# Community Water Model

# CWATM Documentation
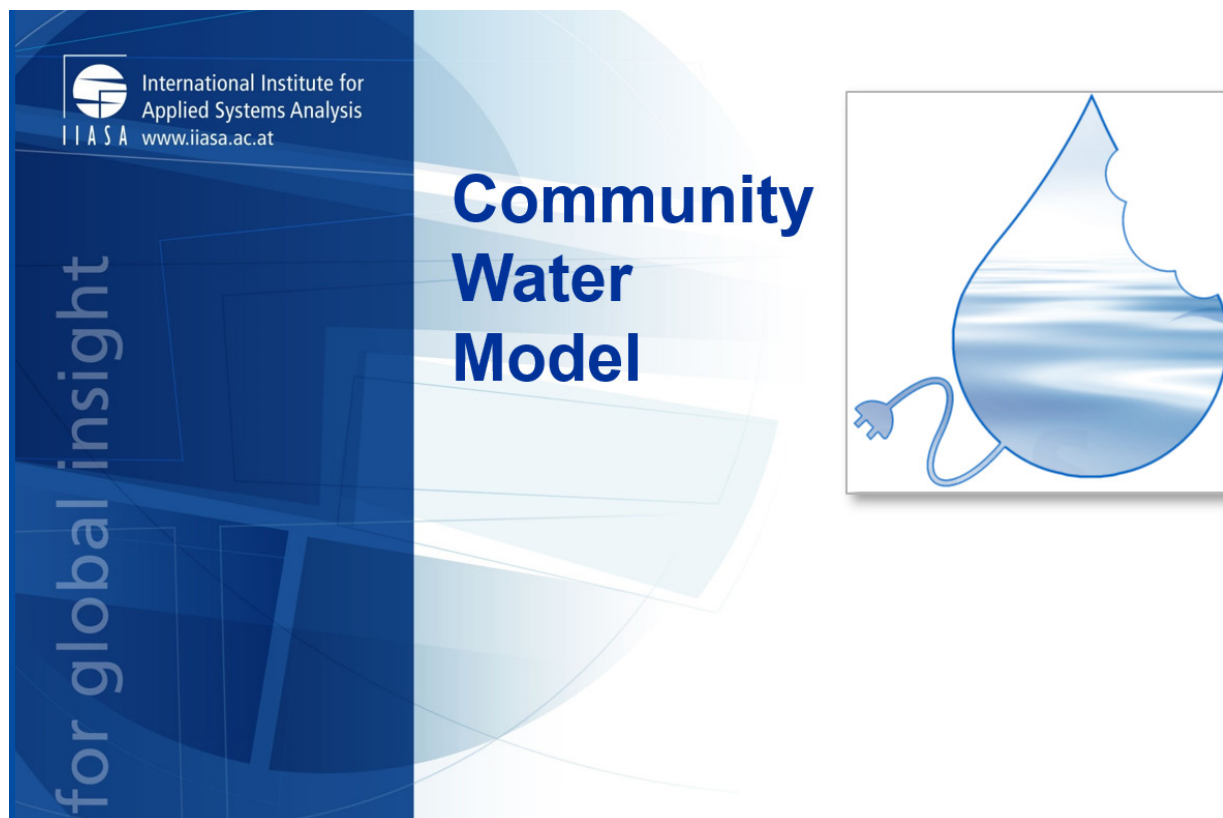
*Release 1*

**Peter Burek, IIASA WAT**

**Jan 04, 2019**

**Copyright** IIASA WAT Program

**Authors** *Peter Burek, Yusuke Satoh, Peter Greve*

**Version** 0.03

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**Content:**

# 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.

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**Download pdf**

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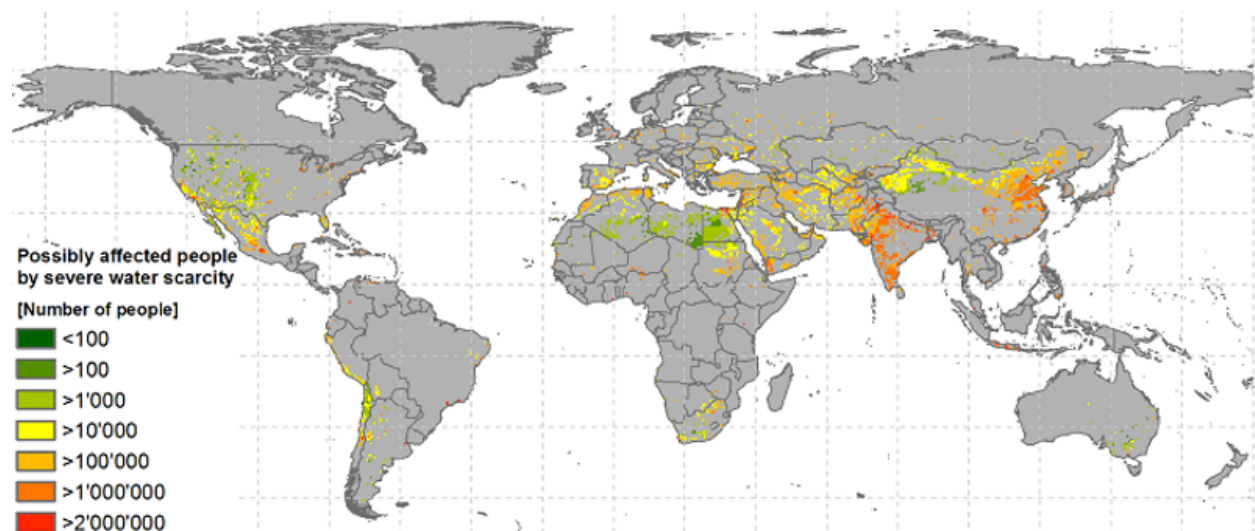
Figure 1: Potential population under severe water scarcity in 2050 - Middle of the Road Scenario - WFAS fast-track analysis

### 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
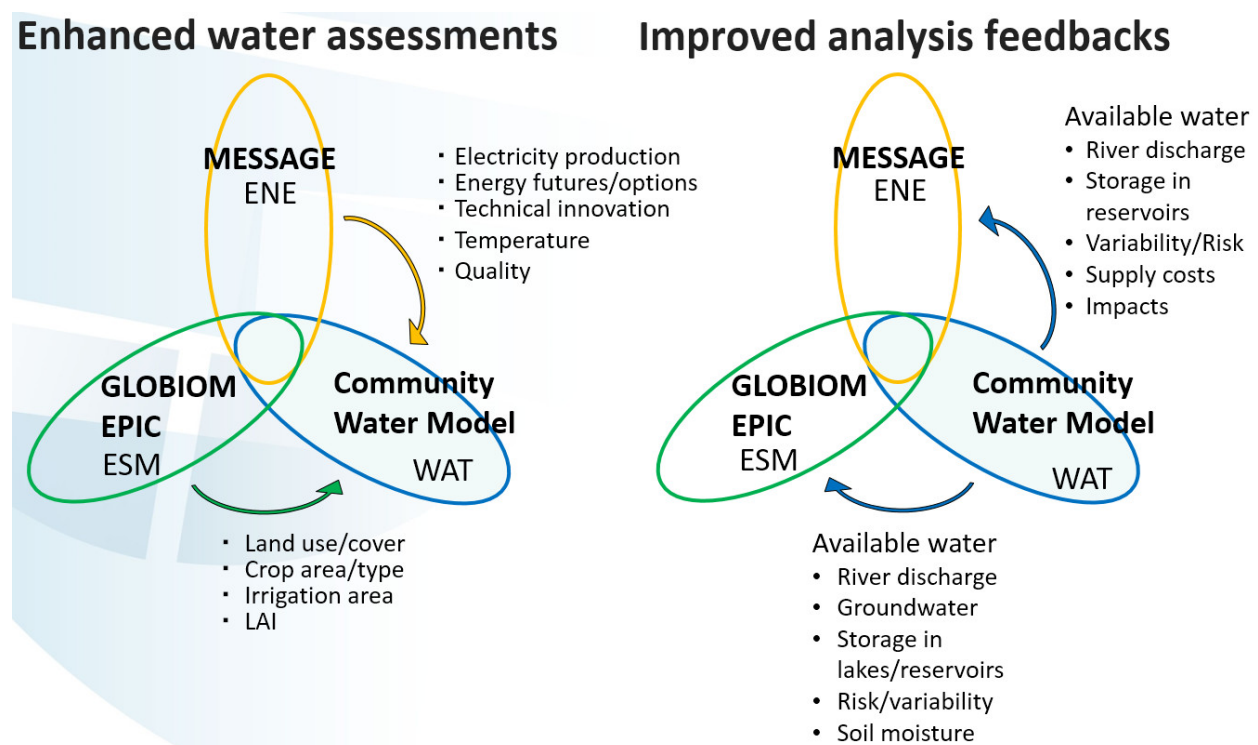


Figure 2: IIASA model interactions

### 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.
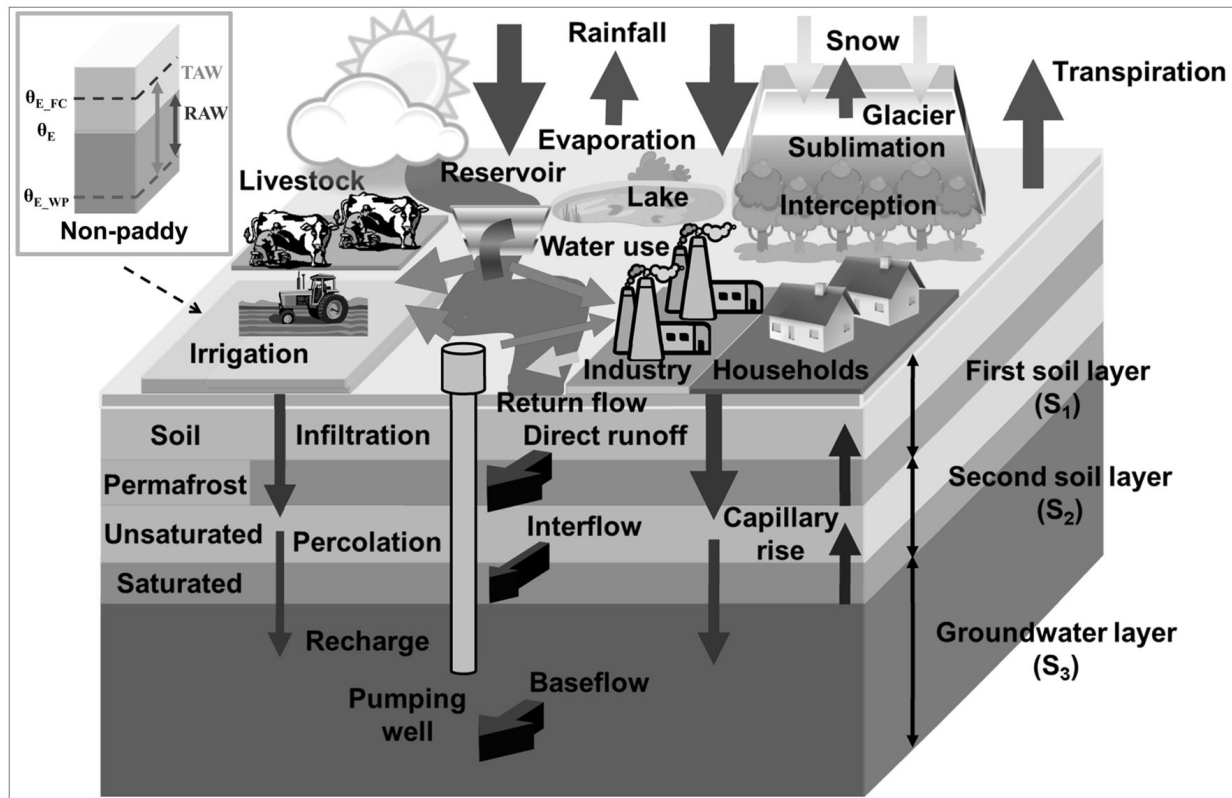


Figure 3: CWATM - Water related processes included in the model design

### 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

# 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

# Setup of the model

**Contents**

# 4.1 Setup

## 4.1.1 Requirements

**Python version**

NEW from 2019 on: Requirements are a 64 bit Python 3.7.x version

Reason for this step:

- Python 2.7 support ends in 2019

- We will be able to provide a better error handling

- We are able to provide an executable of CWATM for Windows

---

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

---

> **Warning:** From 2019 on we are changing to Python 3.7. We do not provide further support for Python 2.7

## Libraries

These external libraries are needed:

- Numpy
- Scipy
- netCDF4
- GDAL

**Windows**

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

## Windows executeable Python version

A CWATM executable cwatm.exe can be used instead of the Python version

- It is done with cx_freeze library
- It includes all Libraries
- ADVANTAGE: you can run it without installing or knowledge of Python
- DISADVANTAGE 1: You cannot see the source code or change it
- DISADVANTAGE 2: We do not update this version as often as the Python version

At the moment it is (will be!) stored on our FTP server due to the big size
But we are looking for a better place

## PCRaster

CWATM is not using anymore anything from PCRaster
But the general idea of PCraster to split the modules in a initial part and a dynamic part
is still used

Anyway PCRaster is still a great tool
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

## 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*

**Note:** A compiled version is already provided for Windows and Linux.

**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 library used with Windows is named *t5.dll*, if you generate a library *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

> **Warning:** Please use the right version of CWATM with the right version of Python (either 2.7 or 3.7)

## 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

```
1  ######## ##             ##  ####  ######  ##     ##
2  ##      ##             ## ## ##    ##    ####  ####
3  ##      ##            ## ## ##    ##    ## #### ##
4  ##      ##    ##    ## ########  ##  ##   ##   ##
5  ##       ## #### ##   ##     ##  ##  ##        ##
```

```
6    ##           ####  #### ##        ## ## ##            ##
7    ##########  ##     ## ##          ## ## ##            ##
8
9    # 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

```
15   [OPTIONS]
16   #-------------------------------------------------------
17   # OPTION - to switch on/off
18   #-------------------------------------------------------
19
20   # Data otions
21   # if temperature is stored in Kelvin instead Celsius
22   TemperatureInKelvin = True
23   # if lat/lon the area has to be user defined = precalculated
24   gridSizeUserDefined = True
25
26   #-----------------------------------------------
27   # Evaporation: calculate pot. evaporation (True) or use precalculated pot.evaporation␣
     ↪map stacks (False)
28   calc_evaporation = False
29
30   #-----------------------------------------------
31   # Irrigation and water demand
32
33   # if irrigation is included, otherwise paddy and non paddy is put into 'grassland'
34   includeIrrigation = True
35   # if water demand from irrigation, industry and domestic is included
36   includeWaterDemand = False
37   # Water allocation
38   # if water demand and availability is calculated for region to compare demand vs.␣
     ↪avail
39   usingAllocSegments = False
40   # limit abstraction to available groundwater (True) include fossil groundwater (False)
41   limitAbstraction = False
42
43   # Environmental Flow
44   calc_environflow = False
45   use_environflow = False
46
47   #-----------------------------------------------
48   # Soil
49   # use preferential flow, that bypasses the soil matrix and drains directly to the␣
     ↪groundwater (not for irrPaddy)
50   preferentialFlow = False
51   # Capillar rise
52   CapillarRise = True
53
54   #-----------------------------------------------
55   # Routing
56
```

```
57    # if runoff concentration to the edge of a cell is included
58    includeRunoffConcentration = True
59    # Waterbodies like lakes and reservoirs
60    includeWaterBodies = True
61    # kinematic wave routing, if False no routing is calculated
62    includeRouting = True
63
64    #-----------------------------------------------
65    # Inflow from outside of the modelled area
66    inflow = False
67
68    # --- Reporting & Debugging ------------------ --------------------------------------
      ↪--------
69    # Reporting options
70    writeNetcdfStack = True
71    reportMap = True
72    reportTss = True
73    # Checking water balance (for debugging)
74    calcWaterBalance = False
75    sumWaterBalance = False
76    # use additional PCRaster GIS commands
77    PCRaster = False
78
79
80
81
82
83
84    #---------------------------------------------------------
85    # 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

```
102   [NETCDF_ATTRIBUTES]
103   institution = IIASA
104   title = Global Water Model - WATCH WDFEI
105   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

---

```
88    #---------------------------------------------------------
89    [FILE_PATHS]
90    #---------------------------------------------------------
91    PathRoot = E:/CWATM_rhine
92
```

---

```
93  PathOut = $(PathRoot)/output
94  PathMaps = $(PathRoot)/cwatm_input
95  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

```
108  # AREA AND OUTLETS
109  #-------------------------------------------------------
110  [MASK_OUTLET]
111
112  # Area mask
113  # A pcraster map, tif or netcdf map e.g.  $(FILE_PATHS:PathRoot)/data/areamaps/area_
     →indus.map
114  # or a retancle: Number of Cols, Number of rows, cellsize, upper left corner X, upper
     →left corner Y
115  MaskMap = $(FILE_PATHS:PathRoot)/source/rhine30min.tif
116  #MaskMap = 14 12 0.5 5.0 52.0
117
118
119  #-------------------------------------------------------
120  # Station data
121  # either a map e.g. $(FILE_PATHS:PathRoot)/data/areamaps/area3.map
122  # or a location coordinates (X,Y) e.g. 5.75 52.25 9.25 49.75 )
123  # Lobith/Rhine
124  Gauges = 6.25 51.75
125
126  # if .tif file for gauges, this is a flag if the file is global or local
127  # e.g. Gauges = $(FILE_PATHS:PathRoot)/data/areamaps/gaugesRhine.tif
128  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

```
130  #--------------------------------------------------------
131  [TIME-RELATED_CONSTANTS]
132  #--------------------------------------------------------
133
134  # StepStart has to be a date e.g. 01/06/1990
135  # SpinUp or StepEnd either date or numbers
136  # SpinUp: from this date output is generated (up to this day: warm up)
137
138  StepStart = 1/1/1990
139  SpinUp =  1/01/1995
140  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

---

```
145  #--------------------------------------------------------
146  [INITITIAL CONDITIONS]
147  #--------------------------------------------------------
148
149  # for a warm start initial variables a loaded
150  # e.g for a start on 01/01/2010 load variable from 31/12/2009
151  load_initial = False
152  initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc
153
154  # saving variables from this run, to initiate a warm start next run
155  # StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
156  save_initial = False
157  initSave = $(FILE_PATHS:PathRoot)/init/Rhine
158  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

---

```
335  # Topography - tangent slope, slope length
336  tanslope = $(PathTopo)/tanslope.map
337  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:

```
279   #---------------------------------------------------------
280   [SNOW]
281   #---------------------------------------------------------
282
283   # Number of vertical Snow layers
284   NumberSnowLayers = 7
285   # up to which layer the ice melt is calculated with the middle temperature
286   GlacierTransportZone = 3
287
288   # Temperature lapse rate with altitude [deg C / m]
289   TemperatureLapseRate = 0.0065
290   # Multiplier applied to precipitation that falls as snow
291   SnowFactor = 1.0
292   # Range [m C-1 d-1] of the seasonal variation, SnowMeltCoef is the average value
293   SnowSeasonAdj = 0.001
294   # Average temperature at which snow melts
295   TempMelt =1.0
296   # Average temperature below which precipitation is snow
297   TempSnow = 1.0
298   # Snow melt coefficient: default: 4.0
299   # SRM: 0.0045 m/C/day ( = 4.50 mm/C/day), Kwadijk: 18 mm/C/month (= 0.59 mm/C/day)
300   # See also Martinec et al., 1998.
301
302   # use in CALIBRATION -> copied to CALIBRATION
303   #SnowMeltCoef = 0.004
304   IceMeltCoef  = 0.007
305
306   #---------------------------------------------------------------
307   # INITIAL CONDITIONS - Initial snow depth in snow zone 1-7 [mm]  - SnowCoverIni
308
309   [FROST]
310   # Snow water equivalent, (based on snow density of 450 kg/m3) (e.g. Tarboton and␣
      ↪Luce, 1996)
311   SnowWaterEquivalent = 0.45
312   # Daily decay coefficient, (Handbook of Hydrology, p. 7.28)
313   Afrost = 0.97
314   # Snow depth reduction coefficient, [cm-1], (HH, p. 7.28)
315   Kfrost = 0.57
316   # Degree Days Frost Threshold (stops infiltration, percolation and capillary rise)
317   # Molnau and Bissel found a value 56-85 for NW USA.
318   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:

```xml
<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.
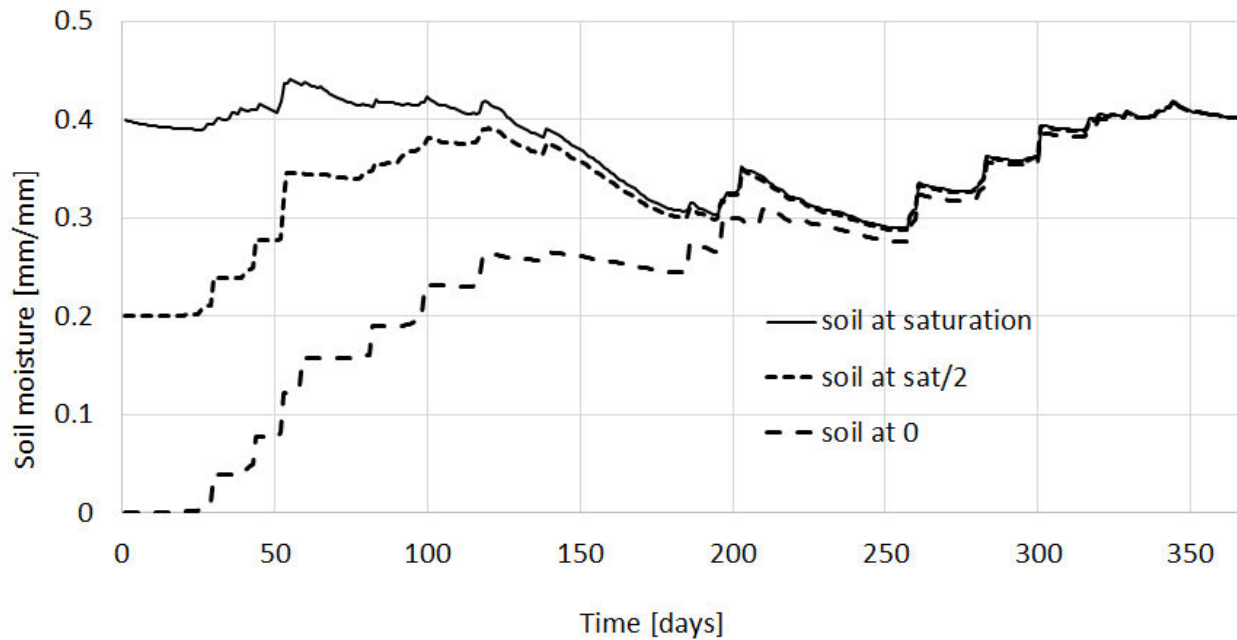


Figure: Simulation of soil moisture in the lower soil with different initial conditions

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.
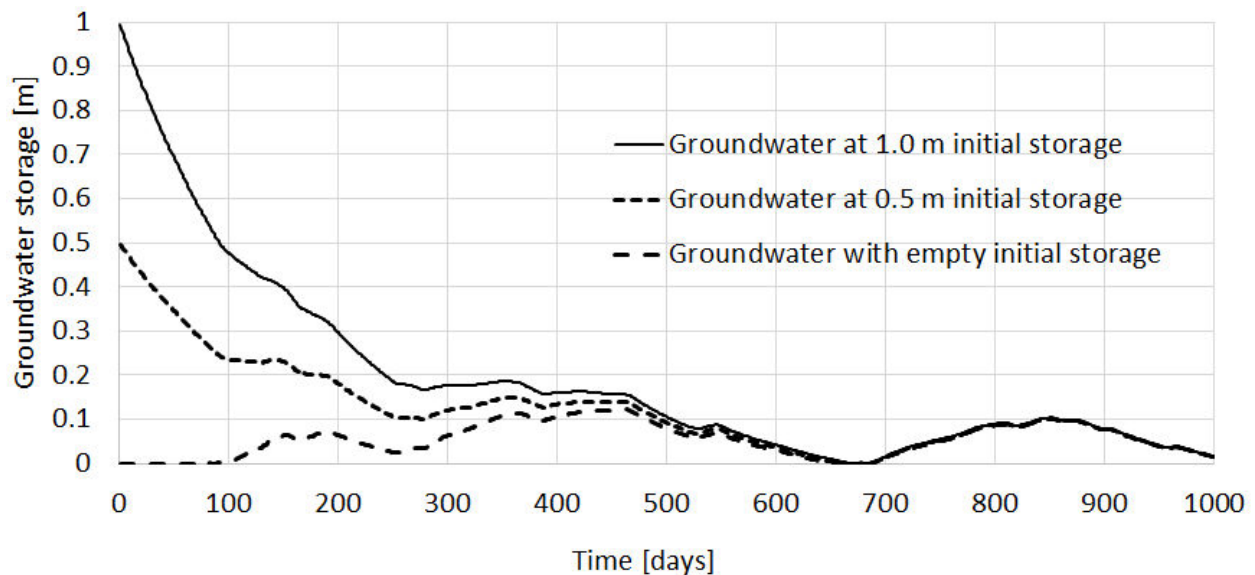


Figure: Simulation of groundwater storage with different initial conditions

## 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**

```
145  #---------------------------------------------------
146  [INITITIAL CONDITIONS]
147  #---------------------------------------------------
148
149  # for a warm start initial variables a loaded
150  # e.g for a start on 01/01/2010 load variable from 31/12/2009
151  load_initial = False
152  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

```
154  # saving variables from this run, to initiate a warm start next run
155  # StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
156  save_initial = False
157  initSave = $(FILE_PATHS:PathRoot)/init/Rhine
158  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

---

```
145  #-------------------------------------------------------
146  [INITITIAL CONDITIONS]
147  #-------------------------------------------------------
148
149  # for a warm start initial variables a loaded
150  # e.g for a start on 01/01/2010 load variable from 31/12/2009
151  load_initial = False
152  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*

## 4.6.5 Most important output variables - a selection

```
#Variable name     : Description
discharge          : river discharge
runoff             : runoff
Precipitation      : rainfall + snow
Tavg               : average temperature
ETRef: potential   : evaporation from reference soil
sum_gwRecharge     : total groundwater recharge
totalET            : total actual evapotranspiration
baseflow           : baseflow from groundwater
... (to be continued)
```

## 4.6.6 Output variables - starting a list

A list of variables can be produced by using:

grep -d recurse 'self.var.' *.py

Every self.var.variable can be used as output variable

For a description of the variable please take a look at the python module itself.

As output variable please use without self.var.

```
#Python_modul              Variable_name
capillarRise.py            self.var.capRiseFrac
evaporationPot.py          self.var.AlbedoCanopy
evaporationPot.py          self.var.AlbedoSoil
evaporationPot.py          self.var.AlbedoWater
evaporationPot.py          self.var.ETRef
```

```
evaporationPot.py        self.var.EWRef
evaporation.py           self.var.potBareSoilEvap
evaporation.py           self.var.snowEvap
evaporation.py           self.var.SnowMelt
evaporation.py           self.var.potBareSoilEvap
evaporation.py           self.var.cropKC[No]
evaporation.py           self.var.totalPotET[No]
evaporation.py           self.var.potTranspiration[No]
groundwater.py           self.var.recessionCoeff
groundwater.py           self.var.specificYield
groundwater.py           self.var.kSatAquifer
groundwater.py           self.var.storGroundwater
groundwater.py           self.var.baseflow
interception.py          self.var.interceptCap[No]
interception.py          self.var.interceptStor[No]
interception.py          self.var.availWaterInfiltration[No]
interception.py          self.var.potTranspiration[No]
interception.py          self.var.actualET[No]
lakes_reservoirs.py      self.var.waterBodyID
lakes_reservoirs.py      self.var.waterBodyOut
lakes_reservoirs.py      self.var.lakeArea
lakes_reservoirs.py      self.var.lakeDis0
lakes_reservoirs.py      self.var.lakeAC
lakes_reservoirs.py      self.var.lakeEvaFactor
lakes_reservoirs.py      self.var.reslakeoutflow
lakes_reservoirs.py      self.var.lakeVolume
lakes_reservoirs.py      self.var.lakeStorage
lakes_reservoirs.py      self.var.lakeInflow
lakes_reservoirs.py      self.var.lakeOutflow
lakes_reservoirs.py      self.var.reservoirStorage
lakes_reservoirs.py      self.var.lakeResStorage
lakes_reservoirs.py      self.var.sumlakeResInflow
lakes_reservoirs.py      self.var.sumlakeResOutflow
lakes_res_small.py       self.var.smalllakeArea
lakes_res_small.py       self.var.smalllakeDis0
lakes_res_small.py       self.var.smalllakeA
lakes_res_small.py       self.var.smalllakeFactor
lakes_res_small.py       self.var.smalllakeVolumeM3
lakes_res_small.py       self.var.smallevapWaterBodyStorage
landcoverType.py         self.var.coverTypes
landcoverType.py         self.var.totalET
landcoverType.py         self.var.actSurfaceWaterAbstract
landcoverType.py         self.var.minInterceptCap
landcoverType.py         self.var.interceptStor[No]
landcoverType.py         self.var.sum_interceptStor
landcoverType.py         self.var.minCropKC
landcoverType.py         self.var.maxGWCapRise
... (to be continued)
```

# Tutorial

**Contents**

## 5.1 Requirements

### 5.1.1 Requirements

### Python version

NEW from 2019 on: Requirements are a 64 bit Python 3.7.x version

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

> **Warning:** From 2019 on we are changing to Python37. We do not provide further support for Python 2.7

### Libraries

These external libraries are needed:

- Numpy
- Scipy
- netCDF4
- GDAL

**Windows**

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

### Windows executeable Python version

A CWATM executable cwatm.exe can be used instead of the Python version

## 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
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*

---

## 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*

---

### 5.8.3 Most important output variables - a selection

```
#Variable name     : Description
discharge          : river discharge
runoff             : runoff
Precipitation      : rainfall + snow
Tavg               : average temperature
ETRef: potential   : evaporation from reference soil
sum_gwRecharge     : total groundwater recharge
totalET            : total actual evapotranspiration
baseflow           : baseflow from groundwater
... (to be continued)
```

### 5.8.4 Output variables - starting a list

A list of variables can be produced by using:

grep -d recurse 'self.var.' *.py

Every self.var.variable can be used as output variable

For a description of the variable please take a look at the python module itself.

As output variable please use without self.var.

```
#Python_modul            Variable_name
capillarRise.py          self.var.capRiseFrac
evaporationPot.py        self.var.AlbedoCanopy
evaporationPot.py        self.var.AlbedoSoil
evaporationPot.py        self.var.AlbedoWater
evaporationPot.py        self.var.ETRef
evaporationPot.py        self.var.EWRef
evaporation.py           self.var.potBareSoilEvap
evaporation.py           self.var.snowEvap
evaporation.py           self.var.SnowMelt
evaporation.py           self.var.potBareSoilEvap
evaporation.py           self.var.cropKC[No]
evaporation.py           self.var.totalPotET[No]
evaporation.py           self.var.potTranspiration[No]
groundwater.py           self.var.recessionCoeff
groundwater.py           self.var.specificYield
groundwater.py           self.var.kSatAquifer
groundwater.py           self.var.storGroundwater
groundwater.py           self.var.baseflow
interception.py          self.var.interceptCap[No]
interception.py          self.var.interceptStor[No]
interception.py          self.var.availWaterInfiltration[No]
interception.py          self.var.potTranspiration[No]
interception.py          self.var.actualET[No]
lakes_reservoirs.py      self.var.waterBodyID
lakes_reservoirs.py      self.var.waterBodyOut
lakes_reservoirs.py      self.var.lakeArea
lakes_reservoirs.py      self.var.lakeDis0
lakes_reservoirs.py      self.var.lakeAC
lakes_reservoirs.py      self.var.lakeEvaFactor
lakes_reservoirs.py      self.var.reslakeoutflow
```

```
lakes_reservoirs.py      self.var.lakeVolume
lakes_reservoirs.py      self.var.lakeStorage
lakes_reservoirs.py      self.var.lakeInflow
lakes_reservoirs.py      self.var.lakeOutflow
lakes_reservoirs.py      self.var.reservoirStorage
lakes_reservoirs.py      self.var.lakeResStorage
lakes_reservoirs.py      self.var.sumlakeResInflow
lakes_reservoirs.py      self.var.sumlakeResOutflow
lakes_res_small.py       self.var.smalllakeArea
lakes_res_small.py       self.var.smalllakeDis0
lakes_res_small.py       self.var.smalllakeA
lakes_res_small.py       self.var.smalllakeFactor
lakes_res_small.py       self.var.smalllakeVolumeM3
lakes_res_small.py       self.var.smallevapWaterBodyStorage
landcoverType.py         self.var.coverTypes
landcoverType.py         self.var.totalET
landcoverType.py         self.var.actSurfaceWaterAbstract
landcoverType.py         self.var.minInterceptCap
landcoverType.py         self.var.interceptStor[No]
landcoverType.py         self.var.sum_interceptStor
landcoverType.py         self.var.minCropKC
landcoverType.py         self.var.maxGWCapRise
... (to be continued)
```

# 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

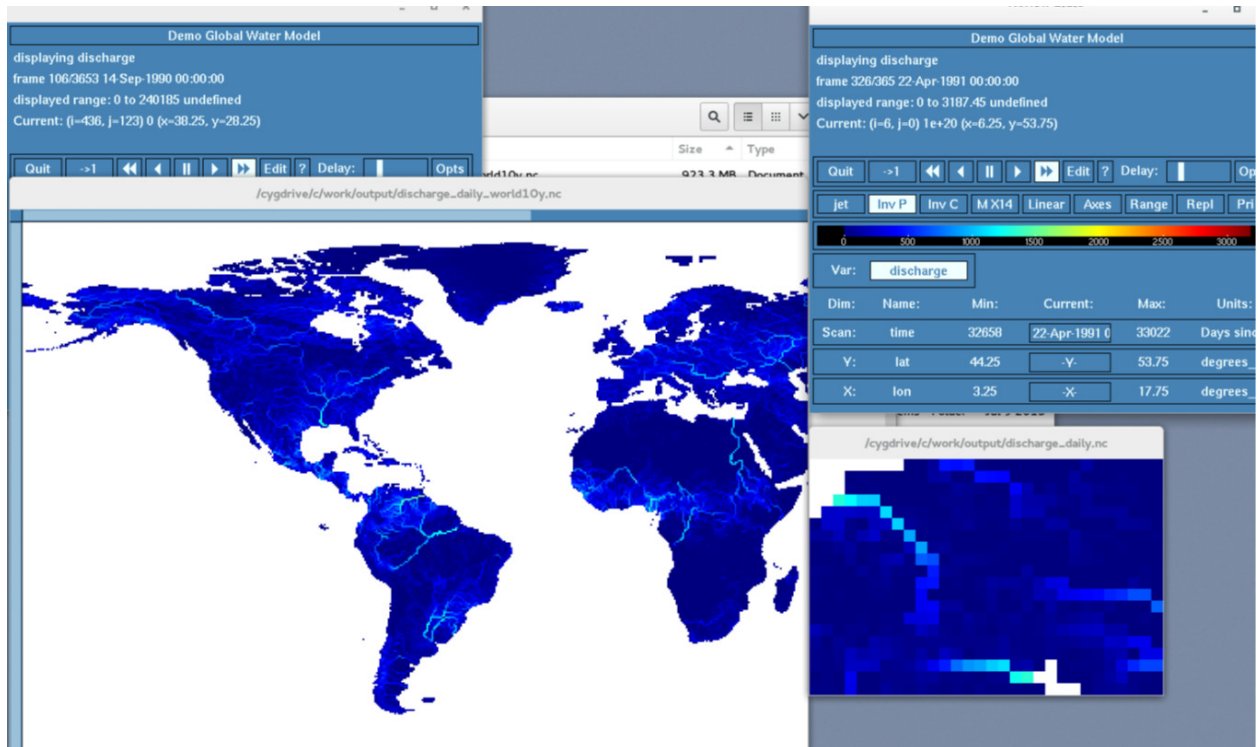### 6.2.2 Global potential evaporation [mm/day]

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
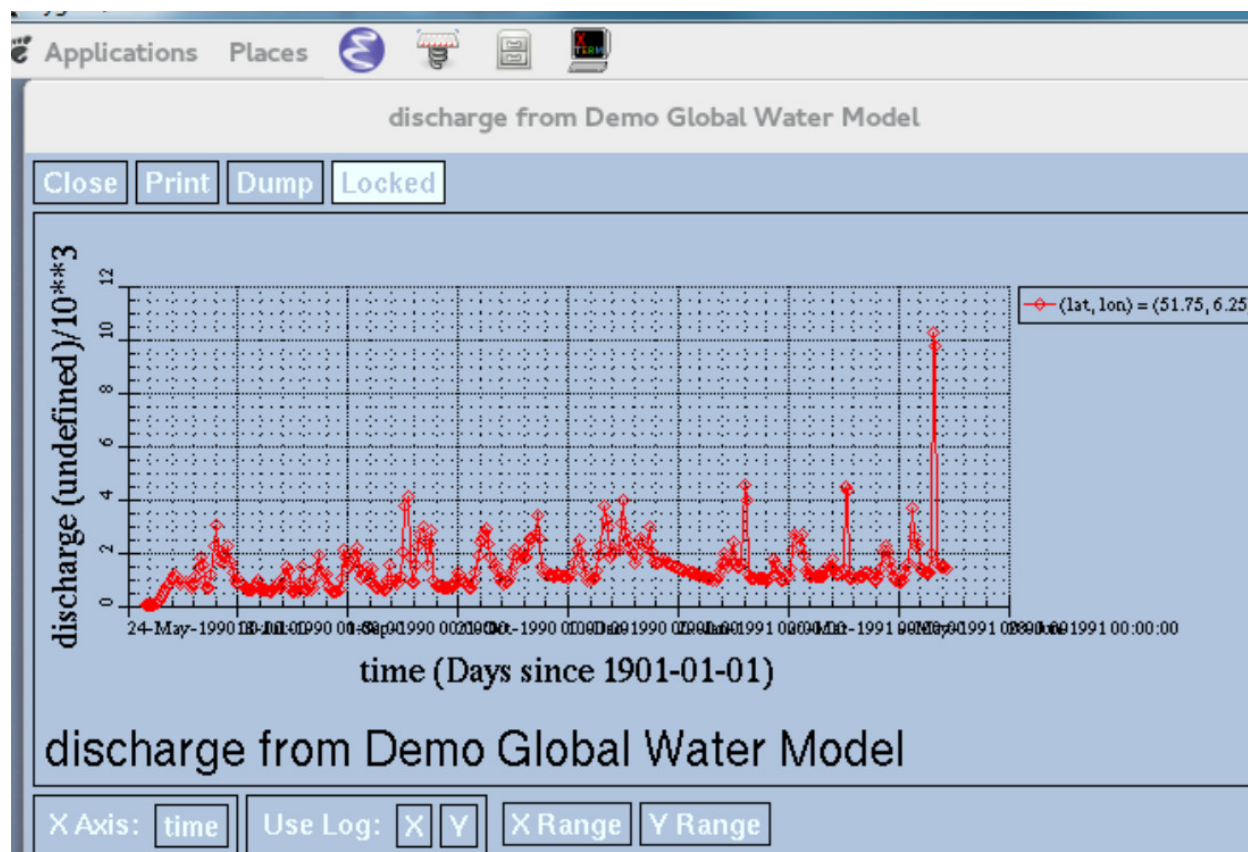
## 6.4 Demo 3 - NcView timeserie
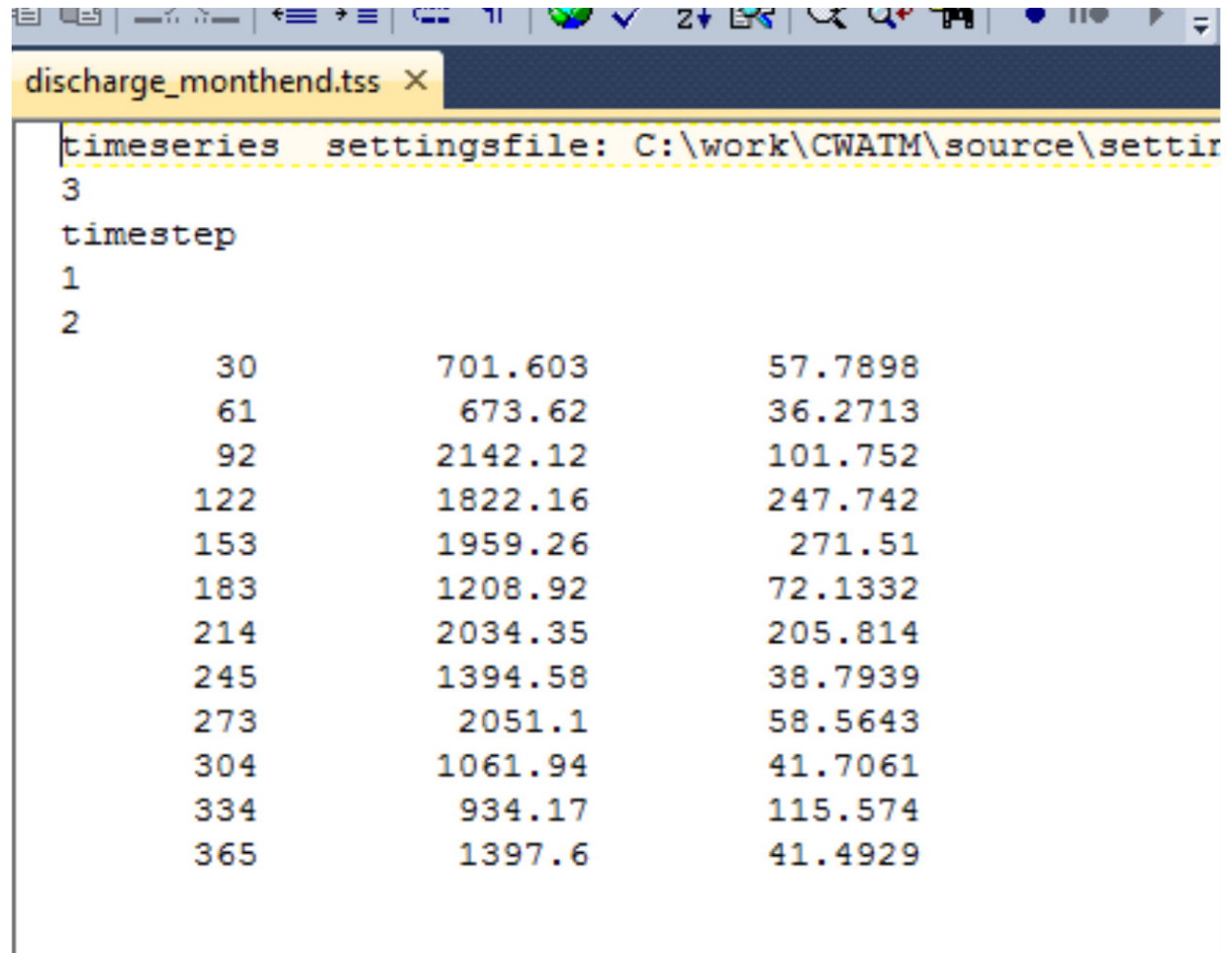
Discharge as timeseries
Output from NcView

## 6.5 Demo 4 - Monthly timeserie

Discharge as monthly timeseries
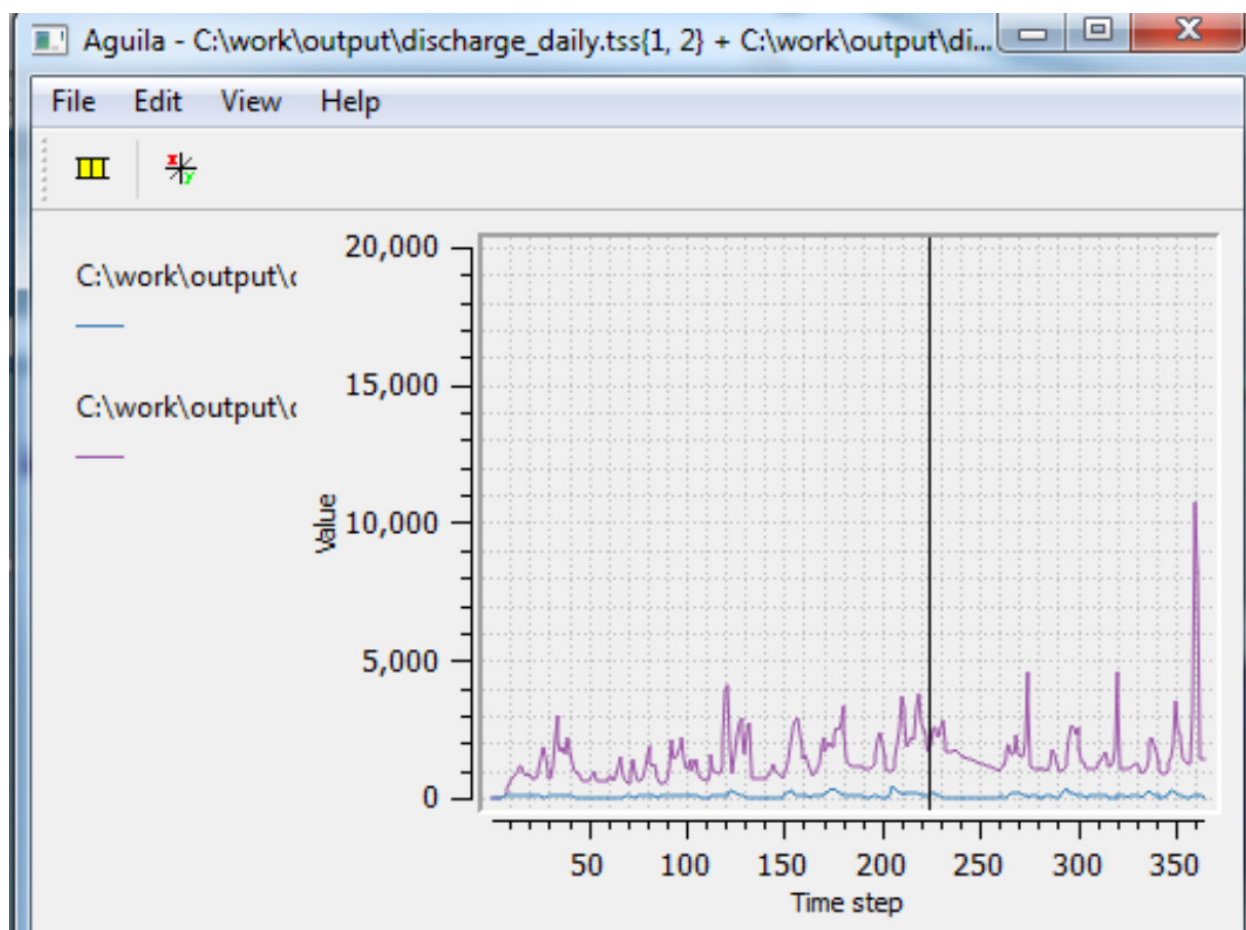
## 6.6 Demo 5 - PCRaster Aguila output

Discharge as timeseries Output from PCRaster Aquila

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
```

# 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**

4/01/2019

- Change to Python 3.7

- added a lot of changes in the mean time please see change track on github

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 - ability 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 | Impor-tance | DONE |
|-------|------|-------------|---------|------|
| Documen-tation | Documentation | start writing a user manual | 1 | . |
| Documen-tation | Source code documentation | Improve comment-lines in the code and include them in the autodocu sphinx | 1 | . |
| Documen-tation | 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 | Impor-tance | 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 | . |

# 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)

## 8.7 References

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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), $\beta$ as the bias ratio (dimensionless) and $\gamma$ 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, $\mu$ is the mean streamflow [m3 s1] and $\sigma$ is the standard deviation of the streamflow [m3 s1]. KGE', r, $\beta$ and $\gamma$ 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 ($\lambda$) 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

```
28  #-------------------------------------------------------
29  # CALIBARTION PARAMETERS
30  #-------------------------------------------------------
31  [CALIBRATION]
32
33  # These are parameter which are used for calibration
34  # could be any parameter, but for an easier overview, tehey are collected here
35  # in the calibration template a placeholder (e.g. %arnoBeta) instead of value
36
37  OUT_Dir = %run_rand_id
```

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

```
38  OUT_TSS_Daily = discharge
39  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

```
42  # Snow  SnowMeltCoef = 0.004
43  SnowMeltCoef = %SnowMelt
44  # Cropf factor correction
45  crop_correct =  %crop
46  #Soil
47  soildepth_factor = %soildepthF
48  #Soil preferentialFlowConstant = 4.0, arnoBeta_factor = 1.0
49  preferentialFlowConstant = %pref
50  arnoBeta_add = %arnoB
51  # interflow part of recharge factor = 1.0
```

```
52   factor_interflow = %interF
53   # groundwater recessionCoeff_factor = 1.0
54   recessionCoeff_factor = %reces
55   # runoff concentration factor runoffConc_factor = 1.0
56   runoffConc_factor = %runoff
57   #Routing manningsN factor [0.1 - 10.0] default  1.0
58   manningsN = %CCM
59   # reservoir  normal storage limit (fraction of total storage, [-]) [0.15 - 0.85]␣
     ↪default 0.5
60   normalStorageLimit = %normalStorageLimit
61   # lake parameter - factor to alpha: parameter of of channel width and weir␣
     ↪coefficient  [0.33 - 3.] dafault 1.
62   lakeAFactor = %lakeAFactor
63   # lake wind factor - factor to evaporation from lake [0.8 - 2.] dafault 1.
64   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

```
1    #---------------------------------------------------------
2    [TIME-RELATED_CONSTANTS]
3    #---------------------------------------------------------
4
5    # StepStart has to be a date e.g. 01/06/1990
6    # SpinUp or StepEnd either date or numbers
7    # SpinUp: from this date output is generated (up to this day: warm up)
8
9    StepStart = 1/1/1990
10   SpinUp = 1/1/1995
11   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.

```
146  [INITITIAL CONDITIONS]
147  #------------------------------------------------------
148
149  # for a warm start initial variables a loaded
150  # e.g for a start on 01/01/2010 load variable from 31/12/2009
151  load_initial = False
152  initLoad = $(FILE_PATHS:PathRoot)/init/Rhine_19891231.nc
153
154  # saving variables from this run, to initiate a warm start next run
155  # StepInit = saving date, can be more than one: 10/01/1973 20/01/1973
156  save_initial = False
157  initSave = $(FILE_PATHS:PathRoot)/init/Rhine
158  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)

## 9.7 References

- Beck, H. E., A. I. J. M. van Dijk, A. de Roo, D. G. Miralles, T. R. McVicar, J. Schellekens and L. A. Bruijnzeel (2016). "Global-scale regionalization of hydrologic model parameters." Water Resources Research 52(5): 3599-3622.

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# Calibration tutorial

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

## 10.1  Calibration method

## 10.2  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

## 10.3 Calibration tool structure

## 10.4 References

- Beck, H. E., A. I. J. M. van Dijk, A. de Roo, D. G. Miralles, T. R. McVicar, J. Schellekens and L. A. Bruijnzeel (2016). "Global-scale regionalization of hydrologic model parameters." Water Resources Research 52(5): 3599-3622.

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## 11.1.3 Terms and Conditions of Use of the Community Water Model

Stipulations regarding the use of the Commumunity Water Model (hereinafter *CWATM*) provided here by the International Institute for Applied System Analysis, Laxenburg, Austria (IIASA) are as follows:

### 1. Copyright

The owners of the copyright of CWATM are Peter Burek, Yoshihide Wada, Yusuke Satoh and Peter Greve (hereinafter the "Developer") at IIASA.

### 2. Reprints and quotations

In the event of the publication of a document or scientific paper using CWATM or its modified version, the following paper must be referenced:

paper is still under work.

At the moment refer to:

Burek, P., Satoh, Y., Greve, P., Kahil, T. and Wada, Y. 2017: The Community Water Model (CWATM) / Development of a community driven global water model. Geophysical Research Abstracts. Vol. 19, EGU2017-9769

### 3. Usage

Usage is regulated by GNU General Public License V3 (see above)

### 4. Final Remarks

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

## 11.2 Download

**Warning:** This is a pre-release alpha version! We will announce the "official" release. But for testing feel free to use it.

### 11.2.1 Download pdf

`CWATM_MANUAL.pdf`

### 11.2.2 Source code - Community Water Model

The source code of CWATM is freely available under the GNU General Public License. Please see its *Terms and Conditions of Use of the Community Water Model*
Source code on Github repository of CWATM

### 11.2.3 Global dataset

If you are interested in obtaining the gloabl data set, please send an email to wfas.info@iiasa.ac.at
We will give you access to our ftp server

### 11.2.4 Contact CWATM

www.iiasa.ac.at/cwatm
wfas.info@iiasa.ac.at

## 11.3 Source code

```
## --------------------------------------------------
######## ##            ##  ####  ######  ##    ##
##       ##            ## ## ##    ##    ####  ####
##        ##           ## ## ##    ##   ## #### ##
##        ##    ##    ## #######  ##  ##   ##   ##
##         ## #### ## ##    ## ## ##         ##
##          #### #### ##     ## ## ##         ##
########## ##     ## ##     ## ## ##         ##
# Community WATer Model
# --------------------------------------------------
```

## 11.3.1 cwatm module

---

**Note:** Inheritance









---
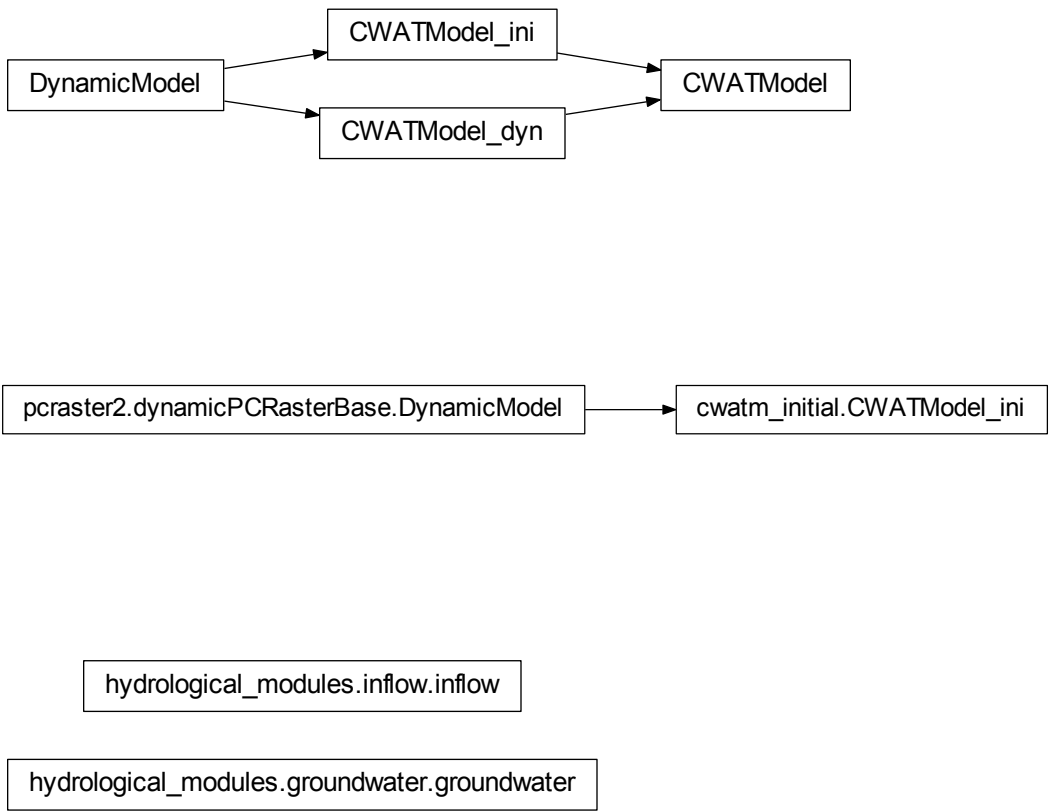
**Note:** Base module: run with settings file e.g. python cwatm.py settings.ini

---

```
## ————————————————————————- ######## ## ## #### ###### ## ## ## ## ## ## ## ## #### #### ## ##
## ## ## ## ## #### ## ## ## ## ## ######## ## ## ## ## ## ## #### ## ## ## ## ## ## ## #### #### ## ##
## ## ## ########## ## ## ## ## ## ## ##
```

Community WATer Model

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CWATM is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details <http://www.gnu.org/licenses/>.

# ————————————————————————

cwatm.**CWATMexe**()
> Base subroutine of the CWATM model

> > •parses the settings file

> > •read the information for the netcdf files

> > •check if dates are alright

> > •check flags for screen output

> > •runs the model

**class** cwatm.**CWATModel**
> Bases: *cwatm_initial.CWATModel_ini*, *cwatm_dynamic.CWATModel_dyn*

> Initial and dynamic part of the CWATM model

> > •initial part takes care of all the non temporal initialiation procedures

> > •dynamic part loops over time

> **currentTimeStep**()
> > Return the current time step in the range from firstTimeStep to nrTimeSteps.

> **dynamic**()
> > Dynamic part of LISFLOOD calls the dynamic part of the hydrological modules Looping through time and space

> > ---

> > **Note:** if flags set the output on the screen can be changed e.g.

> > > •v: no output at all

> > > •l: time and first gauge discharge

> > > •t: timing of different processes at the end

> > ---

> **firstTimeStep**()
> > Return first timestep of a model.

> **initial**()

> **nrTimeSteps**()
> > Return the number of time steps

> **setQuiet**(*quiet=True*)
> > Disables the progress display of timesteps.

---

**timeSteps**()
> Return a list of time steps

cwatm.**GNU**()
> prints GNU General Public License information

cwatm.**headerinfo**()
> Print the information on top of each run

cwatm.**usage**()
> Prints some lines describing how to use this program which arguments and parameters it accepts, etc
>
> > • -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

## 11.3.2 cwatm_dynamic module

**class** cwatm_dynamic.**CWATModel_dyn**
> Bases: pcraster2.dynamicPCRasterBase.DynamicModel
>
> **currentTimeStep**()
> > Return the current time step in the range from firstTimeStep to nrTimeSteps.
>
> **dynamic**()
> > Dynamic part of LISFLOOD calls the dynamic part of the hydrological modules Looping through time and space
> >
> > ---
> >
> > **Note:** if flags set the output on the screen can be changed e.g.
> >
> > > • v: no output at all
> > >
> > > • l: time and first gauge discharge
> > >
> > > • t: timing of different processes at the end
> >
> > ---
>
> **firstTimeStep**()
> > Return first timestep of a model.
>
> **initial**()
>
> **nrTimeSteps**()
> > Return the number of time steps
>
> **setQuiet**(*quiet=True*)
> > Disables the progress display of timesteps.
>
> **timeSteps**()
> > Return a list of time steps

---

### 11.3.3 cwatm_initial module

```
DynamicModel  ────▶  CWATModel_ini
```

```
DynamicModel  ────▶  CWATModel_dyn
```

**class** cwatm_initial.**CWATModel_ini**
    Bases: pcraster2.dynamicPCRasterBase.DynamicModel

    CWATN initial part this part is to initialize the variables. It will call the initial part of the hydrological modules

    **currentTimeStep**()
        Return the current time step in the range from firstTimeStep to nrTimeSteps.

    **dynamic**()

    **firstTimeStep**()
        Return first timestep of a model.
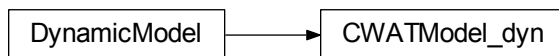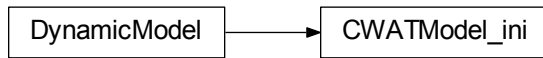
    **initial**()

    **nrTimeSteps**()
        Return the number of time steps

    **setQuiet**(*quiet=True*)
        Disables the progress display of timesteps.

    **timeSteps**()
        Return a list of time steps

### 11.3.4 hydrological_modules package

#### Submodules

#### hydrological_modules.miscInitial module

**class** hydrological_modules.miscInitial.**miscInitial**(*misc_variable*)
    Bases: object

    Miscellaneous repeatedly used expressions Definition if cell area comes from regular grid e.g. 5x5km or from irregular lat/lon Conversion factors between m3 and mm etc.

---

**Note:** Only used in the initial phase.

---

**initial**()

> •grid area, length definition
>
> •conversion factors
>
> •conversion factors for precipitation and pot evaporation

## hydrological_modules.initcondition module

class hydrological_modules.initcondition.**initcondition**(*initcondition_variable*)

> Bases: object
>
> READ/WRITE INITIAL CONDITIONS all initial condition can be stored at the end of a run to be used as a **warm** start for a following up run
>
> **dynamic**()
>
> > Dynamic part of the initcondition module write initital conditions into a single netcdf file
>
> ---
>
> **Note:** Several dates can be stored in different netcdf files
>
> ---
>
> **initial**()
>
> > **initial part of the initcondition module** Puts all the variables which has to be stored in 2 lists:
> >
> > > • initCondVar: the name of the variable in the init netcdf file
> > >
> > > • initCondVarValue: the variable as it can be read with the 'eval' command
> >
> > Reads the parameter *save_initial* and *save_initial* to know if to save or load initial values
>
> **load_initial**(*name*, *default=0.0*, *number=None*)
>
> > First it is checked if the initial value is given in the settings file
> >
> > •if it is <> None it is used directly
> >
> > •if None it is loaded from the init netcdf file
> >
> > > **Parameters**
> > >
> > > > • **name** – Name of the init value
> > > >
> > > > • **default** – default value -> default is 0.0
> > > >
> > > > • **number** – in case of snow or runoff concentration several layers are included: number = no of the layer
> > >
> > > **Returns** spatial map or value of initial condition

## hydrological_modules.inflow module

class hydrological_modules.inflow.**inflow**(*inflow_variable*)

> Bases: object
>
> READ INFLOW HYDROGRAPHS (OPTIONAL) If option "inflow" is set to 1 the inflow hydrograph code is used otherwise dummy code is used

---

> **Warning:** Not included at moment

---

**Todo**

has to be revamped The pcraster routine timeinputscalar has to be replaced by reading txt -> numpy

---

**dynamic()**
    Dynamic part of the inflow module

**initial()**
    Initial part of the inflow module

## hydrological_modules.readmeteo module

class hydrological_modules.readmeteo.**readmeteo**(*readmeteo_variable*)
    Bases: `object`

    READ METEOROLOGICAL DATA reads all meteorological data from netcdf4 files

    **dynamic()**
        Dynamic part of the readmeteo module Read meteo input maps from netcdf files

        ---

        > **Note:** If option *calc_evaporation* is False only precipitation, avg. temp., and 2 evaporation vlaues are read Otherwise all the variable needed for Penman-Monteith

        ---

        ---

        > **Note:** If option *TemperatureInKelvin* = True temperature is assumed to be Kelvin instead of Celsius!

        ---

    **initial()**
        Initial part of meteo read multiple file of input :return:

## hydrological_modules.snow_frost module

class hydrological_modules.snow_frost.**snow**(*snow_variable*)
    Bases: `object`

    RAIN AND SNOW

    Domain: snow calculations evaluated for center points of up to 7 sub-pixel snow zones 1 -7 which each occupy a part of the pixel surface

    Variables *snow* and *rain* at end of this module are the pixel-average snowfall and rain

    Inheritace: `inheritance-diagram`

---

```
┌─────────────────┐        ┌─────────────────┐
│  DynamicModel   │───────▶│  CWATModel_ini  │
└─────────────────┘        └─────────────────┘
```

For example:

```
.. inheritance-diagram:: cwatm
```

produces 1:

```
┌──────────────────────────────────────┐
│  hydrological_modules.snow_frost.snow │
└──────────────────────────────────────┘
```

**dynamic**()
 Dynamic part of the snow module Distinguish between rain/snow and calculates snow melt and glacier melt The equation is a modification of:

### References

Speers, D.D., Versteeg, J.D. (1979) Runoff forecasting for reservoir operations - the pastand the future. In: Proceedings 52nd Western Snow Conference, 149-156

Frost index in soil [degree days] based on:

### References

Molnau and Bissel (1983, A Continuous Frozen Ground Index for Flood Forecasting. In: Maidment, Handbook of Hydrology, p. 7.28, 7.55)

---

**Todo**

calculate sinus shape function for the southern hemisspere

---

test of math1

$$a = \sqrt{2}$$

**initial**()
 Initial part of the snow and frost module

  • loads all the parameters for the day-degree approach for rain, snow and snowmelt

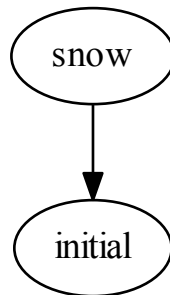  • loads the parameter for frost

---

Since Pythagoras, we know that $a^2 + b^2 = c^2$.

test of math2

$$(a + b)^2 = a^2 + 2ab + b^2 \clubsuit \tag{11.1}$$

$$e^{i\pi} + 1 = 0 \tag{11.2}$$

Euler's identity, equation (**??**), was elected one of the most beautiful mathematical formulas.



## hydrological_modules.evaporationPot module

class `hydrological_modules.evaporationPot.`**`evaporationPot`**(*evaporationPot_variable*)

Bases: `object`

POTENTIAL REFERENCE EVAPO(TRANSPI)RATION Calculate potential evapotranspiration from climate data mainly based on FAO 56 and LISVAP Based on Penman Monteith

### References

http://www.fao.org/docrep/X0490E/x0490e08.htm#penman%20monteith%20equation

http://www.fao.org/docrep/X0490E/x0490e06.htm http://www.fao.org/docrep/X0490E/x0490e06.htm

https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/lisvap-evaporation-pre-processor-lisflood-water-balance-and-flood-simulation-model

**`dynamic`**()

Dynamic part of the potential evaporation module Based on Penman Monteith - FAO 56

---

**Note:** Only run if *calc_evaporation* is True

---

> **Returns** ETRef - potential reference evapotranspiration rate [m/day] EWRef - potential evaporation rate from water surface [m/day]

**initial**()
    Initial part of evaporation type module Load inictial parameters

---

**Note:** Only run if *calc_evaporation* is True

---

## hydrological_modules.landcoverType module

**class** hydrological_modules.landcoverType.**landcoverType**(*landcoverType_variable*)
    Bases: object

    LAND COVER TYPE runs the 6 land cover types through soil procedures This routine calls the soil routine for each land cover type

    **dynamic**()
        Dynamic part of the land cover type module Calculating soil for each of the 6 land cover class * calls evaporation_module.dynamic * calls interception_module.dynamic * calls soil_module.dynamic * calls sealed_water_module.dynamic And sums every thing up depending on the land cover type fraction

    **dynamic_fracIrrigation**(*init=False*, *dynamic=True*)
        Dynamic part of the land cover type module Calculating fraction of land cover * loads the fraction of landcover for each year from netcdf maps * calculate the fraction of 6 land cover types based on the maps

    **initial**()
        Initial part of the land cover type module Initialise the six land cover types * Forest * Grasland/non irrigated land * Irrigation * Paddy iirigation * Sealed area * Water covered area And initialize the soil variables

## hydrological_modules.evaporation module

**class** hydrological_modules.evaporation.**evaporation**(*evaporation_variable*)
    Bases: object

    Evaporation module Calculate potential evaporation and pot. transpiration

    **dynamic**(*coverType*, *No*)
        Dynamic part of the soil module

        calculating potential Evaporation for each land cover class with kc factor get crop coefficient, use potential ET, calculate potential bare soil evaporation and transpiration

        **Parameters**

        - **coverType** – Land cover type: forest, grassland ...

        - **No** – number of land cover type: forest = 0, grassland = 1 ...

        **Returns** potential evaporation from bare soil, potential transpiration

## hydrological_modules.capillarRise module

**class** hydrological_modules.capillarRise.**capillarRise**(*capillarRise_variable*)
    Bases: object

    CAPPILAR RISE calculate cell fraction influenced by capillary rise

    **dynamic**()
        Dynamic part of the capillar Rise module calculate cell fraction influenced by capillary rise depending on appr. height of groundwater and relative elevation of grid cell

---

**Returns** capRiseFrac = cell fraction influenced by capillary rise

## hydrological_modules.interception module

**class** `hydrological_modules.interception.`**`interception`**(*interception_variable*)

Bases: `object`

INTERCEPTION

**dynamic**(*coverType*, *No*)

Dynamic part of the interception module calculating interception for each land cover class

**Parameters**

- **`coverType`** – Land cover type: forest, grassland ...

- **`No`** – number of land cover type: forest = 0, grassland = 1 ...

**Returns** interception evaporation, interception storage, reduced pot. transpiration

## hydrological_modules.soil module

**class** `hydrological_modules.soil.`**`soil`**(*soil_variable*)

Bases: `object`

SOIL Caclulation vertical transfer of water based on improved Arno scheme

**dynamic**(*coverType*, *No*)

Dynamic part of the soil module For each of the land cover classes the vertical water transport is simulated Distribution of water holding capiacity in 3 soil layers based on saturation excess overland flow, preferential flow Dependend on soil depth, soil hydraulic parameters

**initial**()

Initial part of the soil module

- Initialize all the hydraulic properties of soil

- Set soil depth

**Todo**

individual soil properties for each land cover type

## hydrological_modules.sealed_water module

**class** `hydrological_modules.sealed_water.`**`sealed_water`**(*sealed_water_variable*)

Bases: `object`

Sealed and open water runoff

calculated runoff from impermeable surface (sealed) and into water bodies

**dynamic**(*coverType*, *No*)

Dynamic part of the sealed_water module runoff calculation for open water and sealed areas

**Parameters**

- **`coverType`** – Land cover type: forest, grassland ...

- **No** – number of land cover type: forest = 0, grassland = 1 ...

## hydrological_modules.waterdemand module

**Naming convention:**

-
-
-
-

class hydrological_modules.waterdemand.**waterdemand**(*waterdemand_variable*)

    Bases: object

    WATERDEMAND calculating water demand Industrial, domenstic based on precalculated maps Agricultural water demand based on water need by plants

    **dynamic**()

        Dynamic part of the water demand module * calculate the fraction of water from surface water vs. groundwater * get non-Irrigation water demand and its return flow fraction

    **initial**()

        Initial part of the water demand module Set the water allocation

## hydrological_modules.groundwater module

class hydrological_modules.groundwater.**groundwater**(*groundwater_variable*)

    Bases: object

    GROUNDWATER

    **dynamic**()

        Dynamic part of the groundwater module Calculate groundweater storage and baseflow

    **initial**()

        Initial part of the groundwater module

            •load parameters from settings file

            •initial groundwater storage

## hydrological_modules.runoff_concentration module

class hydrological_modules.runoff_concentration.**runoff_concentration**(*runoff_concentration_variable*)

    Bases: object

    *Runoff concentration* this is the part between runoff generation and routing for each gridcell and for each land cover class the generated runoff is concentrated at a corner of a gridcell this concentration needs some lag-time (and peak time) and leads to diffusion lag-time/ peak time is calculated using slope, length and land cover class diffusion is calculated using a triangular-weighting-function

    **dynamic**()

        Dynamic part of the runoff concentration module For surface runoff for each land cover class and for interflow and for baseflow the runoff concentration time is calculated

---

**Note:** the time demanding part is calculated in a c++ library

---

**initial**()
>   Initial part of the runoff concentration module Setting the peaq time for:
>
>> •surface runoff = 3
>>
>> •interflow = 4
>>
>> •baseflow = 5
>
>   based on the slope the concentration time for each land cover type is calculated

---

**Note:** only if option **includeRunoffConcentration** is TRUE

---

## hydrological_modules.lakes_reservoirs module

**class** hydrological_modules.lakes_reservoirs.**lakes_reservoirs**(*lakes_reservoirs_variable*)
>   Bases: object
>
>   LAKES AND RESERVOIRS calculate water retention in lakes and reservoirs
>
>   **dynamic**()
>>   Dynamic part set lakes and reservoirs for each year
>
>   **dynamic_inloop**(*NoRoutingExecuted*)
>>   Dynamic part to calculate outflow from lakes and reservoirs
>>
>>> •lakes with modified Puls approach
>>>
>>> •reservoirs with special filling levels
>>>
>>>> Parameters **NoRoutingExecuted** – actual number of routing substep
>>>>
>>>> Returns outLdd: outflow in m3 to the network

---

**Note:** outflow to adjected lakes and reservoirs is calculated separately

---

**initWaterbodies**()
>   Initialize water bodies Read parameters from maps e.g area, location, initial average discharge, type 9reservoir or lake) etc.
>
>   Compress numpy array from mask map to the size of lakes+reservoirs (marked as capital C at the end of the variable name)

**initial_lakes**()
>   Initial part of the lakes module Using the **Modified Puls approach** to calculate retention of a lake
>
>   **See also:**
>
>   LISFLOOD maunal Annex 3 (Burek et al. 2013)

**initial_reservoirs**()
>   Initial part of the reservoir module Using the appraoch of LISFLOOD
>
>   **See also:**

---

LISFLOOD manual Annex 1: (Burek et al. 2013)

## hydrological_modules.lakes_res_small module

class hydrological_modules.lakes_res_small.**lakes_res_small**(*lakes_res_small_variable*)

Bases: object

LAKES AND RESERVOIRS calculate water retention in lakes and reservoirs

**dynamic**()

Dynamic part to calculate outflow from small lakes and reservoirs

•lakes with modified Puls approach

•reservoirs with special filling levels

> **Returns** outflow in m3 to the network

**initial**()

Initialize small lakes and reservoirs Read parameters from maps e.g area, location, initial average discharge, type: reservoir or lake) etc.

## hydrological_modules.routing_reservoirs.routing_kinematic module

class hydrological_modules.routing_reservoirs.routing_kinematic.**routing_kinematic**(*routing_kinema*

Bases: object

ROUTING routing using the kinematic wave

**dynamic**()

Dynamic part of the routing module

•calculate evaporation from channels

•calcualte riverbed exchange between riverbed and groundwater

•if option **waterbodies** is true, calculate retention from water bodies

•calculate sideflow -> inflow to river

•calcculate kinematic wave -> using C++ library for computational speed

**initial**()

Initial part of the routing module

•load and create a river network

•calculate river network parameter e.g. river length, width, depth, gradient etc.

•calculate initial filling

•calculate manning's roughness coefficient

## hydrological_modules.routing_reservoirs.routing_sub module

hydrological_modules.routing_reservoirs.routing_sub.**Compress**(*map*, *mask*)

compressing map from 2D to 1D without missing values :param map: input map :param mask: mask map :return: compressed map

---

hydrological_modules.routing_reservoirs.routing_sub.**Decompress**(*compmap*, *mask*, *emptymap*)

Decompressing map from 1D to 2D with missing values :param compmap: compressed map :param mask: mask map :param emptymap: map with only 0 in :return: decompressed 2D map

hydrological_modules.routing_reservoirs.routing_sub.**catchment1**(*dirUp*, *points*)

calculates all cells which belongs to a catchment from point onward

> **Parameters**
>
> > • **dirUp** –
> >
> > • **points** –
>
> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**decompress1**(*map*)

redundant have to look if it is still used

---

**Todo**

remove it?

---

> **Parameters map** –
>
> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**defLdd2**(*ldd*)

defines river network

> **Parameters ldd** –
>
> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**dirDownstream**(*dirUp*, *lddcomp*, *dirDown*)

runs the river network tree downstream - from source to outlet

> **Parameters**
>
> > • **dirUp** –
> >
> > • **lddcomp** –
> >
> > • **dirDown** –
>
> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**dirUpstream**(*dirshort*)

runs the network tree upstream from outlet to source

> **Parameters dirshort** –
>
> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**downstream1**(*dirUp*, *weight*)

calculated 1 cell downstream

> **Parameters**
>
> > • **dirUp** –

- **weight** –

> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**lddrepair**(*lddnp*, *lddOrder*)

> repairs a river network

>> •eliminate unsound parts

>> •add pits at points with no connections

>> **Parameters**

>>> - **lddnp** –

>>> - **lddOrder** –

>> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**postorder**(*dirUp*, *catchment*, *node*, *catch*, *dirDown*)

> routine to run a postoder tree traversal :param dirUp: :param catchment: :param node: :param catch: :param dirDown: :return: dirDown and catchment

hydrological_modules.routing_reservoirs.routing_sub.**subcatchment1**(*dirUp*, *points*, *ups*)

> calculates subcatchments of points

>> **Parameters**

>>> - **dirUp** –

>>> - **points** –

>>> - **ups** –

>> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**upstream1**(*downstruct*, *weight*)

> Calculates 1 cell upstream

>> **Parameters**

>>> - **downstruct** –

>>> - **weight** –

>> **Returns**

hydrological_modules.routing_reservoirs.routing_sub.**upstreamArea**(*dirDown*, *dirshort*, *area*)

> calculates upstream area :param dirDown: array which point from each cell to the next downstream cell :param dirshort: :param area: area in m2 for a single gridcell :return:

## hydrological_modules.waterbalance module

**class** hydrological_modules.waterbalance.**waterbalance**(*waterbalance_variable*)

> Bases: object

> WATER BALANCE

> • check if water balnace per time step is ok ( = 0)

> • produce an annual overview - income, outcome storage

**checkWaterSoilGround()**
> Check water balance of snow, vegetation, soil, groundwater

**dynamic()**
> Dynamic part of the water balance module If option **sumWaterBalance** sum water balance for certain variables

**initial()**
> Initial part of the water balance module

**waterBalanceCheck**(*fluxesIn*, *fluxesOut*, *preStorages*, *endStorages*, *processName*, *printTrue=False*)
> Dynamic part of the water balance module Returns the water balance for a list of input, output, and storage map files

>> **Parameters**

>>> • **fluxesIn** – income

>>> • **fluxesOut** – this goes out

>>> • **preStorages** – this was in before

>>> • **endStorages** – this was in afterwards

>>> • **processName** – name of the process

>>> • **printTrue** – calculate it?

>> **Returns**

**waterBalanceCheckSum**(*fluxesIn*, *fluxesOut*, *preStorages*, *endStorages*, *processName*, *printTrue=False*)
> Returns the water balance for a list of input, output, and storage map files and sums it up for a catchment

>> **Parameters**

>>> • **fluxesIn** – income

>>> • **fluxesOut** – this goes out

>>> • **preStorages** – this was in before

>>> • **endStorages** – this was in afterwards

>>> • **processName** – name of the process

>>> • **printTrue** – calculate it?

>> **Returns** Water balance as output on the screen

## Module contents

## 11.3.5 management_modules package

## Submodules

## management_modules.checks module

management_modules.checks.**checkmap**(*\*args*, *\*\*kwargs*)

---

`management_modules.checks.`**`counted`**(*fn*)
> count number of times a subroutine is called
>
> > **Parameters fn** –
> >
> > **Returns**

## management_modules.configuration module

**class** `management_modules.configuration.`**`ExtParser`**(*\*args*, *\*\*kwargs*)
> Bases: `ConfigParser.SafeConfigParser`
>
> addition to the parser to replace placeholders
>
> ### Example
>
> PathRoot = C:/work MaskMap = $(FILE_PATHS:PathRoot)/data/areamaps/area.tif
>
> **`get`**(*section*, *option*, *raw=False*, *vars=None*)
> > placeholder replacement
> >
> > > **Parameters**
> > >
> > > - **section** –
> > >
> > > - **option** –
> > >
> > > - **raw** –
> > >
> > > - **vars** –
> > >
> > > **Returns**

`management_modules.configuration.`**`parse_configuration`**(*settingsFileName*)
> Parse settings file
>
> > **Parameters settingsFileName** – name of the settings file
> >
> > **Returns** parameters in list: binding, options in list: option

`management_modules.configuration.`**`read_metanetcdf`**(*metaxml*, *name*)
> Read the metadata for netcdf output files unit, long name, standard name and additional information
>
> > **Parameters metaxml** – file mit information for netcdf files (metadata)
> >
> > **Returns** List with metadata information: metaNetcdfVar

## management_modules.data_handling module

`management_modules.data_handling.`**`cbinding`**(*inBinding*)

`management_modules.data_handling.`**`checkOption`**(*inBinding*)

`management_modules.data_handling.`**`compressArray`**(*map*, *pcr=True*, *name='None'*, *zeros=0.0*)
> Compress 2D array with missing values to 1D array without missing values
>
> > **Parameters**
> >
> > - **map** – in map
> >
> > - **pcr** – if True input map is used as pcraster map

> • **name** –

> **Returns**

`management_modules.data_handling.`**`decompress`**(*map*, *pcr1=True*)

> Decompress 1D array without missing values to 2D array with missing values

>> **Parameters**

>>> • **map** – numpy 1D array as input

>>> • **pcr1** – if True map is used as pcraster map

>> **Returns** 2D map

`management_modules.data_handling.`**`divideValues`**(*x*, *y*, *default=0.0*)

> returns the result of a division that possibly involves a zero

>> **Parameters**

>>> • **x** –

>>> • **y** – divisor

>>> • **default** – return value if y =0

>> **Returns**

`management_modules.data_handling.`**`getmeta`**(*key*, *varname*, *alternative*)

> get the meta data information for the netcdf output from the global variable metaNetcdfVar

`management_modules.data_handling.`**`loadmap`**(*name*, *pcr=False*, *lddflag=False*, *compress=True*, *local=False*, *cut=True*)

> load a static map either value or pc raster map or netcdf

>> **Parameters**

>>> • **name** – name of map

>>> • **pcr** – if pcr=True - pcraster map is given back

>>> • **lddflag** – if True the map is used as a ldd map

>>> • **compress** – if True the return map will be compressed

>>> • **local** – if True the map will be not cut

>> **Returns** 1D numpy array of map

`management_modules.data_handling.`**`loadsetclone`**(*name*)

> load the maskmap and set as clone

>> **Parameters** **name** – name of mask map, can be a file or - row col cellsize xupleft yupleft -

`management_modules.data_handling.`**`mapattrNetCDF`**(*name*, *check=True*)

> get the map attributes like col, row etc from a netcdf map and define the rectangular of the mask map inside the netcdf map

`management_modules.data_handling.`**`mapattrNetCDFMeteo`**(*name*, *check=True*)

> get the map attributes like col, row etc from a netcdf map and define the rectangular of the mask map inside the netcdf map

`management_modules.data_handling.`**`mapattrTiff`**(*nf2*)

> map attributes of a geotiff file

>> **Parameters** **nf2** –

>> **Returns**

management_modules.data_handling.**metaNetCDF**()
    get the map metadata from netcdf

management_modules.data_handling.**multinetdf**(*meteomaps*, *startcheck='dateBegin'*)

> **Parameters** **meteomaps** – list of meteomaps to define start and end time

> **Returns**

management_modules.data_handling.**readCoord**(*name*)

management_modules.data_handling.**readCoordNetCDF**(*name*, *check=True*)
    reads the map attributes col, row etc from a netcdf map :param name: name of the netcdf file :param check: checking if netcdffile exists :return:

management_modules.data_handling.**readmeteodata**(*name*, *date*, *value='None'*, *addZeros=False*, *zeros=0.0*, *mapsscale=True*)
    load stack of maps 1 at each timestamp in netcdf format

> **Parameters**

> - **name** – file name
> - **date** –
> - **value** – if set the name of the parameter is defined
> - **addZeros** –
> - **cut** – if True the map is clipped to mask map
> - **zeros** – default value

> **Returns**

management_modules.data_handling.**readnetcdf2**(*namebinding*, *date*, *useDaily='daily'*, *value='None'*, *addZeros=False*, *cut=True*, *zeros=0.0*, *meteo=False*, *usefilename=False*, *compress=True*)
    load stack of maps 1 at each timestamp in netcdf format

> **Parameters**

> - **name** – file name
> - **date** –
> - **useDaily** – if True daily values are used
> - **value** – if set the name of the parameter is defined
> - **addZeros** –
> - **cut** – if True the map is clipped to mask map
> - **zeros** – default value

> **Returns**

management_modules.data_handling.**readnetcdfInitial**(*name*, *value*, *default=0.0*)
    load initial condition from netcdf format

management_modules.data_handling.**readnetcdfWithoutTime**(*name*, *value='None'*)
    load stack of maps in netcdf format

management_modules.data_handling.**returnBool**(*inBinding*)
    Test if parameter is a boolean and return an error message if not, and the boolean if everything is ok :param inBinding: parameter in settings file :return: boolean of inBinding

`management_modules.data_handling.`**`setmaskmapAttr`**(*x*, *y*, *col*, *row*, *cell*)
  Definition of cell size, coordinates of the meteo maps and maskmap

  **Todo** need some love for error handling

>   **Parameters**
>
>> • **x** – upper left corner x
>>
>> • **y** – upper left corner y
>>
>> • **col** – number of cols
>>
>> • **row** – number of rows
>>
>> • **cell** – cell size
>
>   **Returns**

`management_modules.data_handling.`**`valuecell`**(*mask*, *coordx*, *coordstr*)
  to put a value into a pc raster map -> invert of cellvalue, map is converted into a numpy array first

>   **Parameters**
>
>> • **mask** – Mask map
>>
>> • **coordx** – x,y or lon/lat coordinate
>>
>> • **coordstr** – String of coordinates
>
>   **Returns**

`management_modules.data_handling.`**`writeIniNetcdf`**(*netfile*, *varlist*, *inputlist*)
  write variables to netcdf init file

`management_modules.data_handling.`**`writenetcdf`**(*netfile*, *prename*, *addname*, *varunits*, *inputmap*, *timeStamp*, *posCnt*, *flag*, *flagTime*, *nrdays=None*, *dateunit='days'*)
  write a netcdf stack

## management_modules.globals module

`management_modules.globals.`**`globalFlags`**(*arg*)
  Read flags - according to the flags the output is adjusted quiet,veryquiet, loud, checkfiles, noheader,printtime, warranty

## management_modules.improvepcraster module

**class** `management_modules.improvepcraster.`**`DynamicFramework2`**(*userModel*, *lastTimeStep=0*, *firstTimestep=1*)
  Bases: `pcraster2.dynamicFramework.DynamicFramework`

  Framework class for dynamic models. *userModel* Instance that models the Dynamic Model Concept <dynamicModelConcept>. *lastTimeStep* Last timestep to run. *firstTimestep* Sets the starting timestep of the model (optional, default is 1). Updated by improvepcraster.py

  **`rquiet`** = **False**

  **`rtrace`** = **False**

**run**()
    Run the dynamic user model.

## management_modules.messages module

**exception** management_modules.messages.**CWATMError**(*msg*)
    Bases: exceptions.Exception

    The error handling class prints out an error

**exception** management_modules.messages.**CWATMFileError**(*filename*, *msg=''*, *sname=''*)
    Bases: *management_modules.messages.CWATMError*

    The error handling class prints out an error

**exception** management_modules.messages.**CWATMRunInfo**(*outputDir*, *Steps=1*, *ensMembers=1*,
                                              *Cores=1*)
    Bases: exceptions.Warning

    prints out an error

    **Warning**   warning given with a header and a message from the subroutine

**exception** management_modules.messages.**CWATMWarning**(*msg*)
    Bases: exceptions.Warning

    the error handling class prints out an error

## management_modules.output module

**class** management_modules.output.**outputTssMap**(*out_variable*)
    Bases: object

    Output of time series and map

    **dynamic**(*ef=False*)
        Dynamic part of the output module

    **initial**()
        Initial part of the output module

## management_modules.replace_pcr module

management_modules.replace_pcr.**npareaaverage**(*values*, *areaclass*)
    numpy area average procedure

        **Parameters**

            • **values** –

            • **areaclass** –

        **Returns**

management_modules.replace_pcr.**npareamajority**(*values*, *areaclass*)
    numpy area majority procedure

        **Parameters**

            • **values** –

            • **areaclass** –

**Returns**

`management_modules.replace_pcr.`**`npareamaximum`**(*values*, *areaclass*)
    numpy area maximum procedure

> **Parameters**
>
>> • **values** –
>>
>> • **areaclass** –
>
> **Returns**

`management_modules.replace_pcr.`**`npareatotal`**(*values*, *areaclass*)
    numpy area total procedure

> **Parameters**
>
>> • **values** –
>>
>> • **areaclass** –
>
> **Returns**

## management_modules.timestep module

`management_modules.timestep.`**`Calendar`**(*input*)
    Get the date from CalendarDayStart in the settings xml Reformatting the date till it fits to datetime

> **Parameters** **`input`** – string from the settingsfile should be somehow a date
>
> **Returns** a datetime date

`management_modules.timestep.`**`checkifDate`**(*start*, *end*, *spinup*)
    Checks if start date is earlier than end date etc And set some date variables

> **Parameters**
>
>> • **start** – start date
>>
>> • **end** – end date
>>
>> • **spinup** – date till no output is generated = warming up time
>
> **Returns** a list of date variable in: dateVar

`management_modules.timestep.`**`ctbinding`**(*inBinding*)

`management_modules.timestep.`**`date2indexNew`**(*date*, *nctime*, *calendar*, *select='nearest'*, *name=''*)

`management_modules.timestep.`**`date2str`**(*date*)

`management_modules.timestep.`**`datetoInt`**(*dateIn*, *begin*, *both=False*)
    Calculates the integer of a date from a reference date

> **Parameters**
>
>> • **dateIn** – date
>>
>> • **begin** – reference date
>>
>> • **both** – if set to True both the int and the string of the date are returned
>
> **Returns** interger value of a date, satarting from begin date

management_modules.timestep.**timemeasure**(*name*, *loops=0*, *update=False*, *sample=1*)
    Measuring of the time for each subroutine

    **Parameters**

- **name** – name of the subroutine

- **loops** – if it it called several times this is added to the name

- **update** –

- **sample** –

    **Returns**  add a string to the time measure string: timeMesString

management_modules.timestep.**timestep_dynamic**(*self*)
    Dynamic part of setting the date Current date is increasing, checking if beginning of month, year

    **Returns**  a list of date variable in: dateVar

## Module contents

- genindex

# c

# h

# m