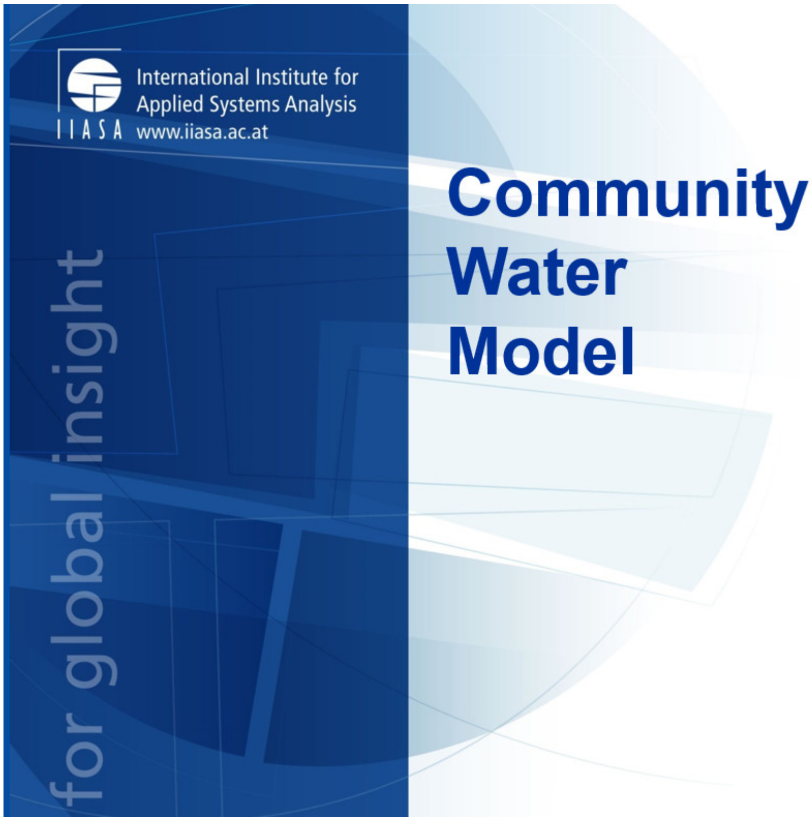
Community Water Model

CWATM Documentation

Release 1

Peter Burek, IIASA WAT

Apr 26, 2018



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Version 0.03

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Content:

CHAPTER 1

Introduction

1.1 Community Water Model - CWATM

With a growing population and economic development, it is expected that water demands will increase significantly in the future, especially in developing regions. At the same time, climate change is expected to alter spatial patterns of precipitation and temperature and will have regional to localized impacts on water availability. Thus, it is important to assess water demand, water supply and environmental needs over time to identify the populations and locations that will be most affected by these changes linked to water scarcity, droughts and floods. The Community Water Model will be designed for this purpose in that they include an accounting of how future water demands will evolve in response to socioeconomic change and how water availability will change in response to climate.

CWAT will represent one of the new key elements of the WAT program going forward and increasing the innovative niche of the work. We will use and develop the model to work at both global and regional (basin) level. The configuration of the model is open source and community-driven to promote our work amongst the wider water community and is flexible enough to introduce further planned developments such as water quality and hydro-economy.

Our vision for the short to medium term work of the group is to introduce water quality (i.e., salinization in deltas and eutrophication associated with mega cities) into the community model and to consider how to include a qualitative/quantitative measure of transboundary river and groundwater governance into a scenario and modelling framework.

Contact CWAT

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wfas.info@iiasa.ac.at

Download pdf

:download:‘ CWATM_MANUAL.pdf <_static/CWATM.pdf>‘

Model Design

Contents

2.1 Background

2.1.1 Water Futures and Solutions Initiatives (WFAS)

Water Futures and Solutions Initiatives is using a multi-model approach for global climatic, hydro-socioeconomic modeling in order to assess possible futures. We use three leading global hydrological models H08, WaterGAP and PCR-GLOBWB for estimating water demand and supply. This approach is used for a better understanding of the uncertainty and limitations of modeling. It provides a degree of confidence in the results an is in-line with the ISI-MIPS approach of multi-modeling

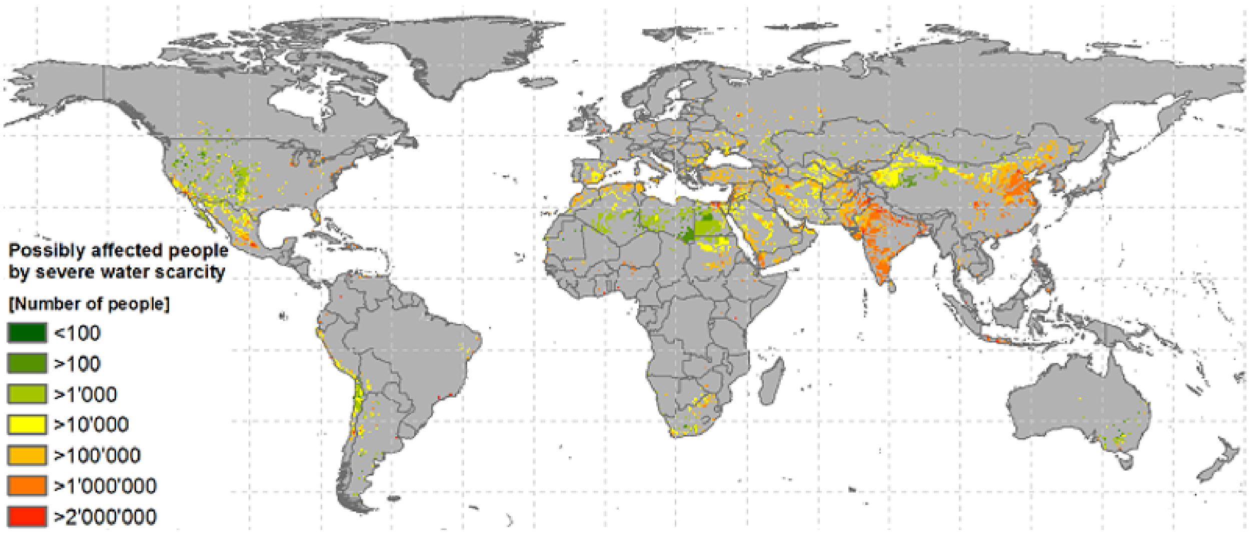


Figure 1: Potential population under severe water scarcity in 2050 - Middle of the Road Scenario - WFAS fast-track analysis

2.1.2 Nexus Integration - Water Energy Food Environment

In the framework of the Integrated Solution project
the Community Water Model (CWATM) will be coupled with the existing IIASA models MESSAGE and GLOBIOM in order to do enhanced water assessments and an improved analysis feedback on water, energy, food and environmental aspects

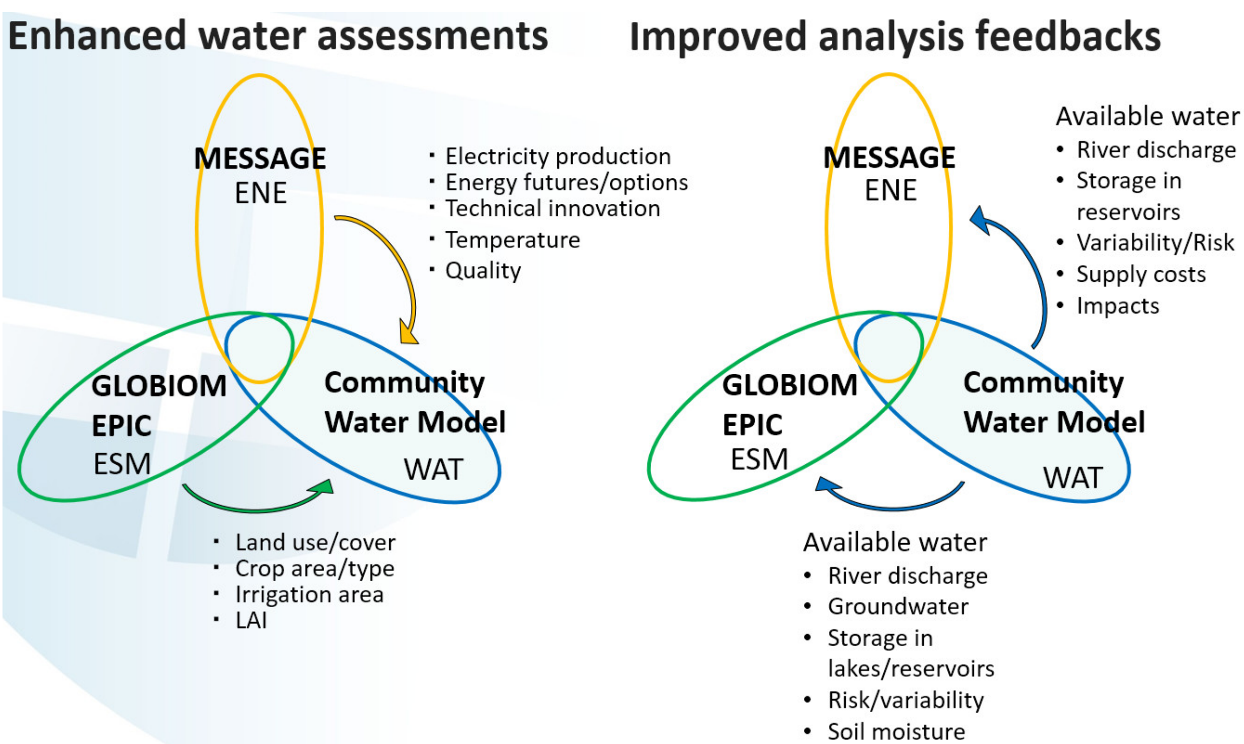


Figure 2: IIASA model interactions

2.1.3 CWAT and the IIASA global hydro-economic model

The Community Water Model will help to develop a next-generation hydro-economic modeling tool that represents the economic trade-offs among water supply technologies and demands. The tool will track water use from all sectors and will identify the least-cost solutions for meeting future water demands under policy constraints. In addition, the tool will track the energy requirements associated with the water supply system (e.g., desalination and water conveyance) to facilitate the linkage with the energy-economic tool. The tool will also incorporate environmental flow requirements to ensure sufficient water for environmental needs. The new hydro-economic model will be linked to CWATM by GAMS output and input files (gdx-files).

2.2 Features of the Model

2.2.1 Community Model

Feature	Description
Community driven	Open-source but lead by IIASA GitHub repository
Well documented	Documentation, automatic source code documentation GitHub Docu
Easy handling	Use of a setting file with all necessary information for the user *Complete settings file* and *Output Meta NetCDF information*
Multi-platform	Windows, Mac, Linux, Unix - to be used on different platforms (PC, clusters, super-computers)
Modular	Processes in subprograms, easy to adapt to the requirements of options/ solutions Modular structure

2.2.2 Water Model

Feature	Description
Flexible	different resolution, different processes for different needs, links to other models, across sectors and across scales
Adjustable	to be tailored to the needs at IIASA i.e. collaboration with other programs/models, including solutions and option as part of the model
Multi-disciplinary	including economics, environmental needs, social science perspectives
Sensitive	Sensitive to option / solution
Fast	Global to regional modeling – a mixture between conceptional and physical modeling – as complex as necessary but not more
Comparable	Part of the ISI-MIP community

2.2.3 Demo of first results

Here are some first demonstration of the model run:

Demo of the model

2.3 Model design and processes

2.3.1 Design

The Community Water Model (CWATM) will be designed for the purpose to assess water availability, water demand and environmental needs. It includes an accounting of how future water demands will evolve in response to socioeconomic change and how water availability will change in response to climate.

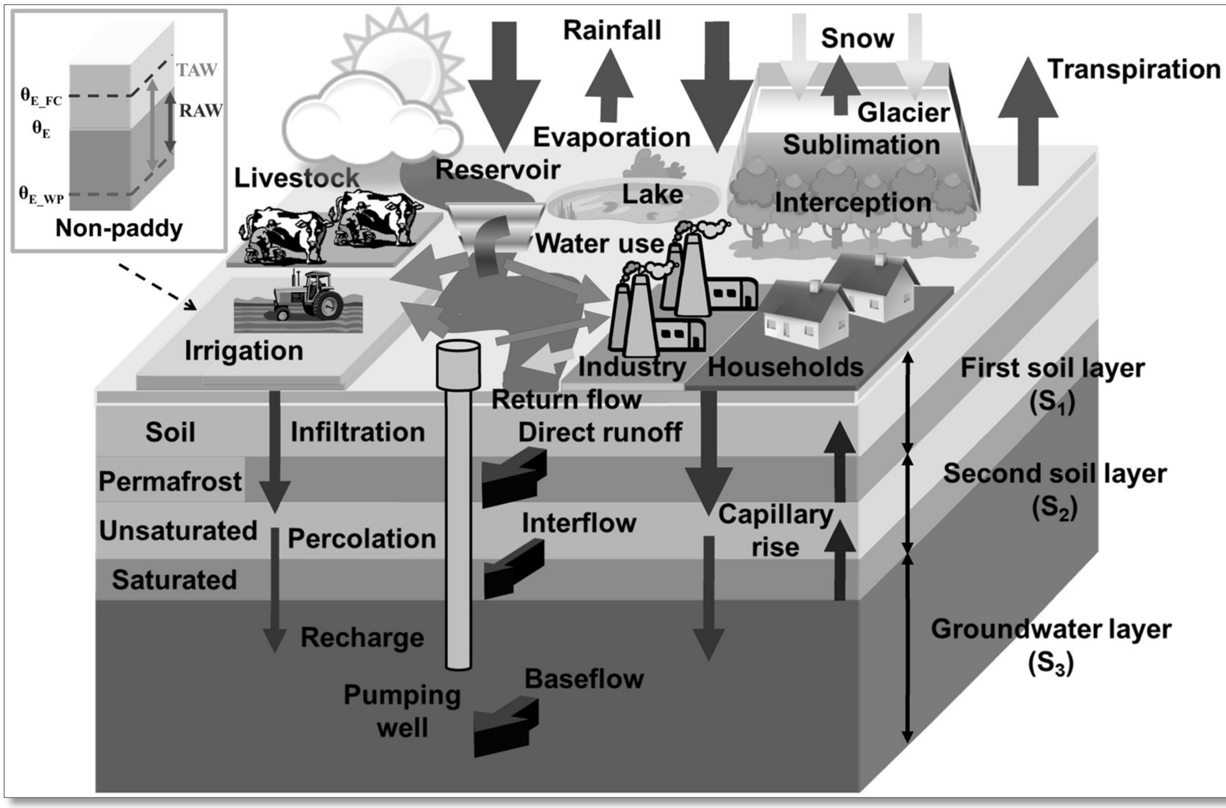


Figure 3: CWATM - Water related processes included in the model design

2.3.2 Processes

Calculation of potential Evaporation

Using Penman-Montheith equations based on FAO 56

Calculation of rain, snow, snowmelt

Using day-degree approach with up to 10 vertical layers Including snow- and glacier melt.

Land cover

using fraction of 6 different land cover types

- Forest

- Grassland
- Irrigated land
- Paddy irrigated land
- Sealed areas (urban)
- Water

Water demand

- including water demand from industry and domestic land use via precalculated monhly spatial maps
- including agricultural water use from calculation of plant water demand
- Return flows

Vegetation

Vegetation taken into account for calculating

- Albedo
- Transpiration
- Interception

Soil

Three soil layers for each land cover type including processes:

- Frost interupting soil processes
- Infiltration
- Preferential flow
- Capillary rise
- Surface runoff
- Interflow
- Percolation into groundwater

Groundwater

Groundwater storage is simulated as linear groundwater reservoir

Lakes & Reservoirs

Lakes are simulated with the weir function Reservoirs are simulated as outflow function between three storage limits (conservative, normal,flood) and three outflow functions (minimum, normal, non-damaging)

Routing

Routing is calculated using the kinematic wave approach

CHAPTER 3

Publication

Contents

3.1 Publication

1. Burek, P.; Y. Satoh; P. Greve; T. Tang; M.T> Kahil; X., He; Y. Wada et al. Development of the CWatM (Community Water Model) – A high resolution hydrological model for regional and global assessment of integrated water management options. In preparation
2. He, X., Poledna, S., Burek, P. Kahil, T, Y. Wada et al. Investigation of drought adaptation options using an integrated hydrological and agent-based model. In preparation
3. Satoh, Y., Kahil, T., Byers, E., Burek, P., Fischer, G., Tramberend, S., Greve, P., Flörke, M., Eisner, S., Hanasaki, N., Magnuszewski, P., Nava, L. F., Cosgrove, W., Langan, S. and Wada, Y. (2017), Multi-model and multi-scenario assessments of Asian water futures: The Water Futures and Solutions (WFaS) initiative. Earth's Future, 5, 823-852
4. Burek, P., Y. Satoh, G. Fischer, M.T. Kahil, A. Scherzer, S. Tramberend, L. F. Nava, Y. Wada, S. Eisner, M. Flörke, N. Hanasaki, P. Magnuszewski, B. Cosgrove, D. Wiberg and A. P. D. W. Bill Cosgrove (2016). Water Futures and Solution - Fast Track Initiative (Final Report). IIASA, Laxenburg, Austria.
5. Wada, Y., M. Flörke, N. Hanasaki, S. Eisner, G. Fischer, S. Tramberend, Y. Satoh, M. T. H. van Vliet, P. Yillia, C. Ringler, P. Burek and D. Wiberg (2016). "Modeling global water use for the 21st century: Water Futures and Solutions (WFaS) initiative and its approaches." Geosci. Model Dev. Discuss. 8(8): 6417-6521.

3.2 Presentations

Burek P, Satoh Y, Greve P, Kahil T, & Wada Y (2017). The Community Water Model (CWATM) / Development of a community driven global water model. In: European Geosciences Union (EGU) General Assembly 2017, 23–28 April 2017, Vienna, Austria - Poster

3.3 Upcoming event

Event: 2017 AGU Fall Meeting, New Orleans, Louisiana

Presentation title: Improving Water Resources Management on Global and Region Scales – Evaluating Strategies for Water Futures with the IIASA's Community Water Model

When: Friday, 15 December 2017 11:50 - 12:05

Where: H52F: Progress in Large-Scale Modeling and Remote Sensing of the Water Cycle Toward Better Human Water

3.4 Developer

Research Scholars, Water Program, IIASA

3.4.1 Peter Burek, Yusuke Satoh, Peter Greve


SAFE

CHAPTER 4

Setup of the model

Contents

4.1 Setup

4.1.1 Requirements

Python version

Requirements are a 64 bit Python 2.7.x version

Warning: a 32 bit version is not able to handle the data requirements!

Libraries

These external libraries are needed:

- Numpy
- Scipy
- netCDF4
- GDAL

Windows

Three libraries can be installed with pip or downloaded at Unofficial Windows Binaries for Python Extension Packages

PCRaster

And the PCRASTER library from Faculty of Geosciences, Utrecht University, The Netherlands - Webpage of PCRaster

Reference:
Karssenberg, D., Schmitz, O., Salamon, P., de Jong, K., and Bierkens, M. F. P.: A software framework for construction of process-based stochastic spatio-temporal models and data assimilation, Environmental Modelling & Software 25(4), 489-502, 2010. doi: 10.1016/j.envsoft.2009.10.004

PCRaster installation

CWATM is using the PCRaster Python framwork of PCRaster but not the GIS commands.
But nevertheless it is quite usefull to install a full PCRaster version:

Windows
Windows installation guide of PCRaster

Linux
Linux installation guide of PCRaster

Note: If it is not possible to install a full version of PCRaster! Copy following files

```
From: PCRasterFolder\python\pcraster\framework

dynamicBase.py
dynamicFramework.py
dynamicPCRasterBase.py
frameworkBase.py
shellscript.py

To: CWATM/source/pcraster2
```

4.1.2 C++ libraries

For the computational time demanding parts e.g. routing, CWATM comes with a C++ library

Compiled versions

Windows and CYGWIN_NT-6.1

a compiled version is provided and CWATM is detecting automatically which system is running and which compiled version is needed

Linux

For Cygwin linux a compiled version *t5cyg.so* is provided in *../source/hydrological_modules/routing_reservoirs/* for version CYGWIN_NT-6.1.

If you use another cygwin version please compile it by yourself and name it *t5_linux.so*

For Linux Ubuntu a compiled version is provided as *t5_linux.so*. The file is in *../source/hydrological_modules/routing_reservoirs/*

Note: If you use another Linux version or the compiled version is not working or you have a compiler which produce faster executables please compile a version on your own.

Compiling a version

C++ sourcecode is in *../source/hydrological_modules/routing_reservoirs/t5.cpp*

Windows

A compiled version is provided, but maybe you have a faster compiler than the "Minimalist GNU for Windows" or "Microsoft Visual Studio 14.0" we used.

To compile with g++:

```
..\g++ -c -fPIC -Ofast t5.cpp -o t5.o
..\g++ -shared -Ofast -Wl,-soname,t5.so -o t5.so  t5.o
```

To compile with Microsoft Visual Studio 14.0:

```
call "C:\Program Files (x86)\Microsoft Visual Studio 14.0\VC\bin\amd64/vcvars64.bat"
cl /LD /O2 t5.cpp
```

Note:

We used Visual Studio, because it seems to be computational faster

the libray used with Windows is named *t5.dll*, if you generate a libray *t5.so* the filename in **../source/management_modules/globals.py** has to be changed!

Linux

To compile with g++:

```
..\g++ -c -fPIC -Ofast t5.cpp -o t5_linux.o
..\g++ -shared -Ofast -Wl,-soname,t5_linux.so -o t5_linux.so  t5_linux.o

    or

    ..\g++ -c -Ofast t5.cpp -o t5_linux.o
..\g++ -shared -Ofast -Wl,-soname,t5_linux.so -o t5_linux.so  t5_linux.o
```

> **Warning:** Please rename your compiled version to t5_linux.so! At the moment the file t5_linux.so is compiled with Ubuntu Linux

4.1.3 Test the model

Windows and Linux

python <modelpath>/cwatm.py

The output should be:

```
Running under platform:  Windows  **(or Linux etc)**
CWatM - Community Water Model
Authors: ...
Version: ...
Date: ...
```

> **Warning:** If python is not set in the environment path, the full path of python has to be used

4.2 Running the model

4.2.1 Start the model

> **Warning:** The model needs a settings file as an argument. See: *Settings file*

Windows

python <modelpath>/cwatm.py settingsfile flags

example:

```
python cwatm.py settings1.ini
or with more information and an overview of computational runtime
python cwatm.py settings1.ini -l -t
```

> **Warning:** If python is not set in the environment path, the full path of python has to be used

Linux

<modelpath>/cwatm.py settingsfile flags

example:

```
cwatm.py settings1.ini -l -t
```

Flags

Flags can be used to change the runtime output on the screen

example:

```
-q --quiet        output progression given as .
-v --veryquiet    no output progression is given
-l --loud         output progression given as time step, date and discharge
-c --check        input maps and stack maps are checked, output for each input map BUT no model run
-h --noheader     .tss file have no header and start immediately with the time series
-t --printtime    the computation time for hydrological modules are printed
    -w --warranty    copyright and warranty information
```

Settings file

The setup of the setings file is shown in the next chapter.

NetCDF meta data

The format for spatial data for output data is netCDF. In the meta data file information can be added e.g. a description of the parameter

Note: It is not necessary to change this file! This is an option to put additional information into output maps

4.3 Settings file

The settings file is controlling the CWATM run

```
######## ##          ##  ####  ######  ##    ##
##       ##          ## ##  ##   ##   ####  ####
##        ##        ##  ##  ##   ##   ## #### ##
##        ##   ##   ## ########  ##  ##   ##   ##
##         ## #### ##  ##    ##  ##  ##        ##
##         ####  #### ##      ## ## ##          ##
##########  ##    ##  ##      ## ## ##          ##

# Community Water Model Version 0.99
```

4.3.1 Components of the settings file

General flags

General flags are set in the first paragraph For example: If Temperature data are in unit ° Celsius ot Kelvin

```
[OPTIONS]
#-------------------------------------------------------
# OPTION - to switch on/off
#-------------------------------------------------------
```

```

# Data otions
# if temperature is stored in Kelvin instead Celsius
TemperatureInKelvin = True
# if lat/lon the area has to be user defined = precalculated
gridSizeUserDefined = True

#-----------------------------------------------
# Evaporation: calculate pot. evaporation (True) or use precalculated pot.evaporation map stacks (False)
calc_evaporation = False

#-----------------------------------------------
# Irrigation and water demand

# if irrigation is included, otherwise paddy and non paddy is put into 'grassland'
includeIrrigation = True
# if water demand from irrigation, industry and domestic is included
includeWaterDemand = False
# Water allocation
# if water demand and availability is calculated for region to compare demand vs. avail
usingAllocSegments = False
# limit abstraction to available groundwater (True) include fossil groundwater (False)
limitAbstraction = False

# Environmental Flow
calc_environflow = False
use_environflow = False

#-----------------------------------------------
# Soil
# use preferential flow, that bypasses the soil matrix and drains directly to the groundwater (not for irrPaddy)
preferentialFlow = False
# Capillar rise
CapillarRise = True

#-----------------------------------------------
# Routing

# if runoff concentration to the edge of a cell is included
includeRunoffConcentration = True
# Waterbodies like lakes and reservoirs
includeWaterBodies = True
# kinematic wave routing, if False no routing is calculated
includeRouting = True

#-----------------------------------------------
# Inflow from outside of the modelled area
inflow = False

# --- Reporting & Debugging ------------------- ---------------------------------------------
# Reporting options
writeNetcdfStack = True
reportMap = True
reportTss = True
```

```
# Checking water balance (for debugging)
calcWaterBalance = False
sumWaterBalance = False
# use additional PCRaster GIS commands
PCRaster = False






#-------------------------------------------------------
# DEFINITIONS OF PARAMETERS
```

NetCDF meta data

The format for spatial data for input and output data is netCDF. For output data the basic information are given in the settingsfile

```
[NETCDF_ATTRIBUTES]
institution = IIASA
title = Global Water Model - WATCH WDFEI
metaNetcdfFile = $(FILE_PATHS:PathRoot)/source/metaNetcdf.xml
```

For each output file the specific information about units, variable name, displayed variable name is given in the metaNetcdf.xml. See: *Output Meta NetCDF information*

Path of data, output

Note: Further on the pathes can be used as placeholders

```
#-------------------------------------------------------
[FILE_PATHS]
#-------------------------------------------------------
PathRoot = E:/CWATM_rhine

PathOut = $(PathRoot)/output
PathMaps = $(PathRoot)/cwatm_input
PathMeteo = $(PathRoot)/climate
```

Defining the modeling area

In general the input data are stored and used at global scale. The modeling area can be defined by:

- a mask map
- coordinates

Note: The mask map can be a .tif, PCraster or a netCDF format | The coordinates have the format: Number of Cols, Number of rows, cellsize, upper left corner X, upper left corner Y

```
# AREA AND OUTLETS
#-------------------------------------------------------
[MASK_OUTLET]

# Area mask
# A pcraster map, tif or netcdf map e.g.  $(FILE_PATHS:PathRoot)/data/areamaps/area_indus.map
# or a retancle: Number of Cols, Number of rows, cellsize, upper left corner X, upper left corner Y
MaskMap = $(FILE_PATHS:PathRoot)/source/rhine30min.tif
#MaskMap = 14 12 0.5 5.0 52.0


#-------------------------------------------------------
# Station data
# either a map e.g. $(FILE_PATHS:PathRoot)/data/areamaps/area3.map
# or a location coordinates (X,Y) e.g. 5.75 52.25 9.25 49.75 )
# Lobith/Rhine
Gauges = 6.25 51.75

# if .tif file for gauges, this is a flag if the file is global or local
# e.g. Gauges = $(FILE_PATHS:PathRoot)/data/areamaps/gaugesRhine.tif
GaugesLocal = True
```

Defining the time

The start and end time have to be defined. Spin-up time is the time for warming up (results will be stored after the spin-up time)

Note: The time can be given as date: dd/mm/yyyy or as relative date: number (but then CalendarDayStart has to be defined)

Note: Spin-up time can be given as date or number

```
#-------------------------------------------------------
[TIME-RELATED_CONSTANTS]
#-------------------------------------------------------

# StepStart has to be a date e.g. 01/06/1990
# SpinUp or StepEnd either date or numbers
# SpinUp: from this date output is generated (up to this day: warm up)

StepStart = 1/1/1990
SpinUp =  1/01/1995
StepEnd =  31/12/2010
```

Initial conditions

Initial conditions can be stored and be loaded in order to initialise a warm start of the model

Note: Initial conditions are store as one netCDF file with all necessary variables

```
#-------------------------------------------------------
[INITITIAL CONDITIONS]
#-------------------------------------------------------

# for a warm start initial variables a loaded
# e.g for a start on 01/01/2010 load variable from 31/12/2009
load_initial = False
initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc

# saving variables from this run, to initiate a warm start next run
# StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
save_initial = False
initSave = $(FILE_PATHS:PathRoot)/init/Rhine
StepInit = 31/12/1989 31/12/2010
```

Initial conditions can be put directly into the settings file. Either as numbers or references to maps (.tif, PCraster or netCDF)

Warning: The values here (if not set to NONE) will overwrite the initial conditions of the general initial condition netCDF file

```
# Topography - tangent slope, slope length
tanslope = $(PathTopo)/tanslope.map
slopeLength = $(PathTopo)/slopeLength.map
```

Output

Output can be spatial/time as netCDF4 map stacks

and/or time series at specified points

Note: For additional information see *Model Output*

Output can be as maps and time series:

- per day [Daily]
- total month [MonthTot], average month [MonthAvg], end of month [MonthEnd]
- total year [AnnualTot], average year [AnnualAvg], end of year [AnnualEnd]
- total sum [TotalTot], total average [TotalAvg]

For each of the following sections output can be defined for different variables:

- Meteo
- Snow
- Soil for different land cover (forest, grassland, irrigated land, paddy irrigated)
- Water demand

- Groundwater
- River routing
- Lakes and reservoirs

Or output can be defined in the section *[output]*

An output directory can be defined and for each sort of output the variable(s) can be set:

*OUT_* defines that this variable(s) are output
*MAP_* or *TSS_* defines if it is a spatial map or a time series of point(s)
Daily or *MonthAvg* or .. is specifying the time
The variable is given after the equal sign e.g. * = discharge*
If more than one variable should be used for output, split with **,**
E.g. OUT_MAP_Daily = discharge -> daily spatial map of discharge

As example output for precipitation, temperature and discharge is shown here:

```
# OUTPUT maps and timeseries
OUT_Dir = $(FILE_PATHS:PathOut)
OUT_MAP_Daily =
OUT_MAP_MonthEnd =
OUT_MAP_MonthTot = Precipitation, Tavg
OUT_MAP_MonthAvg =

OUT_TSS_MonthTot = Precipitation, Tavg
OUT_TSS_Daily = discharge
OUT_TSS_MonthEnd = discharge
OUT_TSS_AnnualEnd = discharge
```

Note: For each variable the meta data information can be defined in *Output Meta NetCDF information*

Reading information

Information will be read in from values in the settings file Here the value definitions for [SNOW] is shown:

```
#-------------------------------------------------------
[SNOW]
#-------------------------------------------------------

# Number of vertical Snow layers
NumberSnowLayers = 7
# up to which layer the ice melt is calculated with the middle temperature
GlacierTransportZone = 3

# Temperature lapse rate with altitude [deg C / m]
TemperatureLapseRate = 0.0065
# Multiplier applied to precipitation that falls as snow
SnowFactor = 1.0
# Range [m C-1 d-1] of the seasonal variation, SnowMeltCoef is the average value
SnowSeasonAdj = 0.001
# Average temperature at which snow melts
```

```
TempMelt =1.0
# Average temperature below which precipitation is snow
TempSnow = 1.0
# Snow melt coefficient: default: 4.0
# SRM: 0.0045 m/C/day ( = 4.50 mm/C/day), Kwadijk: 18 mm/C/month (= 0.59 mm/C/day)
# See also Martinec et al., 1998.

# use in CALIBRATION -> copied to CALIBRATION
#SnowMeltCoef = 0.004
IceMeltCoef  = 0.007

#------------------------------------------------------------
# INITIAL CONDITIONS - Initial snow depth in snow zone 1-7 [mm]  - SnowCoverIni

[FROST]
# Snow water equivalent, (based on snow density of 450 kg/m3) (e.g. Tarboton and Luce, 1996)
SnowWaterEquivalent = 0.45
# Daily decay coefficient, (Handbook of Hydrology, p. 7.28)
Afrost = 0.97
# Snow depth reduction coefficient, [cm-1], (HH, p. 7.28)
Kfrost = 0.57
# Degree Days Frost Threshold (stops infiltration, percolation and capillary rise)
# Molnau and Bissel found a value 56-85 for NW USA.
FrostIndexThreshold = 56
```

Note: TemperatureLapseRate = 0.0065 | for the variable TemperatureLapseRate the value of 0.0065 is set

Variables can also be defined by spatial maps or map stacks

```
tanslope = $(PathTopo)\tanslope.map
forest_coverFractionNC    = $(PathForest)\coverFractionInputForest366days.nc
```

Note: suffix can be .map, but if there is no PCraster map it will look automatically for netCDF .nc

Warning: in most cases values can be replaced by map

4.3.2 Sections of information

- Snow
- Frost
- General information on land cover types
- Soil

- **Information for each of the six land cover types**
    - Forest
    - Grassland
    - Paddy irrigated area
    - Irrigated area
    - Sealed area
    - Water covered area
- Interflow
- Groundwater
- Water demand
- Runoff concentration
- Routing
- Lakes and reservoirs
- Inflow

4.3.3 Complete settings file

Example of a settings file:

```
# ------------------------------------------------

######## ##          ##  ####  ######  ##    ##
##       ##          ## ##  ##   ##   ####  ####
##        ##        ##  ##  ##   ##   ## #### ##
##        ##   ##   ## ########  ##  ##   ##   ##
##         ## #### ##  ##    ##  ##  ##        ##
##         ####  #### ##      ## ## ##          ##
##########  ##    ##  ##      ## ## ##          ##

# Community Water Model Version 0.99
# SETTINGS FILE
# ------------------------------------------------


[OPTIONS]
#-------------------------------------------------------
# OPTION - to switch on/off
#-------------------------------------------------------

# Data otions
# if temperature is stored in Kelvin instead Celsius
TemperatureInKelvin = True
# if lat/lon the area has to be user defined = precalculated
gridSizeUserDefined = True

#-----------------------------------------------
# Evaporation: calculate pot. evaporation (True) or use precalculated pot.evaporation map stacks (False)
calc_evaporation = False
```

```
#-------------------------------------------------------
# Irrigation and water demand

# if irrigation is included, otherwise paddy and non paddy is put into 'grassland'
includeIrrigation = True
# if water demand from irrigation, industry and domestic is included
includeWaterDemand = False
# Water allocation
# if water demand and availability is calculated for region to compare demand vs.␣
↪avail
usingAllocSegments = False
# limit abstraction to available groundwater (True) include fossil groundwater (False)
limitAbstraction = False

# Environmental Flow
calc_environflow = False
use_environflow = False

#-------------------------------------------------------
# Soil
# use preferential flow, that bypasses the soil matrix and drains directly to the␣
↪groundwater (not for irrPaddy)
preferentialFlow = False
# Capillar rise
CapillarRise = True

#-------------------------------------------------------
# Routing

# if runoff concentration to the edge of a cell is included
includeRunoffConcentration = True
# Waterbodies like lakes and reservoirs
includeWaterBodies = True
# kinematic wave routing, if False no routing is calculated
includeRouting = True

#-------------------------------------------------------
# Inflow from outside of the modelled area
inflow = False

# --- Reporting & Debugging ------------------- ---------------------------------------
↪--------
# Reporting options
writeNetcdfStack = True
reportMap = True
reportTss = True
# Checking water balance (for debugging)
calcWaterBalance = False
sumWaterBalance = False
# use additional PCRaster GIS commands
PCRaster = False
```

```
#-------------------------------------------------------
# DEFINITIONS OF PARAMETERS
#-------------------------------------------------------

#-------------------------------------------------------
[FILE_PATHS]
#-------------------------------------------------------
PathRoot = E:/CWATM_rhine

PathOut = $(PathRoot)/output
PathMaps = $(PathRoot)/cwatm_input
PathMeteo = $(PathRoot)/climate




#-------------------------------------------------------
[NETCDF_ATTRIBUTES]
institution = IIASA
title = Global Water Model - WATCH WDFEI
metaNetcdfFile = $(FILE_PATHS:PathRoot)/source/metaNetcdf.xml

#-------------------------------------------------------
# AREA AND OUTLETS
#-------------------------------------------------------
[MASK_OUTLET]

# Area mask
# A pcraster map, tif or netcdf map e.g.  $(FILE_PATHS:PathRoot)/data/areamaps/area_
↪indus.map
# or a retancle: Number of Cols, Number of rows, cellsize, upper left corner X, upper␣
↪left corner Y
MaskMap = $(FILE_PATHS:PathRoot)/source/rhine30min.tif
#MaskMap = 14 12 0.5 5.0 52.0


#-------------------------------------------------------
# Station data
# either a map e.g. $(FILE_PATHS:PathRoot)/data/areamaps/area3.map
# or a location coordinates (X,Y) e.g. 5.75 52.25 9.25 49.75 )
# Lobith/Rhine
Gauges = 6.25 51.75

# if .tif file for gauges, this is a flag if the file is global or local
# e.g. Gauges = $(FILE_PATHS:PathRoot)/data/areamaps/gaugesRhine.tif
GaugesLocal = True

#-------------------------------------------------------
[TIME-RELATED_CONSTANTS]
#-------------------------------------------------------

# StepStart has to be a date e.g. 01/06/1990
# SpinUp or StepEnd either date or numbers
# SpinUp: from this date output is generated (up to this day: warm up)

StepStart = 1/1/1990
SpinUp =  1/01/1995
StepEnd =  31/12/2010
```

```
#-------------------------------------------------------
[INITITIAL CONDITIONS]
#-------------------------------------------------------

# for a warm start initial variables a loaded
# e.g for a start on 01/01/2010 load variable from 31/12/2009
load_initial = False
initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc

# saving variables from this run, to initiate a warm start next run
# StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
save_initial = False
initSave = $(FILE_PATHS:PathRoot)/init/Rhine
StepInit = 31/12/1989 31/12/2010

#-------------------------------------------------------
# CALIBARTION PARAMETERS
#-------------------------------------------------------
[CALIBRATION]

# These are parameter which are used for calibration
# could be any parameter, but for an easier overview, tehey are collected here
# in the calibration template a placeholder (e.g. %arnoBeta) instead of value

# Snow
SnowMeltCoef = 0.0027
# Cropf factor correction
crop_correct =  1.11
#Soil
soildepth_factor = 1.28
#Soil preferentialFlowConstant = 4.0, arnoBeta_add = 0.1
preferentialFlowConstant = 4.5
arnoBeta_add = 0.19
# interflow part of recharge factor = 1.0
factor_interflow = 2.8
# groundwater recessionCoeff_factor = 1.0
recessionCoeff_factor = 5.278
# runoff concentration factor runoffConc_factor = 1.0
runoffConc_factor = 0.1
#Routing manningsN Factor to Manning's roughness = 1.0 [0.1-10.]
manningsN = 1.86
# reservoir  normal storage limit (fraction of total storage, [-]) [0.15 - 0.85]␣
↪default 0.5
normalStorageLimit = 0.44
# lake parameter - factor to alpha: parameter of of channel width and weir␣
↪coefficient  [0.33 - 3.] dafault 1.
lakeAFactor = 0.33
# lake parameter - factor for wind evaporation
lakeEvaFactor = 1.52
#-------------------------------------------------------
# TOPOGRAPHY MAPS
#-------------------------------------------------------
[TOPOP]
# local drain direction map (1-9)
```

```
Ldd = $(FILE_PATHS:PathMaps)/routing/ldd.map

# Elevation standard deviation [m], i.e. altitude difference elevation within pixel.
# Used for sub-pixel modelling of snow accumulation and melt
ElevationStD = $(FILE_PATHS:PathMaps)/landsurface/topo/elvstd.map

# Area of pixel [m2] (for lat/lon every cell has a different area)
CellArea = $(FILE_PATHS:PathMaps)/routing/cellarea.map

#-------------------------------------------------------
# INPUT METEOROLOGICAL TIMESERIES AS MAPS
#-------------------------------------------------------
[METEO]
# precipitation [kg m-2 s-1]
#PrecipitationMaps = $(FILE_PATHS:PathMeteo)/pr*
PrecipitationMaps = $(FILE_PATHS:PathMeteo)/30min/pr_rhine*
# average daily temperature [K]
#TavgMaps = $(FILE_PATHS:PathMeteo)/tavg*
TavgMaps = $(FILE_PATHS:PathMeteo)/30min/tavg_rhine*

# ----------------------------------------
# This is used if calc_evaporation = False

# daily reference evaporation (free water)
E0Maps = $(FILE_PATHS:PathMeteo)/30min/EWRef_rhine.nc
#E0Maps = $(FILE_PATHS:PathMeteo)/EWRef_daily*
# daily reference evapotranspiration (crop)
ETMaps = $(FILE_PATHS:PathMeteo)/30min/ETRef_rhine.nc
#ETMaps = $(FILE_PATHS:PathMeteo)/ETRef_daily*

# --------------------------------
# from kg m-2s-1 to m : 86.4
precipitation_coversion = 86.4

# from MM to m : 0.001
#precipitation_coversion = 0.001

evaporation_coversion = 1.00

# OUTPUT maps and timeseries
#OUT_Dir = $(FILE_PATHS:PathOut)
#OUT_MAP_Daily = Precipitation, prec1

#-------------------------------------------------------
# CALCULATE EVAPORATION - PENMAN - MONTEITH
#-------------------------------------------------------
[EVAPORATION]

# This is used if calc_evaporation = True
# use albedo maps
albedo = True
albedoMaps = $(FILE_PATHS:PathMaps)/landsurface/albedo/albedo.nc

# if not albedo maps use fixed albedo
# Albedo of bare soil surface (Supit et. al.)
AlbedoSoil = 0.15
# Albedo of water surface (Supit et. al.)
AlbedoWater = 0.05
```

```
# Albedo of vegetation canopy (FAO,1998)
AlbedoCanopy = 0.23

# use specific humidity (TRUE) QAir,  or relative humidity (FALSE) - rhs
useHuss = False

# map stacks Temperature [K}]
TminMaps = $(FILE_PATHS:PathMeteo)/tmin*
TmaxMaps = $(FILE_PATHS:PathMeteo)/tmax*
# Instantaneous surface pressure[Pa]
PSurfMaps = $(FILE_PATHS:PathMeteo)/ps*
# 2 m istantaneous specific humidity[kg /kg] (QAir) or relative humidity [%] (rhs)
RhsMaps = $(FILE_PATHS:PathMeteo)/hurs*
# wind speed maps at 10m [m/s]
WindMaps = $(FILE_PATHS:PathMeteo)/wind*
# radiation surface downwelling shortwave maps  [W/m2]
RSDSMaps = $(FILE_PATHS:PathMeteo)/rsds*
# radiation surface downwelling longwave maps [W/m2] [W/m2]
RSDLMaps = $(FILE_PATHS:PathMeteo)/rlds*

# OUTPUT maps and timeseries
#OUT_Dir = $(FILE_PATHS:PathOut)
#OUT_MAP_Daily = EWRef, ETRef, temp, prec

#-------------------------------------------------------
[SNOW]
#-------------------------------------------------------

# Number of vertical Snow layers
NumberSnowLayers = 7
# up to which layer the ice melt is calculated with the middle temperature
GlacierTransportZone = 3

# Temperature lapse rate with altitude [deg C / m]
TemperatureLapseRate = 0.0065
# Multiplier applied to precipitation that falls as snow
SnowFactor = 1.0
# Range [m C-1 d-1] of the seasonal variation, SnowMeltCoef is the average value
SnowSeasonAdj = 0.001
# Average temperature at which snow melts
TempMelt =1.0
# Average temperature below which precipitation is snow
TempSnow = 1.0
# Snow melt coefficient: default: 4.0
# SRM: 0.0045 m/C/day ( = 4.50 mm/C/day), Kwadijk: 18 mm/C/month (= 0.59 mm/C/day)
# See also Martinec et al., 1998.

# use in CALIBRATION -> copied to CALIBRATION
#SnowMeltCoef = 0.004
IceMeltCoef  = 0.007

#--------------------------------------------------------------
# INITIAL CONDITIONS - Initial snow depth in snow zone 1-7 [mm]  - SnowCoverIni

[FROST]
# Snow water equivalent, (based on snow density of 450 kg/m3) (e.g. Tarboton and
↪Luce, 1996)
SnowWaterEquivalent = 0.45
```

```
# Daily decay coefficient, (Handbook of Hydrology, p. 7.28)
Afrost = 0.97
# Snow depth reduction coefficient, [cm-1], (HH, p. 7.28)
Kfrost = 0.57
# Degree Days Frost Threshold (stops infiltration, percolation and capillary rise)
# Molnau and Bissel found a value 56-85 for NW USA.
FrostIndexThreshold = 56

#---------------------------------------------------------------
# INITIAL CONDITIONS: FrostIndexIni

[VEGETATION]
cropgroupnumber = $(FILE_PATHS:PathMaps)/others/cropgrp.nc
# soil water depletion fraction, Van Diepen et al., 1988: WOFOST 6.0, p.86, Doorenbos
↪et. al 1978

#--------------------------------------------------------
[SOIL]
#--------------------------------------------------------

PathTopo = $(FILE_PATHS:PathMaps)/landsurface/topo
PathSoil = $(FILE_PATHS:PathMaps)/landsurface/soil
PathSoil1 =  $(FILE_PATHS:PathMaps)/others

# Topography - tangent slope, slope length
tanslope = $(PathTopo)/tanslope.map
slopeLength = $(PathTopo)/slopeLength.map

# maps of relative elevation above flood plains
relativeElevation = $(PathTopo)/dzRel_hydro1k.nc

# Soil hydraulic properties

# soil (Hypres pedotransfer function - http://esdac.jrc.ec.europa.eu/ESDB_Archive/
↪ESDBv2/popup/hy_param.htm)
KSat1 = $(PathSoil1)/ksat1.map
KSat2 = $(PathSoil1)/ksat2.map
KSat3 = $(PathSoil1)/ksat3.map
# Alpha: an Genuchten's shape parameter
alpha1 = $(PathSoil1)/alpha1.map
alpha2 = $(PathSoil1)/alpha2.map
alpha3 = $(PathSoil1)/alpha3.map
#Lambda: an Genuchten's shape parameter = n-1-> n = lamda+1, m = 1 - (1/n)
lambda1 = $(PathSoil1)/lambda1.map
lambda2 = $(PathSoil1)/lambda2.map
lambda3 = $(PathSoil1)/lambda3.map
# thetas  is the volumetric water content θ saturated
thetas1 = $(PathSoil1)/thetas1.map
thetas2 = $(PathSoil1)/thetas2.map
thetas3 = $(PathSoil1)/thetas3.map
# thetar is the volumetric water content θ residual
thetar1 = $(PathSoil1)/thetar1.map
thetar2 = $(PathSoil1)/thetar2.map
thetar3 = $(PathSoil1)/thetar3.map

percolationImp = $(PathSoil)/percolationImp.map

maxGWCapRise    = 5.0
```

```
minCropKC        = 0.2
minTopWaterLayer = 0.0

# Soil depth
StorDepth1 = $(PathSoil)/storageDepth1.map
StorDepth2 = $(PathSoil)/storageDepth2.map

# preferential flow (between 1.0 and 8.0)
# used in CALIBRATION -> copied to CALIBRATION
#preferentialFlowConstant = 4.0

#-------------------------------------------------------
[LANDCOVER]
PathLandcover = $(FILE_PATHS:PathMaps)/landsurface

coverTypes = forest, grassland, irrPaddy, irrNonPaddy, sealed, water
coverTypesShort = f, g, i, n, s, w
fractionLandcover = $(PathLandcover)/fractionLandcover.nc

# Landcover can vary from year to year
dynamicLandcover = True
# if landcover cannot vary, which year should be taken as fixed year
fixLandcoverYear = 1961

#-------------------------------------------------------

[__forest]
PathForest = $(FILE_PATHS:PathMaps)/landcover/forest
PathSoil1 =  $(FILE_PATHS:PathMaps)/others

# Parameters for the Arno's scheme
# arnoBeta is defined by orographic,+ land cover add + calibration add, the soil␣
↪water capacity distribution is based on this
# range [0.01 - 1.2]
forest_arnoBeta = 0.2

#forest_soil
forest_KSat1 = $(PathSoil1)/forest_ksat1.map
forest_KSat2 = $(PathSoil1)/forest_ksat2.map
forest_KSat3 = $(PathSoil1)/ksat3.map
forest_alpha1 = $(PathSoil1)/forest_alpha1.map
forest_alpha2 = $(PathSoil1)/forest_alpha2.map
forest_alpha3 = $(PathSoil1)/alpha3.map
forest_lambda1 = $(PathSoil1)/forest_lambda1.map
forest_lambda2 = $(PathSoil1)/forest_lambda2.map
forest_lambda3 = $(PathSoil1)/lambda3.map
forest_thetas1 = $(PathSoil1)/forest_thetas1.map
forest_thetas2 = $(PathSoil1)/forest_thetas2.map
forest_thetas3 = $(PathSoil1)/thetas3.map
forest_thetar1 = $(PathSoil1)/forest_thetar1.map
forest_thetar2 = $(PathSoil1)/forest_thetar2.map
forest_thetar3 = $(PathSoil1)/thetar3.map

# other paramater values
forest_minInterceptCap  = 0.001
forest_cropDeplFactor   = 0.0
```

```
forest_fracVegCover  = $(PathForest)/fracVegCover.map
forest_rootFraction1 = $(PathForest)/rootFraction1.map
forest_rootFraction2 = $(PathForest)/rootFraction2.map
#forest_maxRootDepth  = 2.0
forest_maxRootDepth  = $(PathForest)/maxRootDepth.map
forest_minSoilDepthFrac = $(PathForest)/minSoilDepthFrac.map


forest_cropCoefficientNC = $(PathForest)/CropCoefficientForest_10days.nc
forest_interceptCapNC    = $(PathForest)/interceptCapForest10days.nc

# initial conditions: forest_interceptStor, forest_w1, forest_w2, forest_w3,


[__grassland]
PathGrassland = $(FILE_PATHS:PathMaps)/landcover/grassland

# Parameters for the Arno's scheme:
grassland_arnoBeta = 0.0
# arnoBeta is defined by orographic,+ land cover add + calibration add, the soil␣
↪water capacity distribution is based on this
# range [0.01 - 1.2]

# other paramater values

grassland_minInterceptCap  = 0.001
grassland_cropDeplFactor   = 0.0

grassland_fracVegCover  = $(PathGrassland)/fracVegCover.map
grassland_rootFraction1 = $(PathGrassland)/rootFraction1.map
grassland_rootFraction2 = $(PathGrassland)/rootFraction2.map
grassland_maxRootDepth  = $(PathGrassland)/maxRootDepth.map
grassland_minSoilDepthFrac = $(PathGrassland)/minSoilDepthFrac.map


grassland_cropCoefficientNC = $(PathGrassland)/CropCoefficientGrassland_10days.nc
grassland_interceptCapNC    = $(PathGrassland)/interceptCapGrassland10days.nc

# initial conditions: grassland_interceptSto, grassland_w1, grassland_w2, grassland_w3


[__irrPaddy]
PathIrrPaddy = $(FILE_PATHS:PathMaps)/landcover/irrPaddy

# Parameters for the Arno's scheme:
irrPaddy_arnoBeta = 0.2
# arnoBeta is defined by orographic,+ land cover add + calibration add, the soil␣
↪water capacity distribution is based on this
# range [0.01 - 1.2]

# other paramater values

irrPaddy_minInterceptCap  = 0.001
irrPaddy_cropDeplFactor   = 0.0

irrPaddy_fracVegCover  = $(PathIrrPaddy)/fracVegCover.map
irrPaddy_rootFraction1 = $(PathIrrPaddy)/rootFraction1.map
irrPaddy_rootFraction2 = $(PathIrrPaddy)/rootFraction2.map
```

```
irrPaddy_maxRootDepth  = $(PathIrrPaddy)/maxRootDepth.map
irrPaddy_minSoilDepthFrac = $(PathIrrPaddy)/minSoilDepthFrac.map

irrPaddy_cropCoefficientNC = $(PathIrrPaddy)/CropCoefficientirrPaddy_10days.nc

# maximum flooding depth for paddy
irrPaddy_maxtopwater = 0.05



# initial conditions: irrPaddy_interceptStor, irrPaddy_w1, irrPaddy_w2, irrPaddy_w3



[__irrNonPaddy]
PathIrrNonPaddy = $(FILE_PATHS:PathMaps)/landcover/irrNonPaddy

# Parameters for the Arno's scheme:
irrNonPaddy_arnoBeta = 0.2
# arnoBeta is defined by orographic,+ land cover add + calibration add, the soil␣
↪water capacity distribution is based on this
# range [0.01 - 1.2]

# other paramater values


irrNonPaddy_minInterceptCap  = 0.001
irrNonPaddy_cropDeplFactor   = 0.0

irrNonPaddy_fracVegCover  = $(PathIrrNonPaddy)/fracVegCover.map
irrNonPaddy_rootFraction1 = $(PathIrrNonPaddy)/rootFraction1.map
irrNonPaddy_rootFraction2 = $(PathIrrNonPaddy)/rootFraction2.map
irrNonPaddy_maxRootDepth  = $(PathIrrNonPaddy)/maxRootDepth.map
irrNonPaddy_minSoilDepthFrac = $(PathIrrNonPaddy)/minSoilDepthFrac.map


irrNonPaddy_cropCoefficientNC = $(PathIrrNonPaddy)/CropCoefficientirrNonPaddy_10days.
↪nc


# initial conditions: irrNonPaddy_interceptStor, irrNonPaddy_w1, irrNonPaddy_w2,␣
↪irrNonPaddy_w3


[__sealed]
PathSealed = $(FILE_PATHS:PathMaps)/landcover/sealed

sealed_minInterceptCap  = 0.001

# initial conditions: sealed_interceptStor


[__open_water]
PathWater = $(FILE_PATHS:PathMaps)/landcover/water

water_minInterceptCap  = 0.0

#------------------------------------------------------
```

```
[GROUNDWATER]
#-------------------------------------------------------

PathGroundwater = $(FILE_PATHS:PathMaps)/groundwater

recessionCoeff = $(PathGroundwater)/recessionCoeff.map
# baseflow = recessionCoeff * storage groundwater
specificYield = $(PathGroundwater)/specificYield.map
kSatAquifer = $(PathGroundwater)/kSatAquifer.map
# both not used at the moment in groundwater modul, but already loaded

#--------------------------------------------------------------
# INITIAL CONDITIONS: storGroundwater


#-------------------------------------------------------
[WATERDEMAND]
#-------------------------------------------------------

PathWaterdemand = $(FILE_PATHS:PathMaps)/landsurface/waterDemand
# For water demand vs. availability: areas have to be aggregated
# Allocation map
allocSegments = $(PathWaterdemand)/catchx.nc

domesticWaterDemandFile = $(PathWaterdemand)/domesticWaterDemand.nc
industryWaterDemandFile = $(PathWaterdemand)/industryWaterDemand.nc

irrNonPaddy_efficiency = $(FILE_PATHS:PathMaps)/landsurface/waterDemand/efficiency.nc
irrPaddy_efficiency = $(FILE_PATHS:PathMaps)/landsurface/waterDemand/efficiency.nc

#irrNonPaddy_efficiency = 0.8
#irrPaddy_efficiency = 0.8
irrigation_returnfraction = 0.5

# ------------------------------------------------------------
# Estimate of fractions of groundwater and surface water abstractions
# Either a fixed fraction for surface water abstration
# based on fraction of average baseflow and upstream average discharge
# if swAbstractionFrac < 0: fraction is taken from baseflow / discharge
# if swAbstractionFrac > 0 this value is taken as a fixed value
swAbstractionFrac = 0.9
averageDischarge = $(FILE_PATHS:PathOut)/discharge_totalavg_rhine30min.nc
# in [m3/s]
averageBaseflow  = $(FILE_PATHS:PathOut)/baseflow_totalavg_rhine30min.nc
# in [m3/s]
baseflowInM = True
# if baseflow is in [m] instead of [m3/s] it will be converted


#-------------------------------------------------------
# RUNOFF CONCENTRATION
#-------------------------------------------------------
[RUNOFF_CONCENTRATION]

# using triagular weigthning method
# the bigger the factor, more lag time
forest_runoff_peaktime = 1.0
grassland_runoff_peaktime = 0.5
```

```
irrPaddy_runoff_peaktime = 0.5
irrNonPaddy_runoff_peaktime = 0.5
sealed_runoff_peaktime = 0.15
water_runoff_peaktime = 0.01

interflow_runoff_peaktime =1.0
baseflow_runoff_peaktime = 2.0

# initial conditions:
# here only 1 layer is shown, but there are up to 10: runoff_concIni


#-------------------------------------------------------
# ROUTING MAPS and PARAMETERSD
#-------------------------------------------------------
[ROUTING]

PathRouting = $(FILE_PATHS:PathMaps)/routing

# Number of substep per day
# should be 10 for 0.5 deg but 24 for 0.1 deg

NoRoutingSteps = 10
#kinematic wave parameter: 0.6 is for broad sheet flow
chanBeta = 0.6

# Channel gradient (fraction, dy/dx)
chanGrad = $(PathRouting)/kinematic/changrad.nc
# Minimum channel gradient (for kin. wave: slope cannot be 0)
chanGradMin = 0.0001

#Channel Manning's n
chanMan = $(PathRouting)/kinematic/chanman.nc
#Channel length [meters]
chanLength = $(PathRouting)/kinematic/chanleng.nc
#Channel bottom width [meters]
chanWidth = $(PathRouting)/kinematic/chanbw.nc
#Bankfull channel depth [meters]
chanDepth = $(PathRouting)/kinematic/chanbnkf.nc

# initial conditions: channelStorageIni, riverbedExchangeIni, dischargeIni

#-------------------------------------------------------
# LAKES AND RESERVOIRS
#-------------------------------------------------------
[LAKES_RESERVOIRS]

PathLakesRes = $(FILE_PATHS:PathMaps)/routing/lakesreservoirs

# Use reservoirs and lakes (otherwise use only lakes Lake ID=1 and 3 => natural
↪conditions)
useResAndLakes = True
# Reservoirs do have a year of implementation
dynamicLakesRes = True
# if Reservoirs does not have a year of implemtation, which year should be taken as
↪fixed year
fixLakesResYear = 1950
```

```
#----------------------------
#Big lakes and Reservoirs

# ID of every lake, reservoir from HydroLakes database
waterBodyID = $(PathLakesRes)/lakesResID.nc
# 1 for lake, 2 for reservoir, 3 for lake and reservoir
waterBodyTyp = $(PathLakesRes)/lakesResType.nc
# Avergae discharge from HydroLakes Database
waterBodyDis = $(PathLakesRes)/lakesResDis.nc

# Lakes surface area from HydroLakes Database
waterBodyArea = $(PathLakesRes)/lakesResArea.nc
# a factor to scale the outlet of a lake
#lakeAFactor = 1.0  -> calibration

#----------------------------
# Small lakes and reservoirs

useSmallLakes = True

smallLakesRes = $(PathLakesRes)/smallLakesRes.nc
smallwaterBodyDis = $(PathLakesRes)/smalllakesresDis.nc

# averageRunoff in [m] (if not given smallwaterBodyDis is taken instead)
#averageRunoff  = $(FILE_PATHS:PathOut)/runoff_totalavg_cali.nc

# for water demand
#min storage in [m3] (if not give it is calculated)
#minStorage  = $(FILE_PATHS:PathOut)/minsmalllakeStorage_cali.nc


# initial conditions: lakeInflowIni, lakeStorageIni, outLakeIni, lakeOutflowIni,␣
↪reservoirStorageIni

#------------------
# Reservoirs
# reservoir volume from HydroLakes database
waterBodyVolRes = $(PathLakesRes)/lakesResVolRes.nc
# reservoir starting year from HydroLakes database
waterBodyYear = $(PathLakesRes)/lakesResYear.nc

#  Conservative, normal and flood storage limit (fraction of total storage, [-])
conservativeStorageLimit = 0.1
#normalStorageLimit = 0.5   # --> put into calibration
floodStorageLimit = 0.9
# adjusting the balance between normal and flood storage
# [0 ..1]  0: NormalstorageLimit      1: (= closer to flood) results in keeping the␣
↪normal qoutflow longer constant
adjust_Normal_Flood = 0.5

# Minimum, Normal and Non-damaging reservoir outflow  (fraction of average discharge,␣
↪[-])
MinOutflowQ = 0.2
NormalOutflowQ = 1.0
NonDamagingOutflowQ = 4.0

# initial conditions: lakeInflowIni, lakeStorageIni, outLakeIni, lakeOutflowIni,␣
↪reservoirStorageIni
```

```
#-------------------------------------------------------
[INFLOW]
#-------------------------------------------------------

# if option inflow = true
# the inflow from outside is added at inflowpoints
In_Dir = $(FILE_PATHS:PathRoot)/in

# nominal map with locations of (measured)inflow hydrographs [cu m / s]
InflowPoints = $(In_Dir)/in.map
#InflowPoints = 8.25 49.75 7.75 50.25

# if InflowPoints is a map, this flag is to identify if it is global (False) or local␣
↪(True)
# observed or simulated input hydrographs as time series [cu m / s]
# Note: that identifiers in time series have to correspond to InflowPoints
# can be several timeseries in one file or different files e.g. main.tss mosel.tss
#QInTS = main1.tss mosel1.tss
QInTS = mm.tss



#-------------------------------------------------------
[ENVIRONMENTALFLOW]
#-------------------------------------------------------

# Either calculate without run with predone discharge (set calc_ef_after = False)
calc_ef_after = True
# Or calculate after run (set calc_ef_after = False) and defining the file to be used
EFDis = $(FILE_PATHS:PathOut)/discharge_rhine.nc

# if predone discharge, do the maps need to be cut to fit to the mask?
cut_ef_map = False

EnvironmentalFlowFile = $(FILE_PATHS:PathOut)/MQ90_12month.nc

# MAF: Mean, Q90: percentile 90, MMF: monthly average, MQ90: monthly Q90 9averagwed␣
↪over al Jan, Feb..
# EF_VMF: Environmental flow - variable monthly flow, EF_VMF_LIH - EF- variable␣
↪monthly flow, high intermediate, low class
OUT_Dir = $(FILE_PATHS:PathOut)
#OUT_MAP_Once = MAF, Q90
#OUT_MAP_12month = MMF, MQ90, EF_VMF, EF_VMF_LIH
#OUT_MAP_12month = MQ90, EF_VMF



#+++++++++++++++++++++++++++++++++++++++++++++++++++++++
#+++++++++++++++++++++++++++++++++++++++++++++++++++++++


[OUTPUT]

# OUTPUT maps and timeseries
OUT_Dir = $(FILE_PATHS:PathOut)
```

```
OUT_TSS_Daily = discharge
#OUT_TSS_MonthAvg = discharge
#OUT_TSS_AnnualAvg = discharge

#OUT_Map_Daily = discharge
#OUT_Map_MonthAvg = discharge, precipitation, runoff
#OUT_Map_AnnualAvg = discharge
#OUT_MAP_TotalAvg = discharge, baseflow
```

4.4 NetCDF meta data

4.4.1 Output Meta NetCDF information

The metaNetcdf.xml includes information on the output netCDF files e.g. description of the parameter, unit ..

Example of a metaNetcdf.xml file:

```
<CWATM>
# METADATA for NETCDF OUTPUT DATA

# varname: name of the variable in the CWAT code
# unit: unit of the varibale
# long name# standard name

# Discharge maps
<metanetcdf varname="discharge" unit="m3/s"  standard_name="Discharge" long_name=
↪"Discharge in cubic meter per second"  title="1st Demo CWATM" author="PB" />

# others
<metanetcdf varname="soilmoisture" unit="mm"  standard_name="soil moisture" long_name=
↪"Soil moisture"  title ="1st Demo CWATM" author="PB" />

# Initial condition Files
<metanetcdf varname="initcondition"  purpose ="Initial Conditions CWATM" author="PB" /
↪>
<metanetcdf varname="SnowCover1" unit="mm"  standard_name="SnowCover1" long_name=
↪"Snow cover top layer"  />
<metanetcdf varname="SnowCover2" unit="mm"  standard_name="SnowCover2" long_name=
↪"Snow cover middle layer"  />
<metanetcdf varname="SnowCover3" unit="mm"  standard_name="SnowCover3" long_name=
↪"Snow cover lower layer"  />
<metanetcdf varname="FrostIndex" unit="degree/days"  standard_name="FrostIndex" long_
↪name="Frost index based on Molnau, Bissel (1983)"  />
</CWATM>
```

4.4.2 Name and location of the NetCDF meta data file

In the settings file the name and location of the metadata file is given.

```
#-------------------------------------------------------
[NETCDF_ATTRIBUTES]
institution = IIASA
title = Global Water Model - WATCH WDFEI
metaNetcdfFile = $(FILE_PATHS:PathRoot)/CWATM/source/metaNetcdf.xml
```

4.5 Initialisation

CWATM needs to have estimates of the initial state of the internal storage variables, e.g. the amount of water stored in snow, soil, groundwater etc.

There are two possibilities:

1. The initial state of the internal storage variables are unknown and a **first** guess has to be used e.g. all storage variables are half filled.
2. The initial state is known from a previous run, where the variables are stored at a certain time step. This is called **warm start**

The the **warm start** is usful for:

- using a long pre-run to find the steady-state storage of the groundwater storage and use it as initial value
- using the stored variables to shorten the warm-up period
- using the stored variables to restart every day with the values from the pre3vious day (forecasting mode)

4.5.1 Example of soil moisture

The next figure shows the impact of different initial condition on the soil moisture of the lower soil. In one of the simulations the soil is initially almost ompletely saturated. In another simulation the soil is completely dry and the third simulation starts with initial conditions in between the two extremes.

In the beginning the effect of different initial condition can be seen clearly. But after one year the three curves converge. The **memory** of the lower soil goes back for about one year.

For all the initial condition apart from groundwater the memory is about 12 month. That means practically a spin-up of one year is sufficient to habve enough warm-up time.

Figure: Simulation of soil moisture in the lower soil with different initial conditions

For the groundwater zone a longer warm-up period is needed, because of the slow response of groundwater. Here a rather fast reacting groundwater storage is shown with the three curves coverge after two years.

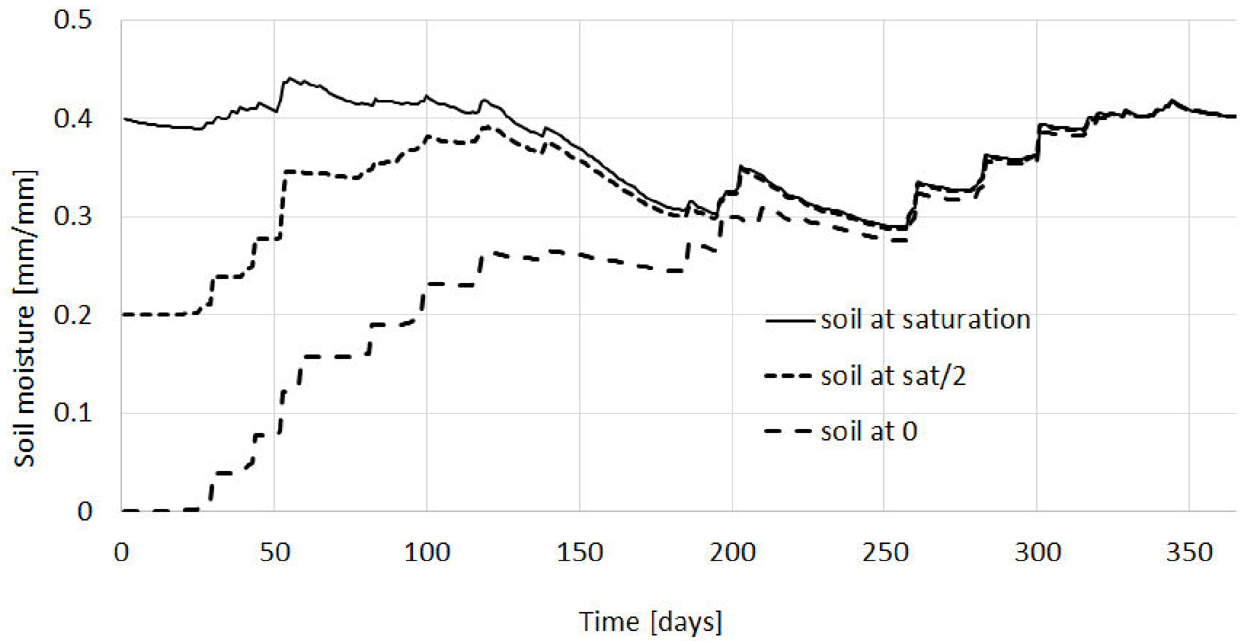
Figure: Simulation of groundwater storage with different initial conditions

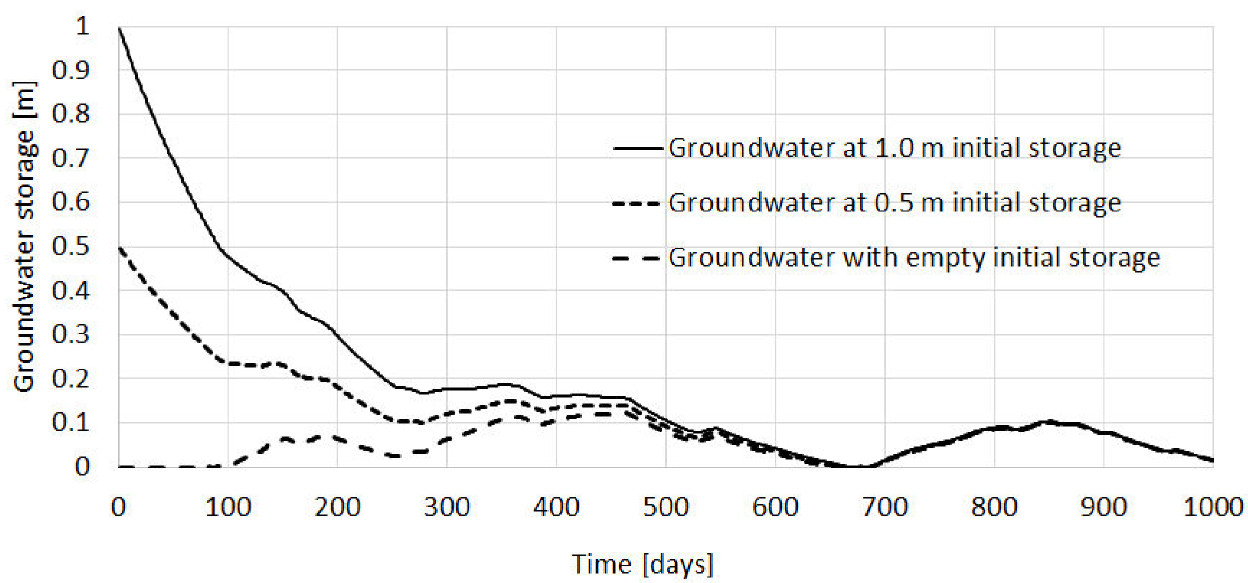
4.5.2 Cold start

For a **cold start** the values of the storage variables are unknown and set to a "first" guess. A list of variables and their default value for a **cold start** is given below in: *Initial conditions*

Set up a cold start in the settingsfile

In the settings file the option: **load_initial** has to be set on **False**


0.5
0.4
0.3
0.2
0.1
0
Soil moisture [mm/mm]
0
50
100
150
200
250
300
350
Time [days]
soil at saturation
soil at sat/2
soil at 0


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Groundwater storage [m]
0
100
200
300
400
500
600
700
800
900
1000
Time [days]
Groundwater at 1.0 m initial storage
Groundwater at 0.5 m initial storage
Groundwater with empty initial storage

```
#-------------------------------------------------------
[INITITIAL CONDITIONS]
#-------------------------------------------------------

# for a warm start initial variables a loaded
# e.g for a start on 01/01/2010 load variable from 31/12/2009
load_initial = False
initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc
```

Note: It is possible to exclude the warming up period of your model run for further analysis of results by setting the **SpinUp** option

```
[TIME-RELATED_CONSTANTS]
SpinUp =  01/01/1995
```

4.5.3 Storing initial variables

In the settings file the option **save_intitisal** has to be set to **True**

The name of the initial netCDF4 file has to be put in **initsave**

and one or more dates have to be specified in StepInit

```
# saving variables from this run, to initiate a warm start next run
# StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
save_initial = False
initSave = $(FILE_PATHS:PathRoot)/init/Rhine
StepInit = 31/12/1989 31/12/2010
```

4.5.4 Warm start

CWATM can write internal variables to a netCDF file for choosen timesteps. These netCDF files can be used as the initial conditions for a suceeding simulation.

This is useful for establishing a steady-state with a long-term run and then using this steady-state for succeding simulations or for an every day run (forecasting mode)

Warning: If the parameters are changes after a run(especially the groundwater parameters) the stored initial values do not represent the conditions of the storage variables. Stored initial conditions should **not** be used as initial values for a model run with another set of parameters. If you do this during calibration, you will not be able to reproduce the calibration results!

Set up a cold start in the settingsfile

In the settings file the option: **load_initial** has to be set on **True** And define the name of the netcdf4 file in **initLoad**

Note: Use the initial values of the previous day here. E.g. if you run the model from 01/01/2006 use the inital condition from 31/12/2005

```
#-------------------------------------------------------
[INITITIAL CONDITIONS]
#-------------------------------------------------------

# for a warm start initial variables a loaded
# e.g for a start on 01/01/2010 load variable from 31/12/2009
load_initial = False
initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc
```

4.5.5 Initial conditions

No.	Variable	Description	Default value	Number of maps
1	SnowCover	Snow cover for up to 7 zones	0	7
2	FrostIndex	Degree days frost threshold	0	1
3	Forest state	Interception storage	0	1
		Top water layer	0	1
		Soil storage for 3 soil layers	0	3
4	Grassland state	Interception storage	0	1
		Top water layer	0	1
		Soil storage for 3 soil layers	0	3
5	Paddy irrigation state	Interception storage	0	1
		Top water layer	0	1
		Soil storage for 3 soil layers	0	3
6	Irrigation state	Interception storage	0	1
		Top water layer	0	1
		Soil storage for 3 soil layers	0	3
7	Sealed area state	Interception storage	0	1
8	Groundwater	Groundwater storage	0	1
9	Runoff concentration	10 layers of runoff concentration	0	10
10	Routing	Channel storage	0.2 * total cross section	1
	Routing	Riverbed exchange	0	1
	Routing	Discharge	depending on ini channel stor.	1
11	Lakes and Reservoirs	Lake inflow	from HydroLakes database	1
		Lake outflow	same as lake inflow	1
		Lake&Res outflow to other lakes&res	same as lake inflow	1
		Lake storage	based on inflow and lake area	1
		Reservoir storage	0.5 * max. reservoir storage	1
		Small lake storage	based on inflow and lake area	1
		Small lake inflow	from HydroLakes database	1
		Small lake outflow	same as small lake inflow	1

4.6 Model Output

An advantage of **CWATM** is the full flexibility of the output variables.

- All parameters and variables can be used for output as maps or time series.
- Even if the model is run at daily timestep, output can be daily, monthly, annual, at the end of a run
- all variables maps are stored as netcdf and the meta data information can be added

4.6.1 Time depending and non depending output maps

Output maps will be produced as spatial maps, stack of spatial maps (over time)
Format: netCDF4

The netCDF maps can be read with:

Windows

- Panoply

Linux

- ncview
- cdo

4.6.2 Or time series at specified points

Timeseries are procuded as ASCII files, which can be read with every text editor
or with PCRaster Aquila

The specific point where timeseries are provided are defined in the settings file as *Gauges*:

```
# Station data
# either a map e.g. $(FILE_PATHS:PathRoot)/data/areamaps/area3.map
# or a location coordinates (X,Y) e.g. 5.75 52.25 9.25 49.75 )
# Lobith/Rhine
Gauges = 6.25 51.75

# if .tif file for gauges, this is a flag if the file is global or local
# e.g. Gauges = $(FILE_PATHS:PathRoot)/data/areamaps/gaugesRhine.tif
GaugesLocal = True
```

4.6.3 Output variables

Output can be every global defined variable in the model Variable are e.g. Precipitation, runoff, baseflow

but also not so common variables as:

- reservoirStorage (amount of water in the reservoirs in [m3])
- nonIrrReturnFlowFraction (returnflow from domenstic and industrial water use [m3])

- actualET[1] (actual evapotranspiration from grassland [m/day])
- ...

4.6.4 Daily, monthly - at the end or average

- per day
- total month, average month, end of month
- total year, average year, end of year
- total average, total at the end

for example

```
[OUTPUT]
# OUTPUT maps and timeseries
OUT_Dir = $(FILE_PATHS:PathOut)
OUT_MAP_Daily = discharge, runoff
OUT_MAP_MonthAvg = Precipitation
OUT_MAP_TotalEnd = lakeStorage
OUT_MAP_TotalAvg = Tavg

OUT_TSS_Daily = discharge
OUT_TSS_AnnualAvg = Precipitation
```

Note: For each variable the meta data information can be defined in *Output Meta NetCDF information*

Note: For information how to adjust the output in the settings file see *Output*

CHAPTER 5

Tutorial

Contents

5.1 Requirements

5.1.1 Python version

Requirements are a 64 bit Python 2.7.x version

Warning: a 32 bit version is not able to handle the data requirements!

5.1.2 Libraries

These external libraries are needed:

- Numpy
- netCDF4
- GDAL

Windows

Three libraries can be installed with pip or downloaded at Unofficial Windows Binaries for Python Extension Packages

5.2 Test the model

Windows and Linux

python <modelpath>/cwatm.py

The output should be:

```
Running under platform:  Windows  **(or Linux etc)**
CWatM - Community Water Model
Authors: ...
Version: ...
Date: ...
Arguments list:
settings.ini     settings file
-q --quiet       output progression given as .
-v --veryquiet   no output progression is given
-l --loud        output progression given as time st
-c --check       input maps and stack maps are check
-h --noheader    .tss file have no header and start
-t --printtime   the computation time for hydrologic
-w --warranty    copyright and warranty information
```

> **Warning:** If python is not set in the environment path, the full path of python has to be used

5.2.1 Error because the python libraries are installed incorrectly

If the model is causing an error at this stage, please check the python libraries:

```
python
import numpy
import scipy.ndimage
import gdal
import netCDF4
```

5.3 Running the model 1

Warning: The model needs a settings file as an argument. See: *Settings file*

python <modelpath>/cwatm.py settingsfile flags

example:

```
python cwatm.py settings_rhine.ini -l
```

The flag -l show the output on screen as date and discharge

At this point you should receive this eror message:

```
======================== CWATM FILE ERROR ===========================
Cannot find option file: d:/work/CWATM/source/metaNetcdf.xml In  "metaNetcdfFile"
searching: "d:/work/CWATM/source/metaNetcdf.xml"
path: d:/work/CWATM/source does not exists
```

5.4 Downloading and installing the spatial dataset

The spatial dataset contains:

- static data ie. data that does not change over time (a model assumption) e.g. soil data
- time dependend (inter annual) data that change periodical during a year e.g. crop coefficient of vegetation
- time dependend (intra annual) data that change by month or year e.g. fraction of landcover

These data are stored as global dataset:

- cwat_input.zip for the 30' global version
- cwat_input5min.zip for the 5' global version

As climate data different forcings can be used e.g:

- PGMFD v.2 (Princeton), GSWP3, etc.
- precipitation from e.g. MSWEP http://www.gloh2o.org/
- WATCH+WFDEI https://www.isimip.org/gettingstarted/details/5/

and as projection e.g.:

- ISI-MIP dataset https://www.isimip.org/gettingstarted/#input-data-bias-correction

For the tutorial we cut out Rhine basin and included the WATCH+WFDEI precipitation, average temperature and the calculated potential evaporation .
A 30' and a 5' version can be found on FTP in rhine/climate

Reference:

Weedon, G.P., S.S. Gomes, P.P. Viterbo, W.J. Shuttleworth, E.E. Blyth, H.H. Österle, J.C. Adam, N.N. Bellouin, O.O. Boucher, and M.M. Best, 2011: Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. J. Hydrometeor., 12, 823–848, doi: 10.1175/2011JHM1369.1

Weedon, G. P., G. Balsamo, N. Bellouin, S. Gomes, M. J. Best, and P. Viterbo (2014), The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data, Water Resour. Res., 50, 7505–7514, doi:10.1002/2014WR015638.

Note:

Please copy and unpack the spatial dataset (either 30' or 5')in a folder

Please copy the the climate dataset 30min_meteo_rhine.zip or 5min_meteo_rhine.zip in a seperate folder

Please create a folder called output

5.5 Changing the Settings file

to run the model the pathes to data have to be set correctly: The information of pathes are stored in the settings file around line 80-100

[FILE_PATHS]:

```
PathRoot = E:/
PathOut = $(PathRoot)/output
PathMaps = E:/cwatm_input
PathMeteo = E:/climate
#-------------------------------------
[NETCDF_ATTRIBUTES]
institution = IIASA
title = Global Water Model - WATCH WDFEI
metaNetcdfFile = $(FILE_PATHS:PathRoot)/CWATM/source/metaNetcdf.xml
```

Note: Please change the pathes according to your file system

5.6 Running the model 2

If you type now:

```
python cwatm.py settings_rhine.ini -l
```

You should see:

```
E:\CWATM_rhine\source>python cwatm.py settings_rhine30min.ini -l
CWATM - Community Water Model  Version: 0.991  Date:  16/09/2017
International Institute of Applied Systems Analysis (IIASA)
Running under platform:  Windows
-----------------------------------------------------------
CWATM Simulation Information and Setting
The simulation output as specified in the settings file: settings_rhine30min.ini
```

```
can be found in E:/CWATM_rhine/output
Step         Date   Discharge
1      01/01/1961        4.20
2      02/01/1961        4.23
...
```

If you don't see this. Something went wrong and you mifght see this instead:

```
E:\CWATM_rhine\source>python cwatm.py settings_rhine30min.ini -l
CWATM - Community Water Model  Version: 0.991  Date:  16/09/2017
International Institute of Applied Systems Analysis (IIASA)
Running under platform:  Windows
-----------------------------------------------------------
ERROR 4: `E:/CWATM_rhine/cwatm_input/routing/ldd.map' does not exist in the file␣
↪system,
and is not recognised as a supported dataset name.
management_modules.messages.CWATMFileError:
======================== CWATM FILE ERROR ===========================
In  "Ldd"
searching: "E:/CWATM_rhine/cwatm_input/routing/ldd.map"
path: E:/CWATM_rhine/cwatm_input/routing does not exists
```

The model tries to help you on finding the error.
In this case it is looking for the river network map ldd.map or ldd.nc or ldd.tif
but it cannot find the file and not even the path to the file.

Here you might change:

```
[FILE_PATHS]
PathRoot = E:/CWATM_rhine
PathMaps = $(PathRoot)/cwatm_input
```

or:

```
[TOPOP]
# local drain direction map (1-9)
Ldd = $(FILE_PATHS:PathMaps)/routing/ldd.map
```

But many other error can occure too! Have fun.

5.7 Changing parameters of the model

Note: An overview of possibilities is given in see *Settings file*

_rst_settingdoc

5.8 Changing the Output

5.8.1 Output variables

Output can be every global defined variable in the model Variable are e.g. Precipitation, runoff, baseflow

but also not so common variables as:

- reservoirStorage (amount of water in the reservoirs in [m3])
- nonIrrReturnFlowFraction (returnflow from domenstic and industrial water use [m3])
- actualET[1] (actual evapotranspiration from grassland [m/day])
- ...

5.8.2 Daily, monthly - at the end or average

- per day
- total month, average month, end of month
- total year, average year, end of year
- total average, total at the end

for example

```
[OUTPUT]
# OUTPUT maps and timeseries
OUT_Dir = $(FILE_PATHS:PathOut)
OUT_MAP_Daily = discharge, runoff
OUT_MAP_MonthAvg = Precipitation
OUT_MAP_TotalEnd = lakeStorage
OUT_MAP_TotalAvg = Tavg

OUT_TSS_Daily = discharge
OUT_TSS_AnnualAvg = Precipitation
```

Note: For each variable the meta data information can be defined in *Output Meta NetCDF information*

Note: For information how to adjust the output in the settings file see *Output*

Demo of the model

6.1 Resolution

CWATM can be run globally at 0.5° or separately for any basin or any clipping of a global map.
Depending on the data provided the model can also run for any other resolutions (e.g. 5 arcmin).
Timestep is daily, output of maps, time series can be daily, monthly, yearly

Here some outputs of the global run on 0.5° are shown:

6.2 Demo 1 - NetCDF videos

6.2.1 Global discharge

One year run example: 1/1/1991- 31/12/1992

6.2.2 Global potential evaporation [mm/day]

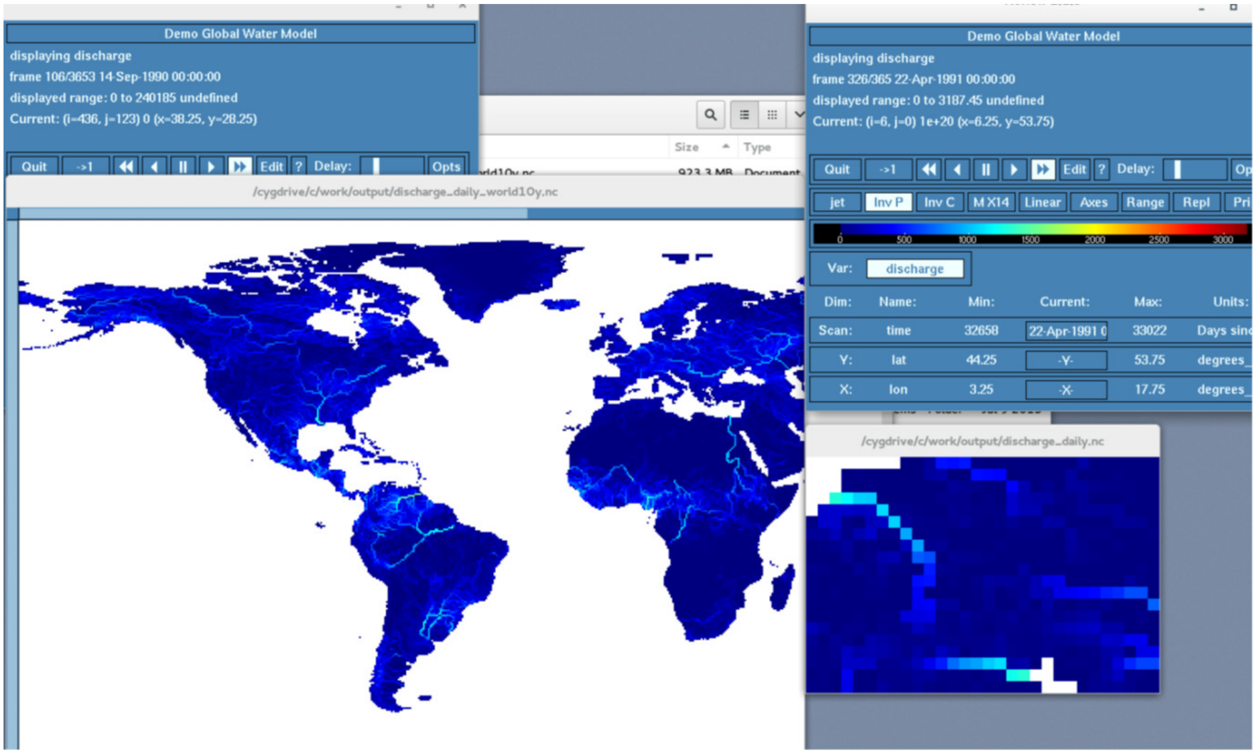
One year run example

6.2.3 Global soil moisture [mm/mm]

One year run example

6.3 Demo 2 - NcView output

Global discharge as world map
Output from NcView



6.4 Demo 3 - NcView timeserie

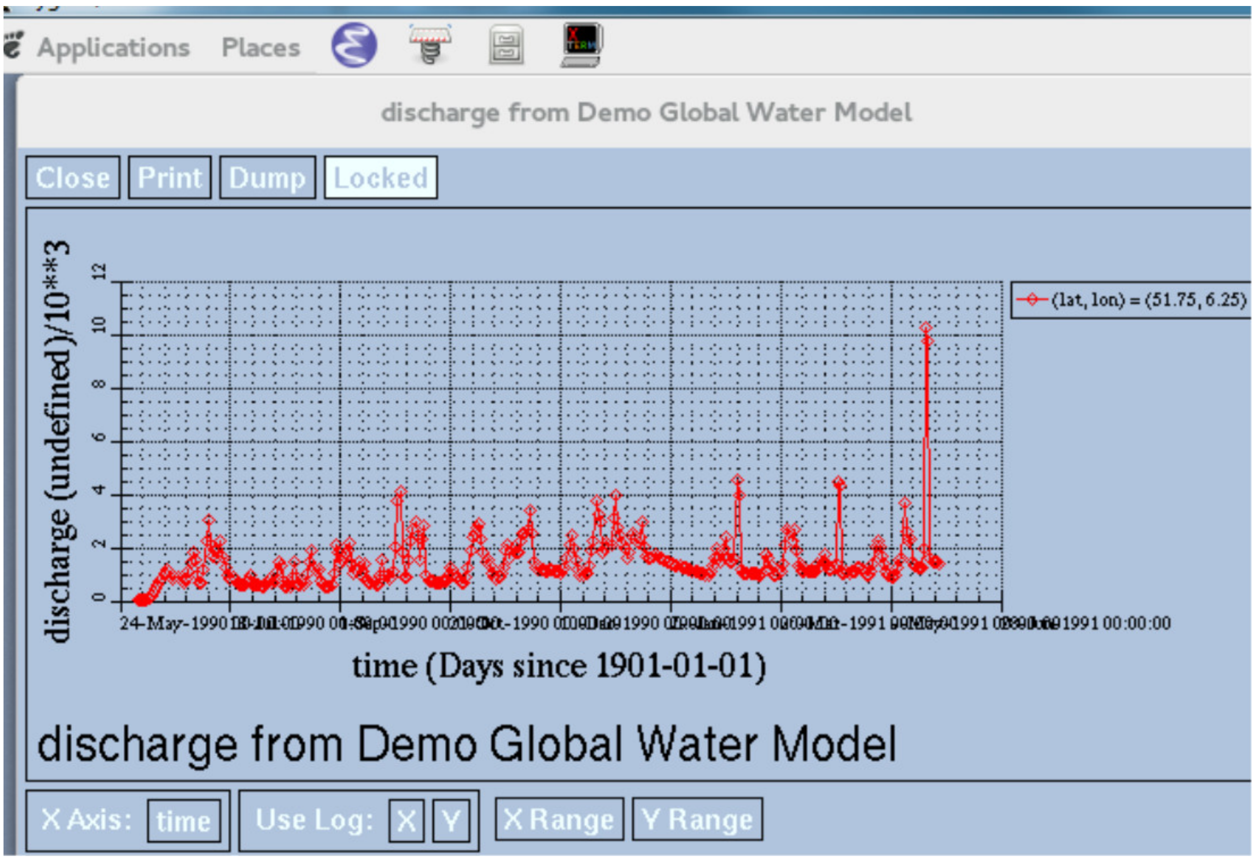
Discharge as timeseries
Output from NcView

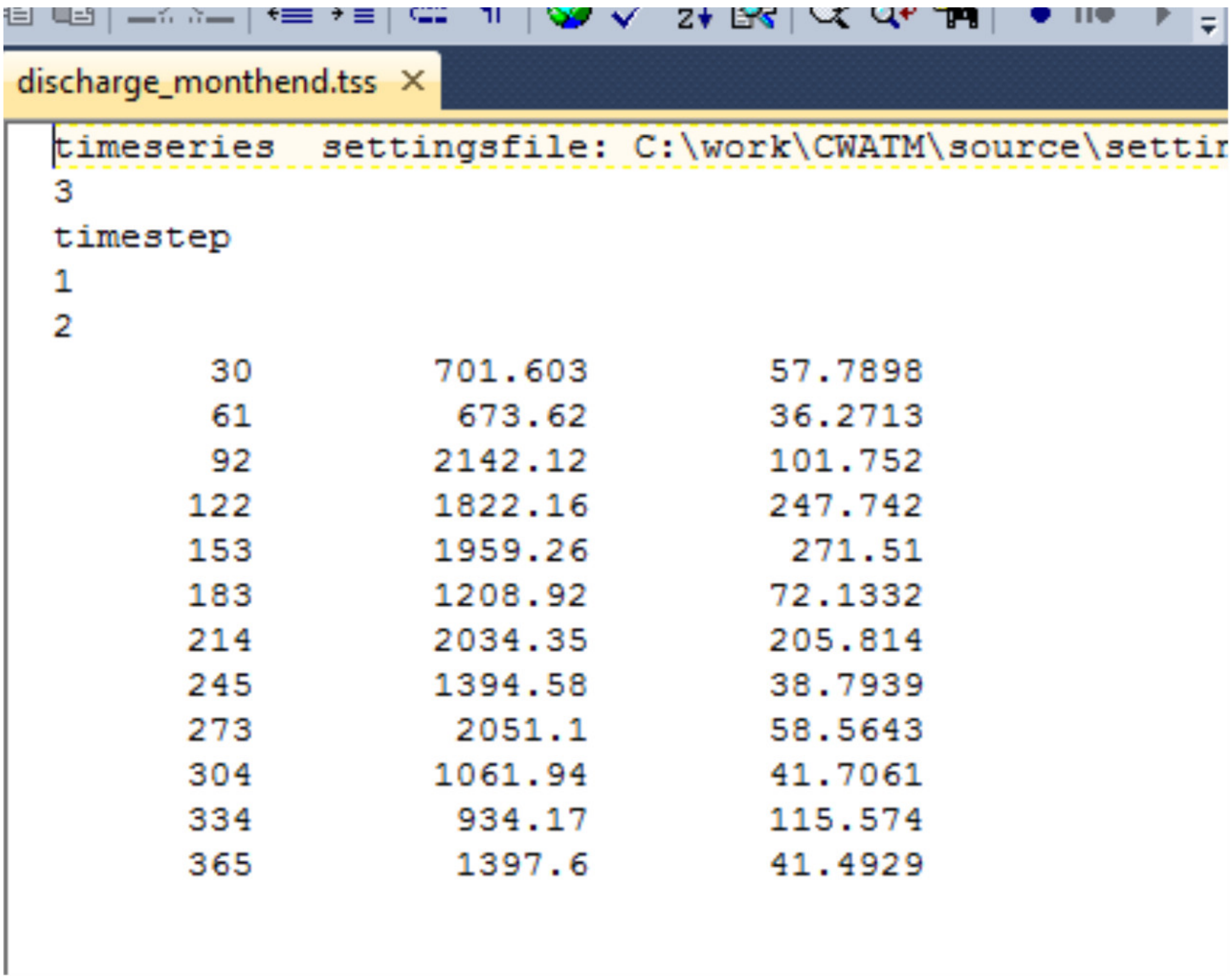
6.5 Demo 4 - Monthly timeserie

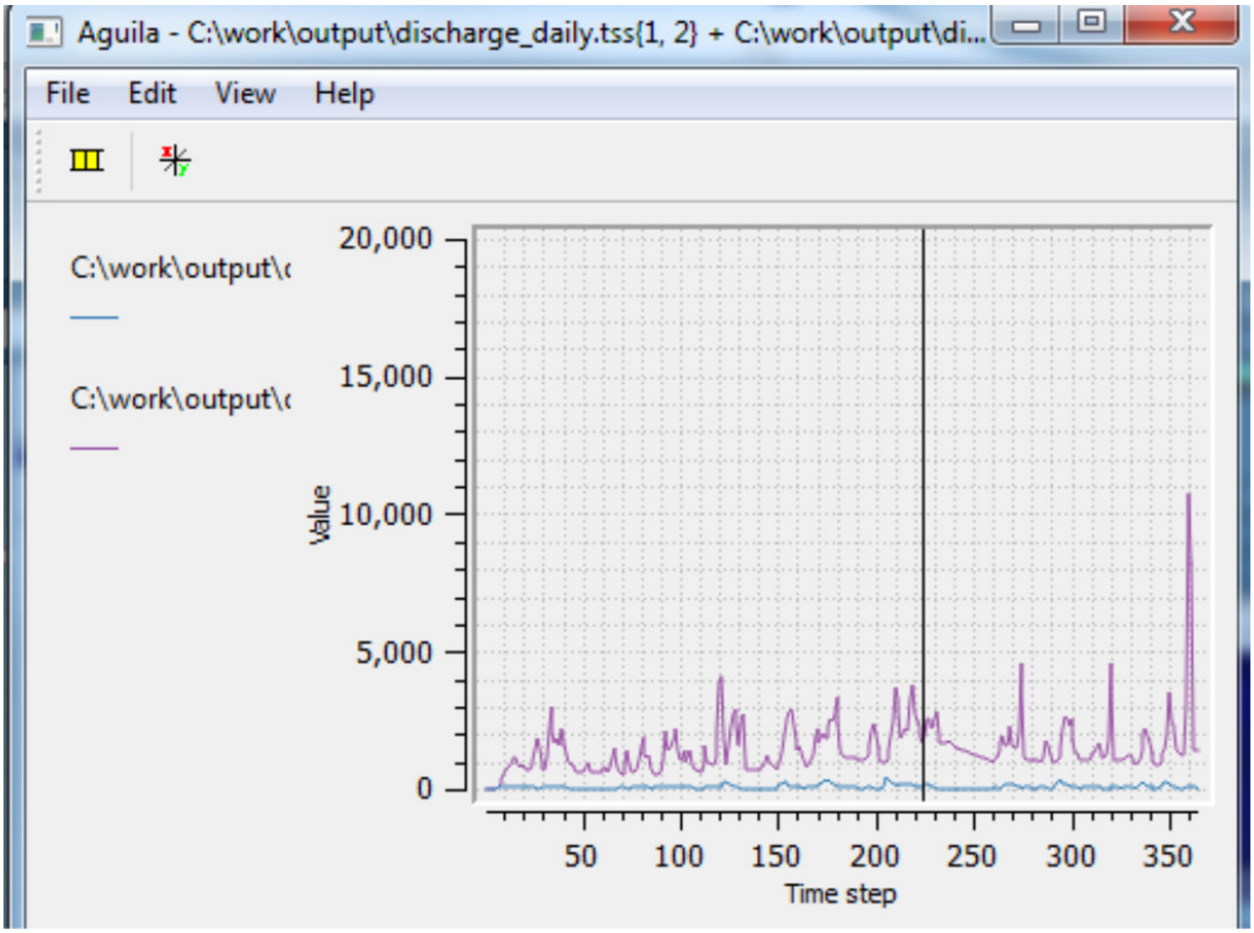
Discharge as monthly timeseries

6.6 Demo 5 - PCRaster Aguila output

Discharge as timeseries Output from PCRaster Aquila


Applications
Places
discharge from Demo Global Water Model
Close
Print
Dump
Locked
discharge (undefined)/10**3
(lat, lon) = (51.75, 6.25)
time (Days since 1901-01-01)
discharge from Demo Global Water Model
X Axis:
time
Use Log:
X
Y
X Range
Y Range


discharge_monthend.tss
timeseries settingsfile: C:\work\CWATM\source\settir
3
timestep
1
2
30 701.603 57.7898
61 673.62 36.2713
92 2142.12 101.752
122 1822.16 247.742
153 1959.26 271.51
183 1208.92 72.1332
214 2034.35 205.814
245 1394.58 38.7939
273 2051.1 58.5643
304 1061.94 41.7061
334 934.17 115.574
365 1397.6 41.4929


Aguila - C:\work\output\discharge_daily.tss{1, 2} + C:\work\output\di...
File
Edit
View
Help
C:\work\output\
C:\work\output\
20,000
15,000
10,000
5,000
0
Value
50
100
150
200
250
300
350
Time step

CHAPTER 7

The Model Itself

Contents

7.1 Performance

Computational run time (on a linux single node - 2400 MHz with Intel Xeon CPU E5- 2699A v4):

Daily timestep on 0.5 deg

Global: 100 years in appr. 12h = 7.2min per year

	Process	sum % runtime
1	Read Meteo Data	6.2
2	Et pot	7.6
3	Snow	8.8
4	Soil	59.4
5	Groundwater	59.5
6	Runoff conc	70.1
7	Lakes	70.4
8	Routing	95.5
9	Output	100

For the global setting, soil processes with 50% computing time is the most time consuming part, followed by routing with 25% and runoff concentration with 10%.

Rhine: 640 years in appr. 4.5h = 0.4min per year

	Process	sum % runtime
1	Read Meteo Data	79.4
2	Et pot	80.5
3	Snow	80.9
4	Soil	88.8
5	Groundwater	88.9
6	Runoff conc	89.6
7	Lakes	89.8
8	Routing	99.6
9	Output	100

For the Rhine basin reading input maps 79% is by far the most time consuming process, followed by routing (kinematic wave) 10% and the soil processes (8%)

7.2 Updates

Most recent updates on top

25/09/2017

- bugfix on snow modul
- added additional evaporation from open water (transition loss in channels)

7.2.1 20/08/2017

- improved water demand modul
- added small lakes and reservoirs

7.2.2 24/06/2017

- added netcdf read module - now the netcdf does not need to be merged before - abilitity to read in a stack of netcdf files
- added inflow to a catchment - inflow is given as text file

7.2.3 25/05/2017

- added new soil scheme based on Arno scheme

7.2.4 27/03/2017

- included license term GNU V3 in cwatm.py and globals.py

7.2.5 26/03/2017

- added documentation for autodocu for a lot of subroutines

7.3 Bug and bugfix report

This is the only and first source code without bugs Really!

Hey really!!

7.3.1 Ok some exceptions:

7.4 TODO

7.4.1 Structural improvements

Note: This has to be done. Importance: 1 to be changed first .. 3 to be changed later

Topic	TODO	Description	Importance	DONE
Documentation	Documentation	start writing a user manual	1	.
Documentation	Source code documentation	Improve comment-lines in the code and include them in the autodocu sphinx	1	.
Documentation	Include log file/change log	document the changes in the code/settings	2	.
Output	GAMS output	output/input in GAMS (gdx -files)	2	.
Output	Extent output possibilities	Output as e.g. yearly areatotal, catchment total as maps, as time series	1	.
Handling	Improve error handling	more messages for users if something goes wrong	1	.
Handling	Checks maps	include a pre-run, where input data are checked for plausibility	2	.
Handling	Load multiple netcd files	read meteo input netcdf from split files	2	.

7.4.2 Model improvements

TODO	Description	Importance	DONE
Frost	include frost routine (no soil movement during strong frost)	1	X
Snow	include more than 3 vertical layers (make it flexible)	2	X
Runoff concentration	include a 1st routing to the edge of a grid cell	1	X
Include water & sealed land cover	include 2 more land cover types (water covered area, sealed area)	1	X
Preferential flow	include preferential flow to soil layers	1	X
Calculate Evaporation on PM	include Penman Monteith ET routine	1	X
Reduce reading of time series maps	e.g. interception maps only 1 per month	2	X
Kinematic wave	Add C++ kinematic wave procedure	2	X
soil depend on land cover	include hydropedo transfer function landcover -> soil	2	.
Improve lakes& reservoirs	Add another way of including lakes/reservoirs	2	X
Inflow points	add points where water can be added/substracted	1	X
Include Environmental flow	use environmental flow concept on the fly not only post-processing	2	X
Water allocation	include water demand <-> water supply functionality	2-3	.
Include EPIC approach	to be in line with ESM include the EPIC approach	3	.

CHAPTER 8

Data

Contents

8.1 Data requirements

8.2 Data format

In general data format is netCDF (version3 or version4)

For the mask map (to define the area of calculation) or the stations (to define the time series outputs) in can be either netCDF, Geotiff or PCRaster maps

8.3 Data storage structure

```
project
|-  README.txt
|
--areamaps
|    - maskmap, stationmap
|
--landcover
|    ---forest
|    |    |-  CropCoefficientForest_10days
|    |    |-  interceptcapForest10days
|    |    |-  maxRootdepth, minSoilDepthFrac
|    |    -  rootFraction1, rootFraction2
|    |
|    ---grassland (same var as forest)
|    |
|    ---irrNonPaddy (same var as forest)
|    |
|    ---irrPaddy (same var as forest)
|
---landsurface
|    |- fractionlandcover, global_clone
|    |
|    ---albedo
|    |    - albedo
|    |
|    ---topo
|    |    - dz_Rel_hydro1k, elvstd , tanslope
|    |
|    ---waterDemand
|        - domesticWaterDemand, industryWaterDemand, irrigationArea, efficiency
|
---soil
|    - alpha, forest_alpha, lamdba, forest_lambda, ksat, forest_ksat, thetas, forest_
↪thetas, thetar, forest_thetar
|    -cropgrp
|
---groundwater
|    - kSatAquifer, recessionCoeff, specificYield
|
---routing
    |- ldd, catchment, cellarea
    |
    ---kinematic
    |    - chanbnkf, chanbw, changrad, chanleng, chanman
    |
    ---lakereservoirs
        - lakeResArea, lakeResDis,lakeResID, lakeResType, lakeResVolRes, lakeResYear,
        - smallLakesRes, smalllakesresArea, smalllakesresDis, smallwatershedarea
```

8.4 Static data

8.4.1 Mask map

- mask map or coordinates to model only regions or catchments
- maps or coordinates for station to print time series

8.4.2 Landsurface

Albedo

Global Albedo dataset from Muller et al., (2012) http://www.globalbedo.org

Digital elevation model and river channel network

The model uses a digital elevation model and its derivate (e.g. standards deviation, slope) as variables for the snow processes and for the routing of surface runoff. The Shuttle Radar Topography Mission - SRTM (Jarvis et al., 2008) is used for latitudes <= 60 deg North and DEM Hydro1k (US Geological Survey Center for Earth Resources Observation and Science)is used for latitudes > 60 deg North CWATM uses a local drainage direction map which defines the dominant flow direction in one of the eight neighboring grid cells (D8 flow model). This forms a river network from the springs to the mouth of a basin. To be compliant with the ISIMIP framework the 0.5 deg drainage direction map (DDM30) of (Döll and Lehner, 2002) is used. For higher resolution e.g. 5' different sources of river network maps are available e.g. HydroSheds (Lehner et al., 2008) – DRT (Wu et al., 2011) and CaMa-Flood (Yamazaki et al., 2009). These approaches uses the same hydrological sound digital elevation model but differ in the upscaling methods. Fang et al. (2017) shows the importance of routing schemes and river networks in peak discharge simulation.

8.4.3 Soil and soil hydraulic properties

Soil textural data were derived from the ISRIC SoilGrids1km database http://www.isric.org/explore/soilgrids (Hengl et al. 2014). Pedotransfer functions applied on 1km soil texture data - originating from the HYPRES database (Wösten et al. 1999) were used to obtain the Mualem - VanGenuchten soil hydraulic parameters for soil water transport modeling in the soil module.

8.4.4 Water demand

8.4.5 Groundwater

GLHYMPS—Global Hydrogeology Maps of permeability and porosity http://crustalpermeability.weebly.com/data-sources.html (Gleeson et al., 2014)

Lakes and Reservoirs

The HydroLakes database http://www.hydrosheds.org/page/hydrolakes (Bernhard Lehner et al., 2011; Messager, Lehner, Grill, Nedeva, & Schmitt, 2016) provides 1.4 million global lakes and reservoirs with a surface area of at least 10ha. CWATM differentiate between big lakes and reservoirs which are connected inside the river network and smaller lakes and reservoirs which are part of a single grid cell and part of the runoff concentration within a grid cell. Therefore the HydroLakes database is separated into "big" lakes and reservoirs with an area 100 km2 or a upstream area 5000 km2 and "small" lakes which represents the non-big lakes. All lakes and reservoirs are combined at grid cell level but big lakes can have the expansion of several grid cells. Lakes bigger than 10000 km2 are shifted according to the ISIMIP protocol.

8.5 Temporal data for each year

8.5.1 Crop coefficient

Based on: MIRCA2000—Global data set of monthly irrigated and rainfed crop areas around the year 2000. http://www.uni-frankfurt.de/45218023/MIRCA (Portmann et al., 2010)

8.5.2 Land cover

Land cover is used to calculate fraction of water, forest, irrigated area, rice irrigated area, sealed (impermeable area) and the remaining fraction for each cell. For each fraction the soil module runs separately. The total runoff of each cell is calculated by weighting the cell according to the different fractions.

Source: https://lta.cr.usgs.gov/GLCC (US Geological Survey Center for Earth Resources Observation and Science)

8.6 Continous temporal data

8.6.1 Meteorological data

- max, min, avg temperature [K]
- humidity (relative[%] or specific[%])
- surface pressure [Pa]
- radiation (short wave and long wave downwards) [W m-2]
- windspeed [m/s]

If potential evaporation is already calculated in a prerun or from external source

- Precipitation [Kg m-2 s-1] or [m] or [mm] (can be adjusted by a conversion factor in the settings file)
- Temperature (avg) [K]
- Potential evaporation [Kg m-2 s-1] or [m] or [mm] (can be adjusted by a conversion factor in the settings file)

From observation: (see ISI-MIP 2a)

- WFDEI.GPCC (Weedon et al. 2014) WFD—Watch forcing data set: 0.5 3/6 hourly meteorological forcing from ECMRWF reanalysis (ERA40) bias-corrected and extrapolated by CRU TS and GPCP (rainfall) and corrections for under catch
- PGMFD v.2 - Princeton (Sheffield et al. 2006),
- GSWP3 (Kim et al.)
- MSWEP (Beck et al. 2017) .

From Global Circulation models GCMs (see ISI-Mip 2b)

- HadGem2-ES (Met Office Hadley Centre, UK)
- IPSL-CM5A-LR (Institut Pierre-Simon Laplace, France)

- GFDL-ESM2M (NOAA, USA)
- MIROC-ESM-CHEM (JAMSTEC, AORI, University of Tokyo, NIES, Japan)
- NorESM1-M (Norwegian Climate Centre, Norway)

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Calibration tool

Calibration tool for hydrological models
in ../CWATM/calibration

using a distributed evolutionary algorithms in python: DEAP library
http://deap.readthedocs.io/en/master/
https://github.com/DEAP/deap/blob/master/README.md

Félix-Antoine Fortin, François-Michel De Rainville, Marc-André Gardner, Marc Parizeau and Christian Gagné, "DEAP: Evolutionary Algorithms Made Easy", Journal of Machine Learning Research, vol. 13, pp. 2171-2175

The calibration tool was created by Hylke Beck 2014 (JRC, Princeton) hylkeb@princeton.edu
Thanks Hylke for making it available for use and modification
Modified by Peter Burek

The submodule Hydrostats was created 2011 by:
Sat Kumar Tomer (modified by Hylke Beck)
Please see his book Python in Hydrology

9.1 Calibration method

Calibration is using an evolutionary computation framework in Python called DEAP (Fortin et al., 2012). We used the implemented evolutionary algorithm NSGA-II (Deb et al., 2002) for single objective optimization. As objective function we used the modified version of the Kling-Gupta Efficiency (Kling et al., 2012), 2012), with r as the correlation coefficient between simulated and observed discharge (dimensionless), β as the bias ratio (dimensionless) and γ as the variability ratio.

$KGE' = 1 - \sqrt{(r-1)^2) + (\beta - 1)^2 + (\gamma - 1)^2}$
where: $\beta = \frac{\mu_s}{\mu_o}$ and $\gamma = \frac{CV_s}{CV_o} = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$

Where CV is the coefficient of variation, μ is the mean streamflow [m3 s1] and σ is the standard deviation of the streamflow [m3 s1]. KGE', r, β and γ have their optimum at unity. The KGE' measures the Euclidean distance from the ideal point (unity) of the Pareto front and is therefore able to provide an optimal solution which is simultaneously good for bias, flow variability, and correlation. For a discussion of the KGE objective function and its advantages over the often used Nash–Sutcliffe Efficiency (NSE) or the related mean squared error see (Gupta et al., 2009). The calibration uses general a population size (μ) of 256, a recombination pool size (λ) of 32.The number of generations was set to 30, which we found was sufficient to achieve convergence for stations

9.1.1 Further ideas for calibration

- Regionalization see (Samaniego et al. 2017) and (Beck et al. 2016)
- Using Budyko see (Greve et al. 2016)

9.2 Calibration parameters

Snow
1. Snowmelt coefficient in [m/C deg/day] as a degree-day factor
Evapotranspiration
2. Crop factor as an adjustment to crop evapotranspiration
Soil
3. Soil depth factor: a factor for the overall soil depth of soil layer 1 and 2
4. Preferential bypass flow: empirical shape parameter of the preferential flow relation
5. Infiltration capacity parameter: empirical shape parameter b of the ARNO model
Groundwater
6. Interflow factor: factor to adjust the amount which percolates from interflow to groundwater
7. Recession coefficient factor: factor to adjust the base flow recession constant (the contribution from groundwater to baseflow)
Routing
8. Runoff concentration factor: a factor for the concentration time of run-off in each grid-cell
9. Channel Manning's n factor: a factor roughness in channel routing
10. Channel, lake and river evaporation factor: factor to adjust open water evaporation
Reservoir & lakes
11. Normal storage limit: the fraction of storage capacity used as normal storage limit
12. Lake A factor : factor to channel width and weir coefficient as a part of the Poleni weir equation

9.3 Calibration tool structure

```
calibration
|-  readme.txt
|-  readme.txt
|
--observed_data
|   - lobith2006.cvs, ...
|
--templates
|   -- runpy.bat, runpy.sh
|   -- settings.ini
```

9.4 How it works

The calibration tool builds up a single-objective obtimization framework using the Python libray DEAP For each run it triggers the run of the hydrological model:

- using a template of the settings file
- replacing the output folder in this template file
- replace placeholders with the values of calibration parameters, the limit of the parameter range is given in the file: ParamRanges.csv

After each run the model run is compared to observed values (e.g. observed_data/lobith2006.csv)

After the calibration, statistics and the best run is printed output

9.5 What is needed

1. The template files in ../templates have to be adjusted

- runpy.bat: the path to cwatm.py have to be set correctly (for linux a .sh file has to be created)
- The actual version of a cwatm settings file has to modified:
- replacing the output folder with the placeholder: %run_rand_id

```
#-------------------------------------------------------
# CALIBARTION PARAMETERS
#-------------------------------------------------------
[CALIBRATION]

# These are parameter which are used for calibration
# could be any parameter, but for an easier overview, tehey are collected here
# in the calibration template a placeholder (e.g. %arnoBeta) instead of value

OUT_Dir = %run_rand_id
```

- putting the output variables in e.g. OUT_TSS_Daily = discharge or monthly average discharge OUT_TSS_MonthAvg = discharge

```
OUT_TSS_Daily = discharge
OUT_TSS_MonthAvg = discharge
```

- delete all the output variables in the template (mostly at the end of the file)
- replacing calibration parameter values with a placeholder: e.g. %SnowMelt

```
# Snow  SnowMeltCoef = 0.004
SnowMeltCoef = %SnowMelt
# Cropf factor correction
crop_correct =  %crop
#Soil
soildepth_factor = %soildepthF
#Soil preferentialFlowConstant = 4.0, arnoBeta_factor = 1.0
preferentialFlowConstant = %pref
arnoBeta_add = %arnoB
# interflow part of recharge factor = 1.0
```

```
factor_interflow = %interF
# groundwater recessionCoeff_factor = 1.0
recessionCoeff_factor = %reces
# runoff concentration factor runoffConc_factor = 1.0
runoffConc_factor = %runoff
#Routing manningsN factor [0.1 - 10.0] default  1.0
manningsN = %CCM
# reservoir  normal storage limit (fraction of total storage, [-]) [0.15 - 0.85]␣
↪default 0.5
normalStorageLimit = %normalStorageLimit
# lake parameter - factor to alpha: parameter of of channel width and weir␣
↪coefficient  [0.33 - 3.] dafault 1.
lakeAFactor = %lakeAFactor
# lake wind factor - factor to evaporation from lake [0.8 - 2.] dafault 1.
lakeEvaFactor = %lakeEvaFactor
```

2. the range of parameter space has to be defined in ParamRanges.csv

```
ParameterName,MinValue,MaxValue
SnowMelt,0.001,0.007
crop,0.8,3.0
soildepthF, 0.8,1.8
pref,0.5,8
arnoB,0.01,1.0
interF, 0.33,3.0
reces,0.1,10
runoff,0.1,5
CCM,0.1,10.0
normalStorageLimit,0.15,0.85
lakeAFactor,0.333,3.0
lakeEvaFactor,0.5,3.0
No,1,100
```

3. The observed discharge has to be provided in an .cvs file e.g. observed_data/lobith2006.csv

In the template settings the date has to be set, so that the period of observed discharge is between SpinUp and StepEnd

```
#-------------------------------------------------------
[TIME-RELATED_CONSTANTS]
#-------------------------------------------------------

# StepStart has to be a date e.g. 01/06/1990
# SpinUp or StepEnd either date or numbers
# SpinUp: from this date output is generated (up to this day: warm up)

StepStart = 1/1/1990
SpinUp = 1/1/1995
StepEnd =  31/12/2010
```

4. And empty ../catchments directory needs to be created

5. A few option in the settings.txt have to be adjusted (how many runs?, a first run with standard parameters? etc)

```
[DEFAULT]
Root = /c/watmodel/CWATM
RootPC = C:/watmodel/CWATM
Rootbasin = calibration_rhine

ForcingStart = 1/1/2000
ForcingEnd = 31/12/2010
timeperiod = daily

[ObservedData]
Qtss = observed_data/lobith.csv
Column = lobith
Header = River: Rhine  station: Lobith

[Validate]
Qtss = observed_data/lobith_val.csv
ValStart = 1/1/1990
ValEnd = 31/12/1999


[Path]
Templates = templates
SubCatchmentPath = catchments
ParamRanges = ParamRanges.csv

[Templates]
ModelSettings = settings.ini
RunModel = runpy.sh

[Option]
firstrun = False
para_first = [0.0022, 1.72, 1.24, 7.07, 0.55, 1.92, 2.81, 0.74,1.34,0.35,2.04,1.0, 1.]
# Snowmelt, crop KC, soil depth,pref. flow, arno beta, interflow factor, groundwater␣
↪recession,
# runoff conc., routing, manning factor, normalStorageLimit,␣
↪lakeAFactor,lakeEvaFactor,No of run
bestrun = True

[DEAP]
maximize = True
use_multiprocessing = 1
ngen = 30
mu = 256
lambda_ = 32
```

6. run python calibration_single.py settings.txt

9.6 Recommondations

1. Run the model first to store the pot. evaporation results

Afterwards use the stored evaporation to run the calibration
calc_evaporation = False

2. Run the model and store the last day to be used as initial condition for the calibration runs

Best is to use a long term run for this.

```
[INITITIAL CONDITIONS]
#-------------------------------------------------------

# for a warm start initial variables a loaded
# e.g for a start on 01/01/2010 load variable from 31/12/2009
load_initial = False
initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc

# saving variables from this run, to initiate a warm start next run
# StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
save_initial = False
initSave = $(FILE_PATHS:PathRoot)/init/Rhine
StepInit = 31/12/1989 31/12/2010
```

load_initial = False
save_initial = True

During calibration use:
load_initial = True
save_initial = False

3. Use a long SpinUp time (> 5 years to give groundwater enough time)

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Model download

Contents

10.1 GNU General public license

Version 3, 29 June 2007

10.1.1 Preamble

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The "source code" for a work means the preferred form of the work for making modifications to it. "Object code" means any non-source form of a work.

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We as developers belief that CWATM should be utilize to encourage ideas and to advance hydrological, environmental science and stimulate integration into other science disciplines.

CWATM is based on existing knowledge of hydrology realized with Python and C++. Especially ideas from HBV, PCR-GLOBE, LISFLOOD, H08, Matsiro are used for inspiration.

Your support is more then welcome and highly appreciated

The developers of CWAT Model

10.2 Download

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Source code on Github repository of CWATM

10.2.2 Global dataset

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