h_{i+1} - h_i}{Q_{i+1} - Q_i}$$ (Eq. A.7-10)

The number of reservoirs n is determined by:

$$n = \text{maxint} \left\{ \frac{L_{\text{total}}}{L}, \frac{L_{\text{total}} + 0.5}{L} \right\}$$ (Eq. A.7-11)

If the runoff capacity of the main channel Q_{max} in [m^3/s] is exceeded by inflow Q_{in} in [m^3/s] ($Q_{in} > Q_{max}$) a flow separation between the main channel flow $Q_{in\ mc}$ in [m^3/s] and the flood plain flow $Q_{in\ fp}$ in [m^3/s] is implemented resulting in two parallel reservoir cascades as depicted in the figure hereafter. The separation is defined by the factor α in [-] as follows:

$Q_{in\ fp} = (1 - \alpha) \times (Q_{in} - Q_{max})$ (Eq. A.7-12)

$Q_{in\ mc} = \alpha \times (Q_{in} - Q_{max}) + Q_{max}$ (Eq. A.7-13)

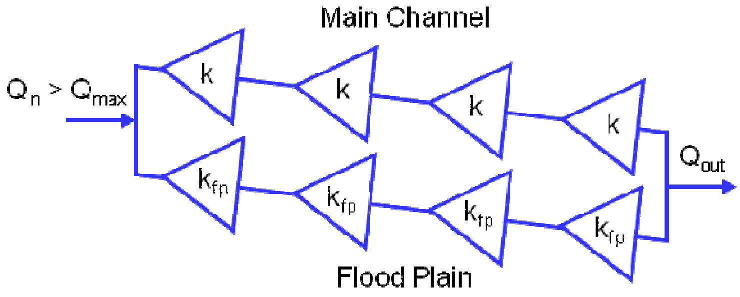

Fig. A.7-5: Two parallel linear reservoir cascades

The retention constant for the linear reservoirs of the flood plain cascade k_{fp} in [h] is determined from the predefined retention constant for the total length of the flood plain k_{fp} total in [h] by $k_{fp} = k_{fp\ total} / n$. The runoff is calculated according to equation (Eq. A.7-6).

The n values of $Q(t+\Delta t)_{in}$ and $Q(t+\Delta t)_{out}$ for the main channel and the flood plain are saved as boundary conditions for the next time step.

A.8 Lateral Runoff

The lateral runoff component simulates the lateral runoff processes. It may be applied for surface and subsurface lateral runoff (interflow). In both cases time area functions are the basis for these calculations. The basics of time area functions are depicted in the following figure.

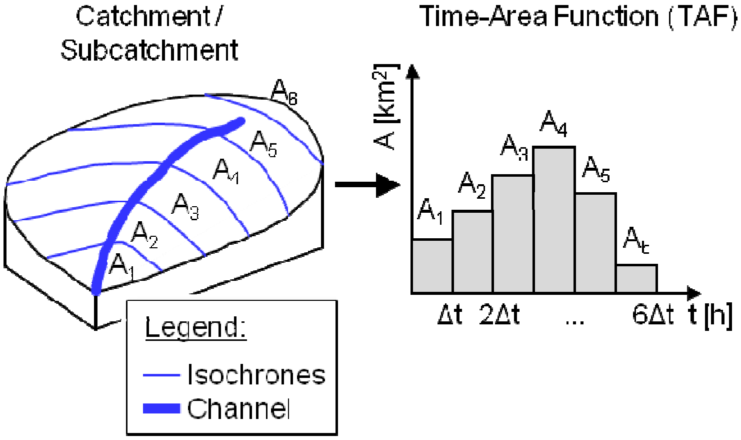

Fig. A.8-1: Time area functions as a basis to determine lateral runoff

The implemented algorithm consists of two consecutive steps for time step t+Δt:

- **Step 1:** Convolution with time area function
- **Step 2:** Passing the resulting outflow through a linear reservoir

<u>Step 1:</u>

In the first step a convolution of the effective lateral runoff lat_{runoff} in [mm/h] and the time area function TAF in [km^2] is performed. This results in Q_{in} in [m^3/s]:

$$Q(t+\Delta t)_{in} = \frac{1}{3.6} \times \sum_{i=1}^{ie} TAF(i\times\Delta t) \times lat(t-[i-2]\times\Delta t)_{runoff} \qquad \text{(Eq. A.8-1)}$$

where

i	index for summation in [-],
ie	total number of time-area function tupels for time step Δt of subcatchment in [-],
$lat(t-[i-2]\times\Delta t)_{runoff}$	(t-[i-2])-th lateral runoff tupel for time step Δt in [mm/h],

$Q(t+\Delta t)_{in}$	runoff during time interval [t,t+Δt] in [m^3/s],
TAF(i×Δt)	i-th time-area function tupel for time step Δt in [km^2],
Δt	time step length in [h].

The lat_{runoff} and TAF values are stored in arrays of identical length. The lat_{runoff} array is organized as a first-in last-out list, where the current lat_{runoff} value is pushed onto the first field of the list.

Step 2:

In a second step the resulting lateral runoff is passed through a linear reservoir with retention constant k in [h] in order to account for retention processes during the runoff process. The procedure is depicted hereafter.

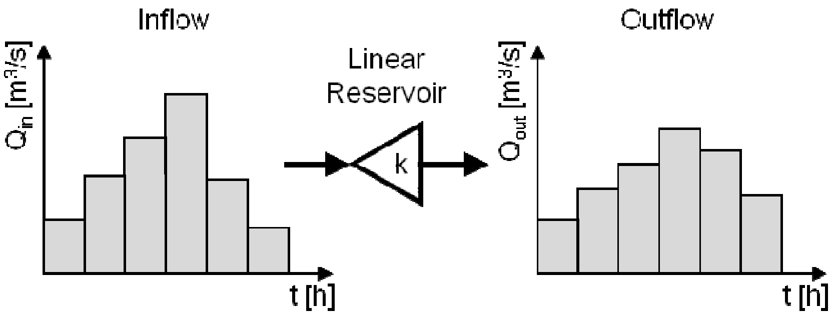

Fig. A.8-2: Passing of lateral outflow through a linear reservoir

The governing equation for the linear reservoir is:

$$\frac{dS(t)}{dt} = Q_{in} - Q_{out} \qquad \text{(Eq. A.8-2)}$$

Replacing $Q(t)_{out} = 1 / k \times S(t)$ into (Eq. A.8-2) and doing unit conversions results in the following inhomogeneous linear differential equation for the linear reservoir:

$$\frac{dS(t)}{dt} + \frac{1}{k \times 3600} \times S(t) = Q_{in} \qquad \text{(Eq. A.8-3)}$$

The solution of this differential equation at the end of time step t+Δt is:

$$S(t+\Delta t) = Q_{in} \times k \times 3600 \times \left(1 - e^{-\Delta t / k}\right) + S0 \times e^{-\Delta t / k} \qquad \text{(Eq. A.8-4)}$$

In order to reduce the volume error for determining the runoff Q(t)out the mean reservoir volume $\overline{S}$ in [m^3] is determined for the time interval [t,t+Δt] which then is used for determining the runoff Q_{out} in [m^3/s]. The mean reservoir volume $\overline{S}$ for the time interval [t,t+Δt] is determined by:

$$\overline{S} = \frac{1}{\Delta t} \times \int_{0}^{\Delta t} S(t)\,dt$$

$$= \frac{1}{\Delta t} \times \left[Q_{in} \times k \times 3600 \times \left(\Delta t - k \times \left(1 - e^{-\Delta t / k}\right)\right) + S0 \times k \times \left(1 - e^{-\Delta t / k}\right)\right]$$

(Eq. A.8-5)

The lateral runoff then results to:

$$Q_{out} = \frac{1}{k \times 3600} \times \overline{S}$$

(Eq. A.8-6)

where

k	retention constant of the linear reservoir in [h],
Q_{in}	runoff during time interval [t,t+Δt] into the linear reservoir in [m^3/s],
Q_{out}	runoff during time interval [t,t+Δt] from the subcatchment in [m^3/s],
S	volume of linear reservoir in [m^3],
$\overline{S}$	mean volume of linear reservoir during time interval [t,t+Δt] in [m^3],
$S0$	volume of linear reservoir at the beginning of time interval [t,t+Δt] in [m^3],
Δt	time step length in [h].

The value S(t+Δt) is saved as boundary condition for the next time step.

A.9 Reservoir

The reservoir component simulates the storage runoff process of stormwater retention tanks (reservoirs). The simulation takes place on the basis of a stage throttle discharge curve and a stage volume curve (characteristic curves) as depicted in the following figure.

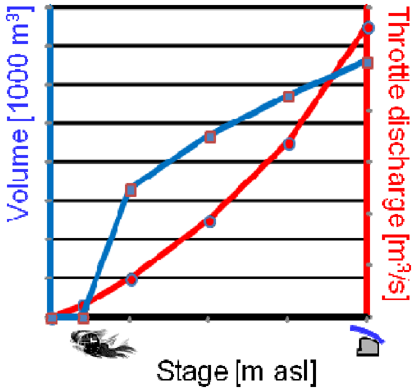

Fig. A.9-1: Stage throttle discharge curve and stage volume curve of a reservoir

The formulations hereafter are given for the time step t+Δt.

The reservoir is characterized by a minimum volume V_{min} in [1000 m^3] and a maximum volume V_{max} in [1000 m^3]. Below minimum volume (dead storage) no runoff occurs, above maximum volume spillover Q_{spill} in [m^3/s] occurs. This spillover may be routed either to the (i) same element as the throttle outflow or to (ii) a different element.

The throttle runoff is determined by iteration. From an initial volume V0 in [1000 m^3] the corresponding throttle runoff $Q0_{thr}$ in [m^3/s] is estimated. The continuity is preserved by:

$$V1(t+\Delta t) = V0 + \left(Q_{in} - Q0_{thr} - Q_{spill}\right) \times \Delta t \times 3.6 \qquad \text{(Eq. A.9-1)}$$

Where denote:

Q_{in}	reservoir inflow during time interval [t,t+Δt] in [m^3/s],
Q_{spill}	reservoir spill flow during time interval [t,t+Δt] in [m^3/s],

$Q0_{thr}$	reservoir throttle release (outflow) during time interval $[t,t+\Delta t]$ in $[m^3]$,
$V0$	reservoir volume at time t in $[1000\ m^3]$,
$V1(t+\Delta t)$	reservoir volume at time $t+\Delta t$ in $[1000\ m^3]$,
Δt	time step length in [h].

On the basis of $V1(t+\Delta t)$ the throttle runoff $Q1_{thr}$ is determined by the characteristic curves. If $Q0_{thr} \neq Q1_{thr}$ then an iteration is started within these boundaries sequentially narrowing the interval $[Q0_{thr}, Q1_{thr}]$ for $Q0_{thr} < Q1_{thr}$ or $[Q1_{thr}, Q0_{thr}]$ for $Q1_{thr} < Q0_{thr}$ by bisection while taking continuity from equation (Eq. A.9-1) into account (interchange $Q0_{thr}$ with $Q1_{thr}$ in equation (Eq. A.9-1)) until $|Q1_{thr} - Q0_{thr}| < \varepsilon$, where ε is a predefined value.

The calculation will provide reservoir storage V at time $t+\Delta t$ in $[1000\ m^3]$ and runoff values Q_{thr} and Q_{spill} during interval $[t,t+\Delta t]$ in $[m^3/s]$.

A.10 Sewer

Sewer processes run quite fast in comparison to other catchment processes. This is reflected in the implemented simulation of sewer systems. Two kinds of sewers are distinguished:

- **Storage sewers:** This function enables the hydrological simulation of runoff in a sewer system with a main sewer and an arbitrary number of contributing minor sewers.
- **Transport sewers / conduits:** This function enables the simulation of a transport sewer or conduit. The runoff retention is determined by the flow time. Storage processes are not taken into account.

If the sewer flow time is $t_f > 0.1 \times \Delta t \times 3600$ in [s] (Δt: simulation time step in [h]), then both processes are simulated as a series of three linear reservoirs where the retention constant of the reservoirs is set to the determined sewer flow time t_f. No spillage is determined in this algorithm. The following figure illustrates the approach.

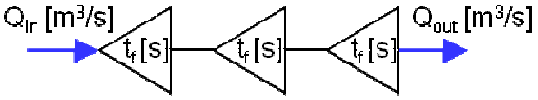

Fig. A.10-1: Sewer system simulated as cascade of linear reservoirs

In case the sewer flow time is $t_f \leq 0.1 \times \Delta t \times 3600$ a differentiation between storage sewers and transport servers is made. In both cases spillage can be routed to a different element.

The general concept of refining a given time series resolution Δt into finer time steps Δt* is depicted in the figure hereafter. The centers of the "columns" of the time series with temporal resolution Δt are connected by straight lines (dashed green line). The mass balance is preserved this way. As the simulation takes place at a constant time step Δt, this would result in an unknown course of the time series for the second half of the time step. By shifting the line at an offset of Δt/2 to the right (red continuous line) this problem can be omitted, but a little volume error will occur. On this basis the time series with temporal resolution Δt will be broken down into a time series of time step Δt*. At the end of each time step the results will be aggregated to time step Δt again.

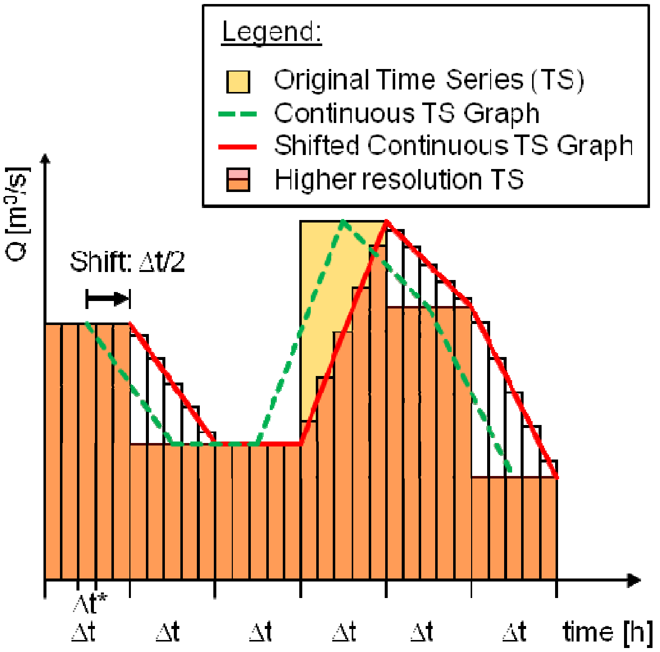

Fig. A.10-2: Approach of time series data refinement

Storage sewer:

The processes in storage sewers are modeled as a reservoir in a sequence starting from an initial volume V(t) in [m^3] as follows:

$$Q_{\mathrm{sewer}} = \begin{cases} \mathrm{V(t)}/t_f & \text{, if } \mathrm{V(t)} < V_{\mathrm{main}} \\ Q_{\mathrm{throttle}} & \text{, if } \mathrm{V(t)} \geq V_{\mathrm{main}} \end{cases} \qquad \text{(Eq. A.10-1)}$$

If V(t) > Vsewer then $Q_{\mathrm{spill}} = \mathrm{V(t)} - V_{\mathrm{sewer}} / t_{\mathrm{ret}}$ (Eq. A.10-2)

$$\mathrm{V(t+\Delta t^*)} = \mathrm{V(t)} + \left(Q_{\mathrm{in}} - Q_{\mathrm{sewer}} - Q_{\mathrm{spill}}\right) \times \Delta t^* \qquad \text{(Eq. A.10-3)}$$

In case V(t+Δt*) < 0 then Q_{spill}, Q_{sewer} are set as follows $Q_{spill} = 0$ and Q_{sewer} = V(t) / Δt* and the volume V(t+Δt*) is determined to V(t+Δt*) = Q in × Δt*.

The values for Q_{spill} and Q_{sewer} for the duration [t,t+Δt] are derived as mean values from the calculated values at the refined for time step Δt*.

The symbols in (Eq. A.10-1) to (Eq. A.10-3) denote:

Q_{in}	inflow to sewer during time interval [t,t+Δt*] in [m^3/s],
Q_{sewer}	runoff from sewer during time interval [t,t+Δt*] in [m^3/s],

Q_{spill}	spillage runoff from sewer during time interval [t,t+Δt*] in [m^3/s],
$Q_{throttle}$	maximum runoff of throttle at the end of the sewer line in [m^3/s],
t_f	flow time in sewer in [s],
V(t)	water volume in sewer at beginning of time step in [m^3],
V(t+Δt*)	water volume in sewer at end of time step Δt* in [m^3],
V_{main}	volume of sewer at maximum throttle flow (Qthrottle × t_f) in [m^3],
V_{sewer}	storage capacity of the sewer in [m^3],
Δt*	refined time step length in [s].

Transport sewer / conduit:

Retention processes for throughflow in transport sewers / conduits are modeled via the Muskingum-Cunge method:

$$Q(t+\Delta t^*) = a \times Q(t) + b \times Q_g + c \times Q_i \tag{Eq. A.10-4}$$

with

$$a + b + c = 1 \tag{Eq. A.10-5}$$

where

$$a = e^{-\Delta t^* / t_f} \tag{Eq. A.10-6}$$

$$b = \frac{t_f}{\Delta t^*} - \left(1 + \frac{t_f}{\Delta t^*}\right) \times e^{-\Delta t^* / t_f} \tag{Eq. A.10-7}$$

$$c = 1 - \frac{t_f}{\Delta t^*} \times \left(1 - e^{-\Delta t^* / t_f}\right) \tag{Eq. A.10-8}$$

The symbols in (Eq. A.10-4) to (Eq. A.10-8) denote:

a	weighing factor according to Muskingum-Cunge in [-],
b	weighing factor according to Muskingum-Cunge in [-],
c	weighing factor according to Muskingum-Cunge in [-],

$Q(t)$	main sewer runoff at time t in [m^3/s],
$Q(t+\Delta t^*)$	main sewer runoff during time interval [$t,t+\Delta t^*$] in [m^3/s],
Q_g	main sewer inflow (see figure hereafter) during time interval [$t,t+\Delta t^*$] in [m^3/s],
Q_i	main sewer inflow (see figure hereafter) during time interval [$t,t+\Delta t^*$] in [m^3/s],
t_f	flow time in sewer in [s],
Δt^*	refined time step length in [s].

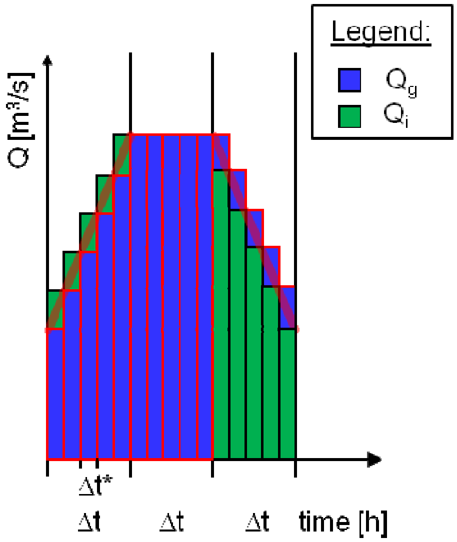

Fig. A.10-3: Time series data refinement for Muskingum-Cunge application

Spillage (diversion flow) Qs in [m^3/s] is determined, if either Q_g or Q_i exceed a limiting value of throttle flow $Q_{throttle}$ in [m^3/s]. Spillage flow is also determined via the Muskingum-Cunge method:

$$Qs(t+\Delta t) = as \times Qs(t) + bs \times Qs_g + cs \times Qs_i \qquad \text{(Eq. A.10-9)}$$

with

$$as + bs + cs = 1 \qquad \text{(Eq. A.10-10)}$$

where

$$as = e^{-\Delta t / t_{ret}} \qquad \text{(Eq. A.10-11)}$$

$$\mathrm{bs} = \frac{t_{\mathrm{ret}}}{\Delta \mathrm{t}} - \left(1 + \frac{t_{\mathrm{ret}}}{\Delta \mathrm{t}}\right) \times e^{-\Delta \mathrm{t} / t_{\mathrm{ret}}} \qquad \text{(Eq. A.10-12)}$$

$$\mathrm{cs} = 1 - \frac{t_{\mathrm{ret}}}{\Delta \mathrm{t}} \times \left(1 - e^{-\Delta \mathrm{t} / t_{\mathrm{ret}}}\right) \qquad \text{(Eq. A.10-13)}$$

The symbols in (Eq. A.10-9) to (Eq. A.10-13) denote:

as	weighing factor according to Muskingum-Cunge in [-],
bs	weighing factor according to Muskingum-Cunge in [-],
cs	weighing factor according to Muskingum-Cunge in [-],
Qs(t)	spillage runoff at time t in [m^3/s],
Qs(t+Δt)	spillage runoff during time interval [t,t+Δt] in [m^3/s],
Qs_g	spillage runoff (see previous figure) determined from the sum of spillage volume increments during refined time intervals [t,t+(n-1)×Δt*] (n=1, 2, 3, ... , for n=1: Qsg = Qs(t)) during time step Δt in [m^3/s],
Qs_i	spillage runoff (see previous figure) determined from the sum of spillage volume increments during refined time intervals [t,t+n×Δt*] (n=1, 2, 3, ...) during time step Δt in [m^3/s],
t_{ret}	retention constant of sewer overflow in [s],
Δt	time step length in [s].

A.11 Snow

The snow simulation module simulates snow processes according to the Snow-Compaction-Method. Three different processes are distinguished herein:

- **Accumulation:** The snow cover grows at temperatures below freezing point.
- **Compaction:** At temperatures above freezing point the snow cover compacts without releasing water until a critical snow density is reached (about 40 to 45 % of water content).
- **Ablation:** The snow cover will release melting water without further compaction at temperatures above freezing point if the critical snow density has been reached.

The processes are depicted in the following figure.

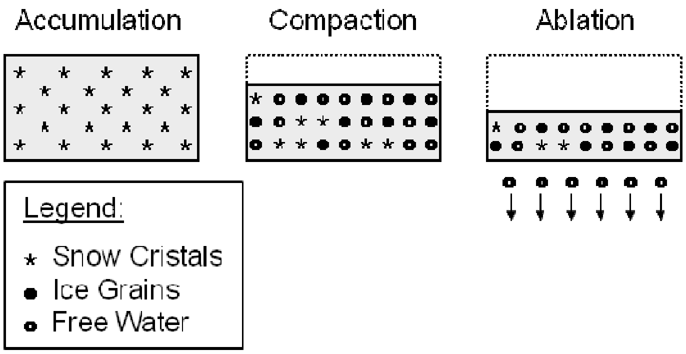

Fig. A.11-1: Basic processes in a snow column

If not referred to otherwise, variables always refer to time t+Δt, hereafter, e.g. snow hight hs := hs(t+Δt).

Snow accumulation:

For temperatures below 0 °C t he snow cover builds up.

$$w(t+\Delta t) = w(t) + Pr(t+\Delta t) \times \Delta t$$ (Eq. A.11-1)

$$hs(t+\Delta t) = hs(t) + \frac{Pr(t+\Delta t)}{\rho_{\text{new snow}} / \rho_{\text{water}}} \times \Delta t$$ (Eq. A.11-2)

Where in (Eq. A.11-1) and (Eq. A.11-2) denote:

hs(t)	hight of snow column at time t in [mm],

$hs(t+\Delta t)$	hight of snow column at time t+Δt in [mm],
$Pr(t+\Delta t)$	precipitation as snow during time interval [t,t+Δt] in [mm/h],
$w(t)$	water content of snow column at time t in [mm],
$w(t+\Delta t)$	water content of snow column at time t+Δt in [mm],
Δt	simulation time step duration in [h],
$\rho_{\text{new snow}}$	density of precipitation on soil in [kg/m^3] - a standard of 130 [kg/m^3] has been implemented in the component,
ρ_{water}	water density in [kg/m^3] (1000 [kg/m^3]).

Potential snow melting rate:

For temperatures above 0 ℃ the snow melts. The potential snow melting rate $i(t)_p$ in [mm/h] according to Knauf (1980) is:

$$i_p = \frac{1}{r_s} \times \left(a_0 + a_1 \times v_{\text{wind}}\right) \times T_{\text{air}} + 0.0125 \times \Pr \times T_{\text{pr}} + c_s \qquad \text{(Eq. A.11-3)}$$

where

a_0	constant in the heat transfer coefficient in [W/℃], according to Knauf (1980) the domain is [1,7] - a mean value of 4.0 [W/℃] is assigned by standard in the component,
a_1	constant in the heat transfer coefficient in [Ws/m℃], according to Knauf (1980) the domain is [0.8,2.5] - a standard value of 1.6 [Ws/m℃] is assigned in the component,
c_s	constant melting rate due to soil heat conduction in [mm/h], according to Knauf (1980) the domain is [0.1,1.0] - a standard value of 0.1 [mm/h] is assigned in the component,
Pr	precipitation (rain) in [mm/h],
T_{air}	air temperature in [℃],
T_{pr}	precipitation (rain) temperature in [℃],
r_s	melting energy of snow (92.6 Wh/kg) in [Wh/kg],
v_{wind}	wind speed at 10 m above ground in [m/s].

Assuming $T = T_{air} = T_{pr}$ the potential snow melting rate i_p results in:

$$i_p = \frac{1}{r_s} \times \left(a_0 + a_1 \times v_{\mathrm{wind}}\right) \times T + 0.0125 \times \mathrm{Pr} \times T + c_s$$ (Eq. A.11-3 a)

Snow compaction:

An empirical relation between the initial snow hight and supplied free water to the snow cover was derived by Bertle (1966) which is based on laboratory experiments carried out by the US-Bureau of Reclamation. The relation reads:

$$P_{\mathrm{height}} = 147.4 - 0.474 \times P_{\mathrm{water}}$$ (Eq. A.11-4)

where

$$P_{\mathrm{height}} = \frac{\mathrm{hs}}{\mathrm{hs}_d} \times 100$$ (Eq. A.11-5)

fraction of total (wet) snow hight hs in [mm] and dry snow height hs_d in [mm] of snow column in [%],

$$P_{\mathrm{water}} = \frac{w_{\mathrm{acc}}}{w_d} \times 100$$ (Eq. A.11-6)

fraction of total accumulated water w_{acc} [mm] and water content of dry snow/ice w_d in [mm] of snow column in [%].

For temperatures above 0 °C and snow densities ρ_s below a critical value $\rho_s = w_{\mathrm{acc}} / \mathrm{hs} \times 1000 < \rho_{\mathrm{crit\ snow}}$ in [kg/m^3] the snow cover does not release water. According to Knauf (1980) the domain of $\rho_{\mathrm{crit\ snow}}$ is [400, 450] in [kg/m^3], a standard value of $\rho_{\mathrm{crit\ snow}} = 420$ [kg/m^3] has been implemented in the component.

Snow ablation:

Once the critical density $\rho_{\mathrm{crit\ snow}}$ has been reached and temperatures are above 0 °C the snow cover starts to release water. Runoff q from snow cover is determined by the difference of total accumulated water w_{acc} [mm] and the equivalent water content of snow column hight hs at critical snow density $\rho_{\mathrm{crit\ snow}}$:

$$q = \left(w_{\mathrm{acc}} - \mathrm{hs} \times \rho_{\mathrm{crit\ snow}} / 1000\right) / \Delta\mathrm{t}$$ (Eq. A.11-7)

$$w = w_{\mathrm{acc}} - q \times \Delta\mathrm{t}$$ (Eq. A.11-8)

Where in (Eq. A.11-7) and (Eq. A.11-8) denote:

hs	hight of snow column at time $t+\Delta t$ in [mm],
q	runoff from snow column during time interval $[t,t+\Delta t]$ in [mm/h],
w	water content of snow column at time $t+\Delta t$ in [mm],
w_{acc}	total accumulated water of snow column at time $t+\Delta t$ in [mm],
Δt	simulation time step duration in [h],
$\rho_{crit\ snow}$	critical snow density [kg/m^3].

The values $w(t+\Delta t)$ and $hs(t+\Delta t)$ are stored as boundary conditions for the next time step.

A.12 Soil Moisture

The soil moisture component simulates the soil moisture accounting. There are three fluxes into and from the soil column which are depicted in the definition sketch below.

- Inf(t): Water infiltrates from the surface into the soil column.
- Eva(t): Water evaporates either directly from the soil or from plants which retrieve their water from the soil column.
- Perc(t): Water percolates from the vadose zone into the saturated zone (groundwater).

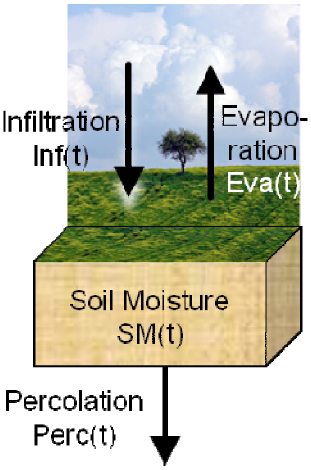

Fig. A.12-1: Fluxes in and out of the vadose zone soil column

This results in the following differential equation for the water balance of a soil column.

$$\frac{dSM(t)}{dt} = Inf(t) - Eva(t) - Perc(t) \qquad \text{(Eq. A.12-1)}$$

Infiltration, evaporation and percolation are all dependent on soil moisture. In natural environments soil moisture can only vary between the permanent wilting point (PWP) and the total porosity (also called total pore volume, TPV). The infiltration rate is highest at PWP and is zero at TPV. The evaporation is zero at PWP and reaches its maximum at field capacity (FC) and stays constant at this rate from thereon to TPV. No water percolates below FC, percolation is at its maximum at TPV. Assuming a linear relationship between these points results in piecewise linear functions for infiltration, evaporation and percolation as a function of soil moisture which is depicted in the graph hereafter.

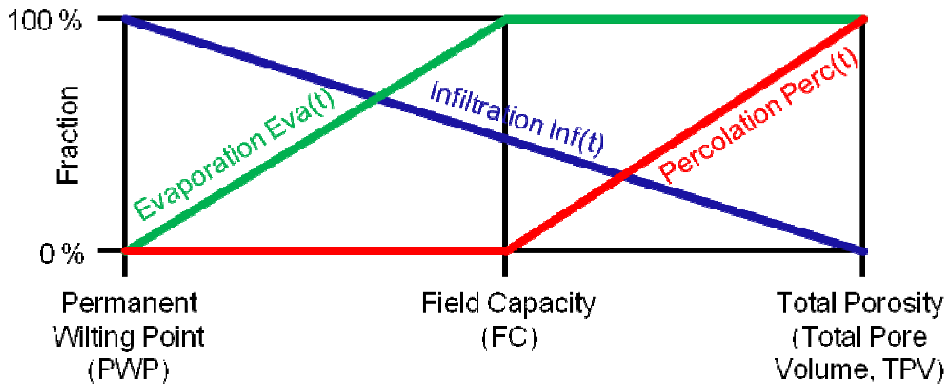

Fig. A.12-2: Piecewise linear functions for infiltration, evaporation and percolation:

This results in a set of equations for infiltration, evaporation and percolation as follows.

Infiltration:

$$\mathrm{Inf(t)} = \begin{cases} \mathrm{Infp(t)}\ ,\ \mathrm{Pr(t)} > \mathrm{Infp(t)} \\ \mathrm{Pr(t)}\ ,\ \mathrm{Pr(t)} \leq \mathrm{Infp(t)} \end{cases} \qquad \text{(Eq. A.12-2)}$$

where

$$\mathrm{Infp(t)} = \mathrm{PINF} - \frac{\mathrm{PINF} \times \mathrm{SM(t)}}{\mathrm{SMTPV}} \qquad \text{(Eq. A.12-3)}$$

PINF can be varied on a monthly basis within the component.

Evaporation:

$$\mathrm{Eva(t)} = \begin{cases} \dfrac{\mathrm{PEVA} \times \mathrm{SM(t)}}{\mathrm{SMFC}}\ ,\ \mathrm{SM} < \mathrm{SMFC} \\ \mathrm{PEVA}\ ,\ \mathrm{SM} \geq \mathrm{SMFC} \end{cases} \qquad \text{(Eq. A.12-4)}$$

Percolation:

$$\mathrm{Perc(t)} = \begin{cases} 0\ ,\ \mathrm{SM} < \mathrm{SMFC} \\ \dfrac{\mathrm{PPERC} \times (\mathrm{SM(t)} - \mathrm{SMFC})}{\mathrm{SMTPV} - \mathrm{SMFC}}\ ,\ \mathrm{SM} \geq \mathrm{SMFC} \end{cases} \qquad \text{(Eq. A.12-5)}$$

Where in (Eq. A.12-1) to (Eq. A.12-5) denote:

Eva(t)	actual evapotranspiration from the soil column in [mm/h],
Inf(t)	actual infiltration in [mm/h],
Infp(t)	potential infiltration in [mm/h],
Perc(t)	actual percolation from the soil column into groundwater [mm/h],
PEVA	maximum evaporation in [mm/h],
PINF	maximum infiltration in [mm/h],
PPERC	maximum percolation in [mm/h],
Pr(t)	precipitation on soil in [mm/h],
SM(t)	soil moisture in [mm],
SMFC	soil moisture at field capacity in [mm],
SMTPV	soil moisture at total porosity in [mm].

Substituting the equations for infiltration (Eq. A.12-2) and (Eq. A.12-3), evaporation (Eq. A.12-4) and percolation (Eq. A.12-5) from above into the original differential equation for soil moisture accounting of the soil column (Eq. A.12-1) results in the following four different cases.

Case 1: SM(t) ≤ SMFC and Pr(t) ≥ Infp

$$\frac{\mathrm{dSM(t)}}{\mathrm{dt}} + \mathrm{SM(t)} \times \left(\frac{\mathrm{PINF}}{\mathrm{SMTPV}} + \frac{\mathrm{PEVA}}{\mathrm{SMFC}}\right) = \mathrm{PINF} \qquad \text{(Eq. A.12-6 a)}$$

Case 2: SM(t) ≤ SMFC and Pr(t) < Infp

$$\frac{\mathrm{dSM(t)}}{\mathrm{dt}} + \mathrm{SM(t)} \times \frac{\mathrm{PEVA}}{\mathrm{SMFC}} = \mathrm{Pr(t)} \qquad \text{(Eq. A.12-6 b)}$$

Case 3: SM(t) > SMFC and Pr(t) ≥ Infp

$$\frac{\mathrm{dSM(t)}}{\mathrm{dt}} + \mathrm{SM(t)} \times \left(\frac{\mathrm{PINF}}{\mathrm{SMTPV}} + \frac{\mathrm{PPERC}}{\mathrm{SMTPV - SMFC}}\right) = \mathrm{PINF} + \frac{\mathrm{PPERC} \times \mathrm{SMFC}}{\mathrm{SMTPV - SMFC}} - \mathrm{PEVA} \qquad \text{(Eq. A.12-6 c)}$$

Case 4: SM(t) > SMFC and Pr(t) < Infp

$$\frac{\mathrm{dSM(t)}}{\mathrm{dt}} + \mathrm{SM(t)} \times \frac{\mathrm{PPERC}}{\mathrm{SMTPV - SMFC}} = \mathrm{Pr(t)} + \frac{\mathrm{PPERC} \times \mathrm{SMFC}}{\mathrm{SMTPV - SMFC}} - \mathrm{PEVA} \qquad \text{(Eq. A.12-6 d)}$$

(Eq. A.12-6 a) to (Eq. A.12-6 d) represent a set of inhomogeneous linear differential equations of the kind:

$$\frac{dSM(t)}{dt} + C1 \times SM(t) = C2$$

(Eq. A.12-7)

Taking the boundary condition SM(t = 0) = SM0 into account a solution for (Eq. A.12-7) is given by the following function:

$$SM(t) = \frac{C2}{C1} + \left(SM0 - \frac{C2}{C1}\right) \times e^{-C1 \times t}$$

(Eq. A.12-8)

In order to reduce the volume error the mean soil moisture $\overline{SM}$ for a time interval [0,t*] is used for determining the corresponding infiltration, evaporation and percolation by equations (Eq. A.12-2), (Eq. A.12-4) and (Eq. A.12-5). The mean soil moisture $\overline{SM}$ for a time interval [0,t*] is determined by:

$$\overline{SM} = \frac{1}{t^*} \times \int_0^{t^*} SM(t)\,dt = \frac{1}{t^*} \times \left[\frac{C2}{C1} \times t^* + \left(SM0 - \frac{C2}{C1}\right) \times \frac{1}{C1} \times \left(1 - e^{-C1 \times t^*}\right)\right]$$

(Eq. A.12-9)

The implemented algorithm first determines whether field capacity (SMFC) will be reached during the simulation time step Δt. It then determines the infiltrated, evaporated and percolated "volume" of water in [mm] into and from the soil column for the time interval $[0,t_{max}]$ with $t_{max} \leq \Delta t$ by using the mean soil moisture for this interval as provided in (Eq. A.12-9). The last step will be repeated for a possible second interval $[t_{max},\Delta t]$. Dividing the sums of the infiltrated, evaporated and percolated "volumes" of water for these two intervals $[0,t_{max}]$ and $[t_{max},\Delta t]$ by Δt will then provide the "mean" infiltration, evaporation and percolation rates in [mm/h] for this time step. The resulting soil moisture SM at the end of time step Δt forms the boundary condition SM0 for the next time step.

A.13 Surface Interflow Separation

The separation of direct runoff $\text{Direct}_{\text{runoff}}$ in [mm/h] into surface runoff $\text{Surf}_{\text{runoff}}$ in [mm/h] and interflow runoff (subsurface runoff) $\text{Intf}_{\text{runoff}}$ in [mm/h] is determined by subcatchment specific maximum interflow rates Intf_{max} in [mm/h]:

$$\text{Surf(t)}_{\text{runoff}} = \begin{cases} 0 & , \text{Direct(t)}_{\text{runoff}} \leq \text{Intf}_{\text{max}} \\ \text{Direct(t)}_{\text{runoff}} - \text{Intf}_{\text{max}} & , \text{Direct(t)}_{\text{runoff}} > \text{Intf}_{\text{max}} \end{cases}$$

(Eq. A.13-1)

$$\text{Intf(t)}_{\text{runoff}} = \begin{cases} \text{Direct(t)}_{\text{runoff}} & , \text{Direct(t)}_{\text{runoff}} \leq \text{Intf}_{\text{max}} \\ \text{Intf}_{\text{max}} & , \text{Direct(t)}_{\text{runoff}} > \text{Intf}_{\text{max}} \end{cases}$$

(Eq. A.13-2)

A.14 Time Area Determination

The time area determination component determines the time area function for a simplified catchment geometry. The module is only run during the "initialize" phase. As time area functions are nowadays determined on the basis of digital elevation models, this component can be used as an auxiliary approach for determining these functions if only topographic maps or digital elevation models with low spatial resolutions are available for setting up a model. Three different geometries are distinguished:

- **Left slope:** A parallelogram bounded to the right by the channel and parallel lower and upper slopes.
- **Right slope:** A parallelogram bounded to the left by the channel and parallel lower and upper slopes.
- **Head area:** A sector element bounded by the upper sides (slopes) of the right and left slopes.

The modeling approach is depicted in the figure hereafter.

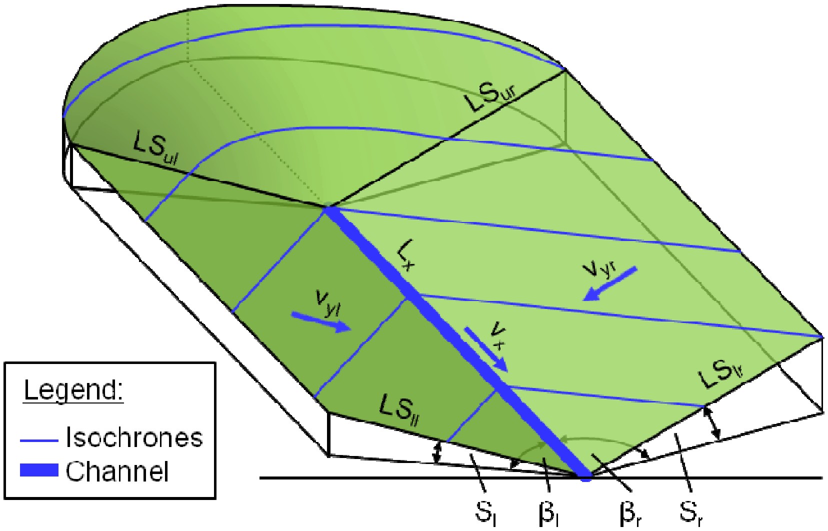

Fig. A.14-1: Time area determination on the basis of a simplified catchment geometry

<u>Left / Right slope:</u>

The left and right slopes are parallelograms which are bound by the channel (length L_x) and parallel lower (LS_{ll}, LS_{lr}) and upper slopes (LS_{ul}, LS_{ur}) with unique slopes (S_l, S_r) and unique angles of projection (β_l, β_r) of these slopes and the channel line (flow paths). The formulations hereafter are given in general terms and hold true for the right slope and left slope as well.

The flow speeds on the slopes in [m/s] are determined by Manning-Strickler:

$$v_y = k_{str} \times \sqrt{S} \times h^{2/3}$$ (Eq. A.14-1)

The angle between the channel and the isochrones is determined by:

$$\gamma = \tan^{-1}\left(\frac{v_y \times \sin\beta}{v_x - v_y \times \cos\beta}\right)$$ (Eq. A.14-2)

Time areas are determined by intersecting the isochrones with the parallelogram of the right slope boundary for fixed Δt. Isochrones are constructed by defining first a line which starts at $x_1 = \Delta x = v_x \times \Delta t$ which runs 10,000 km against an angle of γ_r. By successively moving this line along the x axis by Δx and intersecting the resulting line with the polygon of the slope will result in new polygons AS in [km^2] which are determined by:

$$AS = 0.5 \times \sum_{i=1}^{ie-1} \left(x_{i+1} - x_i\right) \times \left(y_{i+1} + y_i\right)$$ (Eq. A.14-3)

The areas AS_i in [km^2] are determined according to (Eq. A.14-3). The isochrone areas are calculated as the difference $AS_{i+1} - AS_i$ of the time areas for the present and the last isochrone. The procedure is depicted in the sketch hereafter.

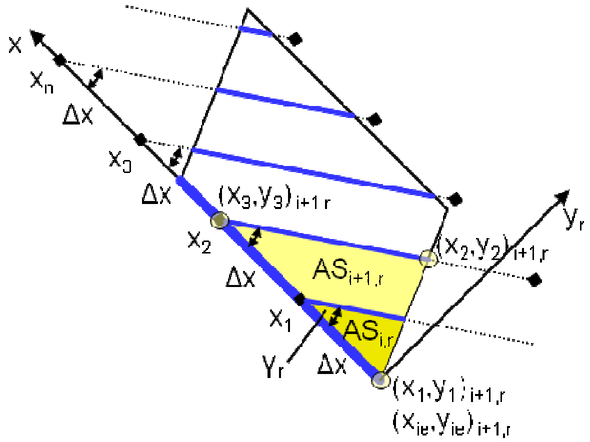

Fig. A.14-2: Determination of time areas on slopes

Where the symbols in (Eq. A.14-1) to (Eq. A.14-3) denote:

$AS_{i,\,l}$, $AS_{i,\,r}$	area of i-th time area on left and right slope in [km^2],
h_l, h_r	flow depths on left and right slope in [m],
ie	number of points in particular time area polygon,
$k_{str,r}$, $k_{str,r}$	Strickler roughness values for left and right slope in [m$^{1/3}$/s],
LS_{ll}, LS_{lr}	lower left and right slope lengths in [km],
LS_{ul}, LS_{ur}	upper left and right slope lengths in [km],
L_x	channel length in [km],
S_l, S_r	slopes of left and right slope in [-],
v_{yl}, v_{vr}	flow speeds on left and right slope in [m/s],
x_i	x coordinates of points making up particular time area in [km],
y_i	y coordinates of points making up particular time area in [km],
β_l, β_r	angles of projection of left, right slopes and channel in [deg],
γ_l, γ_r	angles between channel and left, right slope isochrones in [deg],
Δt	simulation time step duration in [h],
Δx	distance on the channel for time step Δt at given channel speed v_x in [km].

Head area:

The head area is optional, as many subcatchments are not located at a root of the subcatchment tree. The head area is modeled as an Archimedean Spiral, the area AH in [km^2] is determined by:

$$\mathrm{AH} = \frac{\phi \times \Pi}{360 \times 3} \times \left(\mathrm{LS}_{\mathrm{ul}}^{2} + \mathrm{LS}_{\mathrm{ul}} \times \mathrm{LS}_{\mathrm{ur}} + \mathrm{LS}_{\mathrm{ur}}^{2} \right)$$

(Eq. A.14-4)

The isochrone areas on the head area are determined by successively moving along the isochrone intersections with the left and right upper slope lines $ls_{i,\,l}$, $ls_{i,\,r}$ of the left and right slope. The areas AH_i in [km^2] are determined according to (Eq. A.14-4). The isochrone areas are calculated as the difference AH_{i+1} - AH_i of the sector areas for the present and the last isochrone. The procedure is depicted in the figure hereafter.

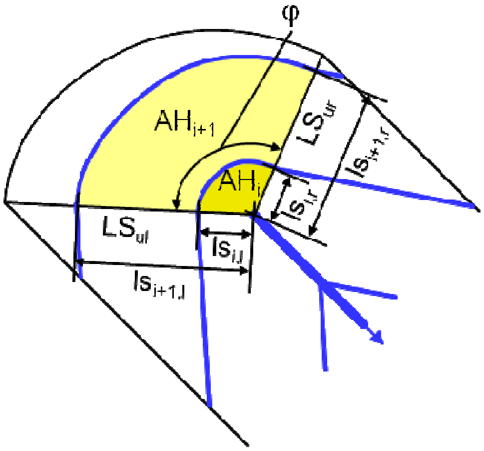

Fig. A.14-3: Determination of time areas on the head area

Where the symbols denote:

AH_i	size of i-th sector defined by $ls_{i,l}$ and $ls_{i,r}$ in [km^2],
$ls_{i,l}$, $ls_{i,r}$	i-th length on left, right upper slope with isochrone intersections in [km],
φ	angle enclosed by left and right upper slope in [deg].

At the end of the calculations the sum of the areas of the time area function is compared with the subcatchment area. The error is linearly distributed onto the time area function values.

A.15 References

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Annex B: Input Files

B.1 Introductory Remarks

The example data in this Annex are hypothetical data, they do not reflect a real catchment. The data are just for module test purposes. Indeed, experienced hydrologists might think of them that they are not worth much.

For details on the data formating please refer to the OMS manuals. All data are CSV files (comma-separated values) which can be edited with MS Excel. Some OMS formating issues are listed hereafter.

@S	Begin of a new section: section name and meta data about the section.
@P	Property: property name and parameter value(s) and size of the value array (bound). Value arrays may be two-dimensional.
@T	Table: table name and meta data about the table.
@H	Header: header of a table consisting of column names, data types and formats followed by table data.
#	Comment.

For readabilty of the listings blancs are depicted as “▪” and end of lines are depicted as “□”. “Blank lines” – lines which just consist of commata – are overread by the input routines.

B.2 Parameter Data File

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,,□
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,,□
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,,□
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,,□
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@P,end_time,1980▪11▪30▪0▪0▪0□
,,□
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236}"□
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```
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,,□
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,,□
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,,□
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,□
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,,□
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,,□
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,,□
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,,□
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,,□
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bound,nmonpyear,ncmt□
,,□
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@P,sm_start,"{60,60,60,60,60,60,60,60,60,60}"□
bound,ncmt,□
,,□
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,,□
#▪Max.▪interflow▪rate▪[mm/h],,□
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bound,ncmt,□
```

B.3 Time Area Data File

```
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▪created▪at,2/5/2013,,,,,,,,,,,,,,,,□
,,,,,,,,,,,,,,,,,□
#▪External▪time▪area▪function▪input▪(0:▪no,▪Table▪”Catchment▪Time▪Area▪Para
meter▪Input”▪must▪be▪filled,▪,,,,,,,,,,,,,,,,□
#▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪1:▪yes,▪Table▪”Catchment▪Time▪Area▪Fun
ction”▪must▪be▪filled),,,,,,,,,,,,,,,,□
@P,external_taf,0□
,,,,,,,,,,,,,,,,,□
,,,,,,,,,,,,,,,,,□
@T,Catchment▪Time▪Area▪Parameter▪Input,,,,,,,,,,,,,,,,□
▪createdat,6/5/2013,,,,,,,,,,,,,,,,□
▪createdby,Michael,,,,,,,,,,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,,,,,,,,,,□
,,,,,,,,,,,,,,,,,□
@H,element,lx,vx,ken,lsru,lsrl,betar,sr,hr,kstr,lslu,lsll,betal,sl,hl,kstl,
tc_sa□
▪type,String,Double,Double,Int,Double,Double,Double,Double,Double,Double,Do
uble,Double,Double,Double,Double,Double,Double□
#▪units,Text,[km],[m/s],[no▪head:▪0;▪head:▪1],[km],[km],[deg],[-
],[m],[m^1/3/s],[km],[km],[deg],[-],[m],[m^1/3/s],[h]□
Format,4s,#.000,#.00,d,#.000,#.000,#.00,#.00,#.00,#.00,#.000,#.000,#.00,#.0
0,#.00,#.00,#.00□
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,1007,7.6,1.5,1,3.7,1.8,60,0.1,0.02,10,4.6,1.8,60,0.1,0.02,10,18□
,1008,8.8,1.5,0,4.5,3.98,90,0.1,0.02,10,2.7,2.65,90,0.1,0.02,10,12□
,1009,4.2,1.5,0,4.6,3.85,90,0.05,0.02,10,3.9,3.8,90,0.05,0.02,10,12□
,1010,8.4,1.5,0,3.2,2.15,90,0.05,0.02,10,1.2,1.12,90,0.05,0.02,10,7□
,,,,,,,,,,,,,,,,,□
,,,,,,,,,,,,,,,,,□
@T,Catchment▪Time▪Area▪Function▪Input,,,,,,,,,,,,,,,,□
▪createdat,6/5/2013,,,,,,,,,,,,,,,,□
▪createdby,Michael,,,,,,,,,,,,,,,,□
▪time_step,24,,,,,,,,,,,,,,,,□
#▪converted_from,xxxxxx,,,,,,,,,,,,,,,,□
,,,,,,,,,,,,,,,,,□
@H,time,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010□
▪type,Double,Double,Double,Double,Double,Double,Double,Double,Double,Double
,Double□
#▪units,[h],[km^2],[km^2],[km^2],[km^2],[km^2],[km^2],[km^2],[km^2],[km^2],
[km^2]□
Format,#.00,#.000,#.000,#.000,#.000,#.000,#.000,#.000,#.000,#.000,#.000□
,24,20,20,20,20,1.024,20,20,20,20,20□
,48,-20,-20,20,20,0,-20,20,20,-20,-20□
,72,0,0,20,-40,0,0,-40,20,0,0□
,96,0,0,-60,0,0,0,0,-60,0,0□
,120,0,0,0,0,0,0,0,0,0,0□
,144,0,0,0,0,0,0,0,0,0,0□
,168,0,0,0,0,0,0,0,0,0,0□
```

```
,192,0,0,0,0,0,0,0,0,0,0□
```

B.4 Channel Data File

```
@S,Channel▪Data,□
▪created▪by,Michael,,,,,,,□
▪created▪at,2/5/2013,,,,,,,□
,,,,,,,,□
,,,,,,,,□
#▪No.▪of▪intervals▪of▪stage-discharge▪curve▪for▪Kalinin-
Miljukov▪iteration,,,,,,,,□
@P,iriver,10□
,,,,,,,,□
#▪Table▪containing▪basic▪parameters▪for▪channel▪flow▪computation,,,,,,,,□
@T,Channel▪Basics,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,element,slope,lx,dhmax,alpha,vmax_fp,qmax_main,tau□
▪type,String,Double,Double,Double,Double,Double,Double,Double□
#▪units,Text,[-],[km],[m],"[0,▪1.0]",[1000▪m^3],[m^3/s],[h]□
Format,4s,#.0000,#.000,#.00,#.00,#.00,#.00,#.00□
,1003,0.0087,13.6,0.1,0.85,5000,300,600□
,1005,0.0087,1.2,0.1,0.85,5000,300,600□
,1008,0.0087,8.8,0.1,0.85,5000,300,600□
,1009,0.0087,4.2,0.1,0.85,5000,300,600□
,1010,0.0087,8.4,0.1,0.85,5000,300,600□
,,,,,,,,□
,,,,,,,,□
#▪Each▪characteristic▪river▪cross▪section▪for▪non-
head▪catchments▪is▪defined▪in▪a▪separate▪table,,,,,,,,□
@T,1003,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,yq,xql,xqr,rql,rqr,rgl,rgr,□
▪type,Double,Double,Double,Double,Double,Double,Double,□
#▪units,[m▪asl],[m],[m],[m^1/3/s],[m^1/3/s],[m^1/3/s],[m^1/3/s],□
Format,#.00,#.00,#.00,#.00,#.00,#.00,#.00,□
,0,1.5,1.5,18,18,0,0,□
,1,3,3,22,22,0,0,□
,1.2,5,5,25,25,0,0,□
,1.5,10,10,30,30,80,80,□
,,,,,,,,□
,,,,,,,,□
#▪Each▪characteristic▪river▪cross▪section▪for▪non-
head▪catchments▪is▪defined▪in▪a▪separate▪table,,,,,,,,□
@T,1005,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,yq,xql,xqr,rql,rqr,rgl,rgr,□
▪type,Double,Double,Double,Double,Double,Double,Double,□
#▪units,[m▪asl],[m],[m],[m^1/3/s],[m^1/3/s],[m^1/3/s],[m^1/3/s],□
Format,#.00,#.00,#.00,#.00,#.00,#.00,#.00,□
,0,1.5,1.5,18,18,0,0,□
,1,3,3,22,22,0,0,□
,1.2,5,5,25,25,0,0,□
```

```
,1.5,10,10,30,30,80,80,□
,,,,,,,,□
,,,,,,,,□
#▪Each▪characteristic▪river▪cross▪section▪for▪non-
head▪catchments▪is▪defined▪in▪a▪separate▪table,,,,,,,,□
@T,1008,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,yq,xql,xqr,rql,rqr,rgl,rgr,□
▪type,Double,Double,Double,Double,Double,Double,Double,□
#▪units,[m▪asl],[m],[m],[m^1/3/s],[m^1/3/s],[m^1/3/s],[m^1/3/s],□
Format,#.00,#.00,#.00,#.00,#.00,#.00,#.00,□
,0,1.5,1.5,18,18,0,0,□
,1,3,3,22,22,0,0,□
,1.2,5,5,25,25,0,0,□
,1.5,10,10,30,30,80,80,□
,,,,,,,,□
,,,,,,,,□
#▪Each▪characteristic▪river▪cross▪section▪for▪non-
head▪catchments▪is▪defined▪in▪a▪separate▪table,,,,,,,,□
@T,1009,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,yq,xql,xqr,rql,rqr,rgl,rgr,□
▪type,Double,Double,Double,Double,Double,Double,Double,□
#▪units,[m▪asl],[m],[m],[m^1/3/s],[m^1/3/s],[m^1/3/s],[m^1/3/s],□
Format,#.00,#.00,#.00,#.00,#.00,#.00,#.00,□
,0,1.5,1.5,18,18,0,0,□
,1,3,3,22,22,0,0,□
,1.2,5,5,25,25,0,0,□
,1.5,10,10,30,30,80,80,□
,,,,,,,,□
,,,,,,,,□
#▪Each▪characteristic▪river▪cross▪section▪for▪non-
head▪catchments▪is▪defined▪in▪a▪separate▪table,,,,,,,,□
@T,1010,,,,,,,□
▪createdat,2/5/2013,,,,,,,□
▪createdby,Michael,,,,,,,□
▪#▪converted_from,xxxxxx,,,,,,,□
,,,,,,,,□
@H,yq,xql,xqr,rql,rqr,rgl,rgr,□
▪type,Double,Double,Double,Double,Double,Double,Double,□
#▪units,[m▪asl],[m],[m],[m^1/3/s],[m^1/3/s],[m^1/3/s],[m^1/3/s],□
Format,#.00,#.00,#.00,#.00,#.00,#.00,#.00,□
,0,1.5,1.5,18,18,0,0,□
,1,3,3,22,22,0,0,□
,1.2,5,5,25,25,0,0,□
,1.5,10,10,30,30,80,80,□
```

B.5 Diversion Data File

No data have been filled into this table.

```
@S,Diversion▪Data,,,,,,□
▪created▪by,Michael,,,,,,□
▪created▪at,8/7/2013,,,,,,□
,,,,,,,□
,,,,,,,□
#▪Table▪containing▪parameters▪for▪diversion▪flow▪computation,,,,,,,□
#▪Three▪different▪diversions▪(id:{1,2,3})▪exist.▪1:▪Sewer▪diversion▪element
▪with▪a▪throttle▪attached▪(maximum▪throughflow),,,,,,,,□
#▪2:▪Sewer▪diversion▪with▪no▪limited▪throughflow,▪3:▪Diversion▪based▪on▪inf
low-runoff▪curve▪(e.g.▪side▪wear),,,,,,,□
@T,Diversion▪Input,,,,,,□
▪createdat,11/5/2013,,,,,,□
▪createdby,Michael,,,,,,□
#▪converted_from,xxxxxx,,,,,,□
,,,,,,,□
@H,element,next_element,div_element,id,limit,max_flow,factor□
▪type,String,String,String,Int,Double,Double,Double□
#▪units,Text,Text,Text,"[-]▪{1,2,3}",[m^3/s],[m^3/s],[-]□
Format,4s,4s,4s,d,#.000,#.000,#.00□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
#▪For▪each▪diversion▪with▪id=3▪the▪diversion▪characteristics▪are▪defined▪in
▪a▪seperate▪table,,,,,,,□
@T,2005,,,,,,□
▪createdat,11/5/2013,,,,,,□
▪createdby,Michael,,,,,,□
#▪converted_from,xxxxxx,,,,,,□
,,,,,,,□
@H,q_in,q_out,,,,,□
▪type,Double,Double,,,,,□
#▪units,[m^3/s],[m^3/s],,,,,□
Format,#.000,#.000,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
```

B.6 Reservoir Data File

No data have been filled into this table.

```
@S,Reservoir▪Data,,,,,,□
▪created▪by,Michael,,,,,,□
▪created▪at,8/7/2013,,,,,,□
,,,,,,,□
,,,,,,,□
#▪Table▪containing▪basic▪parameters▪for▪reservoir▪computation,,,,,,,□
@T,Reservoir▪Input,,,,,,□
▪createdat,13/5/2013,,,,,,□
▪createdby,Michael,,,,,,□
#▪converted_from,xxxxxx,,,,,,□
,,,,,,,□
@H,element,next_element,div_element,id,v_min,v_max,v_start□
▪type,String,String,String,Int,Double,Double,Double□
#▪units,Text,Text,Text,[-]▪{1},[1000▪m^3],[1000▪m^3],[1000▪m^3]□
Format,4s,4s,4s,d,#.000,#.000,#.000□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
#▪Each▪reservoir▪is▪defined▪in▪a▪separate▪table,,,,,,,□
@T,1005,,,,,,□
▪createdat,13/5/2013,,,,,,□
▪createdby,Michael,,,,,,□
#▪converted_from,xxxxxx,,,,,,□
,,,,,,,□
@H,hight,vol,throttle_flow,spillway_flow,,,□
▪type,Double,Double,Double,Double,,,□
#▪units,[m▪asl],[1000▪m^3],[m^3/s],[m^3/s],,,□
Format,#.00,#.000,#.00,#.00,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
```

B.7 Sewer Data File

Both, storage and transport sewers are specified in these structures. No data have been filled into this table.

```
@S,Sewer▪Data,,,,,,□
▪created▪by,Michael,,,,,,□
▪created▪at,8/7/2013,,,,,,□
,,,,,,,□
,,,,,,,□
#▪Table▪containing▪the▪parameters▪for▪sewers▪(both,▪storage▪and▪storage
▪sewers)▪for▪sewer▪computation,,,,,,,□
@T,Sewer▪Input,,,,,,□
▪createdat,8/5/2013,,,,,,□
▪createdby,Michael,,,,,,□
#▪converted_from,xxxxxx,,,,,,□
,,,,,,,□
@H,element,next_element,div_element,throttle_flow,max_vol,tf,ret□
▪type,String,String,String,Double,Double,Double,Double□
#▪units,Text,Text,Text,[m^3/s],[1000▪m^3],[s],[s]□
Format,4s,4s,4s,#.00,#.000,#.00,#.00□
,,,,,,,□
,,,,,,,□
,,,,,,,□
,,,,,,,□
```

B.8 Sequence Data File

```
@S,Sequence▪Data,□
▪created▪by,Michael,□
▪created▪at,24/03/2013,□
,,□
,,□
"#▪Directed▪graph▪definition▪of▪system▪elements▪by▪element▪name▪(there▪migh
t▪be▪more▪than▪one▪exit▪of▪the▪system,▪the▪name▪of▪the▪exit▪must▪start▪with
▪""end"")",,□
@T,Directed▪Graph,□
▪createdat,25/01/2013,□
▪createdby,Michael,□
,,□
@H,elem,next_elem□
▪type,String,String□
Format,4s,4s□
,1001,1003□
,1002,1003□
,1003,1005□
,1004,1005□
,1006,1005□
,1005,1008□
,1008,1009□
,1007,1009□
,1009,1010□
,1010,end□
```

B.9 Time Series Input File

```
@T,Observation,,,,□
·created_at,7/6/2013,,,, •
·created_by,Michael,,,, •
·converted_from,fictive,,,, •
#▪Time▪step▪in▪time▪series▪input▪file▪[h],,,, •
time_step,24,,,, •
·date_start,1980·10·1·0·0·0,,,, •
·date_end,1980·11·30·0·0·0,,,, •
·date_format,yyyy·MM·dd·H·m·s,,,, •
,,,,, •
@H,date,precip[0],temp[0],wind_speed[0],pot_eva[0] •
units,,·mm/h,−·C,m/s,mm/h□
name,,TEST,TEST,TEST,TEST□
ID,,49775,49775,49775,49775□
elevation,,5650,5650,5650,5650□
x,,-119.8,-119.8,-119.8,-119.8□
y,,38.783329,38.783329,38.783329,38.783329□
longitude,,0,0,0,0□
latitude,,0,0,0,0□
·type,Date,Real,Real,Real,Real□
,1980·10·1·0·0·0,0,15,3,1□
,1980·10·2·0·0·0,0.512458333,15,3,1□
,1980·10·3·0·0·0,0.512458333,15,3,1□
,1980·10·4·0·0·0,0.512458333,15,3,1□
,1980·10·5·0·0·0,0.512458333,15,3,1□
,1980·10·6·0·0·0,0.512458333,15,3,1□
,1980·10·7·0·0·0,0.512458333,15,2,1□
,1980·10·8·0·0·0,0.512458333,15,2,1□
,1980·10·9·0·0·0,0.512458333,15,2,1□
,1980·10·10·0·0·0,0,15,2,1□
,1980·10·11·0·0·0,0,15,2,1□
,1980·10·12·0·0·0,0.512458333,15,0,1□
,1980·10·13·0·0·0,0.010458333,15,0,1□
,1980·10·14·0·0·0,0.031375,15,0,1□
,1980·10·15·0·0·0,0.020916667,15,0,1□
,1980·10·16·0·0·0,0.020916667,15,0,1□
,1980·10·17·0·0·0,0,15,0,1□
,1980·10·18·0·0·0,0.8,15,0,1□
,1980·10·19·0·0·0,2,15,0,1□
,1980·10·20·0·0·0,2,15,0,1□
,1980·10·21·0·0·0,0,15,0,1□
,1980·10·22·0·0·0,0,15,0,1□
,1980·10·23·0·0·0,0,15,0,1□
,1980·10·24·0·0·0,0,15,3,1□
,1980·10·25·0·0·0,0.010458333,15,10,1□
,1980·10·26·0·0·0,0.073208333,15,10,1□
,1980·10·27·0·0·0,4,15,10,1□
,1980·10·28·0·0·0,6,15,10,1□
,1980·10·29·0·0·0,7,15,12,1□
,1980·10·30·0·0·0,0,15,12,1□
,1980·10·31·0·0·0,0,15,12,1□
```

```
,1980·11·1·0·0·0,0,15,12,1□
,1980·11·2·0·0·0,0,15,12,1□
,1980·11·3·0·0·0,0,15,13,1□
,1980·11·4·0·0·0,0,15,12,1□
,1980·11·5·0·0·0,0,15,10,1□
,1980·11·6·0·0·0,0,15,12,1□
,1980·11·7·0·0·0,0,15,12,1□
,1980·11·8·0·0·0,0,15,12,1□
,1980·11·9·0·0·0,0,15,12,1□
,1980·11·10·0·0·0,0,15,13,1□
,1980·11·11·0·0·0,0,15,12,1□
,1980·11·12·0·0·0,0,15,10,1□
,1980·11·13·0·0·0,0,15,12,1□
,1980·11·14·0·0·0,0,15,12,1□
,1980·11·15·0·0·0,0,15,12,1□
,1980·11·16·0·0·0,0,15,12,1□
,1980·11·17·0·0·0,0,15,13,1□
,1980·11·18·0·0·0,0,15,12,1□
,1980·11·19·0·0·0,0,15,10,1□
,1980·11·20·0·0·0,0,15,12,1□
,1980·11·21·0·0·0,0,15,12,1□
,1980·11·22·0·0·0,0,15,12,1□
,1980·11·23·0·0·0,0,15,12,1□
,1980·11·24·0·0·0,0,15,13,1□
,1980·11·25·0·0·0,0,15,12,1□
,1980·11·26·0·0·0,0,15,10,1□
,1980·11·27·0·0·0,0,15,12,1□
,1980·11·28·0·0·0,0,15,12,1□
,1980·11·29·0·0·0,0,15,12,1□
,1980·11·30·0·0·0,0,15,12,1□
```

B.10 Time Series System Element Assignment File

```
@T,TS▪Assignment,,,,,,,,□
▪created_at,5/31/2013,,,,,,,,□
▪created_by,michael,,,,,,,,□
▪converted_from,,,,,,,,,□
,,,,,,,,,□
@H,element,precip,pot_eva,temp,wind_speed,inflow,surf_abstr,gw_abstr,obs_runoff□
▪type,String,String,String,String,String,String,String,String,String□
format,4s,8s,8s,8s,8s,8s,8s,8s,8s□
,1001,TEST,TEST,TEST,TEST,,,,□
,1002,TEST,TEST,TEST,TEST,,,,□
,1003,TEST,TEST,TEST,TEST,,,,□
,1004,TEST,TEST,TEST,TEST,,,,□
,1005,TEST,TEST,TEST,TEST,,,,□
,1006,TEST,TEST,TEST,TEST,,,,□
,1007,TEST,TEST,TEST,TEST,,,,□
,1008,TEST,TEST,TEST,TEST,,,,□
,1009,TEST,TEST,TEST,TEST,,,,□
,1010,TEST,TEST,TEST,TEST,,,,□
```

B.11 Time Series Output Definition File

Tab. 5-1 contains the list of possible variable output options which are implemented in CATMO-OMS.

```
@T,TS▪Output,□
▪created_at,5/31/2013,□
▪created_by,michael,□
▪converted_from,,□
,,□
@H,element,variable□
▪type,String,String□
format,4s,15s□
,1001,pr_in□
,1001,runoff□
,1002,pr_in□
,1002,runoff□
,1003,pr_in□
,1003,runoff□
,1004,pr_in□
,1004,runoff□
,1005,pr_in□
,1005,runoff□
,1006,pr_in□
,1006,runoff□
,1007,pr_in□
,1007,runoff□
,1008,pr_in□
,1008,runoff□
,1009,pr_in□
,1009,runoff□
,1010,pr_in□
,1010,runoff□
,1010,gw_td□
,1010,cr□
,1005,cr□
```

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GNU Lesser General Public Licence, Version 2.1

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d) If a facility in the modified Library refers to a function or a table of data to be supplied by an application program that uses the facility, other than as an argument passed when the facility is invoked, then you must make a good faith effort to ensure that, in the event an application does not supply such function or table, the facility still operates, and performs whatever part of its purpose remains meaningful.

   (For example, a function in a library to compute square roots has a purpose that is entirely well-defined independent of the application. Therefore, Subsection 2d requires that any application-supplied function or table used by this function must be optional: if the application does not supply it, the square root function must still compute square roots.)

These requirements apply to the modified work as a whole. If identifiable sections of that work are not derived from the Library, and can be reasonably considered independent and separate works in themselves, then this License, and its terms, do not apply to those sections when you distribute them as separate works. But when you distribute the same sections as part of a whole which is a work based on the Library, the distribution of the whole must be on the terms of this License, whose permissions for other licensees extend to the entire whole, and thus to each and every part regardless of who wrote it.

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This option is useful when you wish to copy part of the code of the Library into a program that is not a library.

4. You may copy and distribute the Library (or a portion or derivative of it, under Section 2) in object code or executable form under the terms of Sections 1 and 2 above provided that you accompany it with the complete corresponding machine-readable source code, which must be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange.

   If distribution of object code is made by offering access to copy from a designated place, then offering equivalent access to copy the source code from the same place satisfies the requirement to distribute the source code, even though third parties are not compelled to copy the source along with the object code.

5. A program that contains no derivative of any portion of the Library, but is designed to work with the Library by being compiled or linked with it, is called a "work that uses the Library". Such a work, in isolation, is not a derivative work of the Library, and therefore falls outside the scope of this License.

   However, linking a "work that uses the Library" with the Library creates an executable that is a derivative of the Library (because it contains portions of the Library), rather than a "work that uses the library". The executable is therefore covered by this License. Section 6 states terms for distribution of such executables.

   When a "work that uses the Library" uses material from a header file that is part of the Library, the object code for the work may be a derivative work of the Library even though the source code is not. Whether this is true is especially significant if the work can be linked without the Library, or if the work is itself a library. The threshold for this to be true is not precisely defined by law.

   If such an object file uses only numerical parameters, data structure layouts and accessors, and small macros and small inline functions (ten lines or less in length), then the use of the object file is unrestricted, regardless of whether it is legally a derivative work. (Executables containing this object code plus portions of the Library will still fall under Section 6.)

   Otherwise, if the work is a derivative of the Library, you may distribute the object code for the work under the terms of Section 6. Any executables containing that work also fall under Section 6, whether or not they are linked directly with the Library itself.

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   b) Use a suitable shared library mechanism for linking with the Library. A suitable mechanism is one that (1) uses at run time a copy of the library already present on the user's computer system, rather than copying library functions into the executable, and (2) will operate properly with a modified version of the library, if the user installs one, as long as the modified version is interface-compatible with the version that the work was made with.

   c) Accompany the work with a written offer, valid for at least three years, to give the same user the materials specified in Subsection 6a, above, for a charge no more than the cost of performing this distribution.

   d) If distribution of the work is made by offering access to copy from a designated place, offer equivalent access to copy the above specified materials from the same place.

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