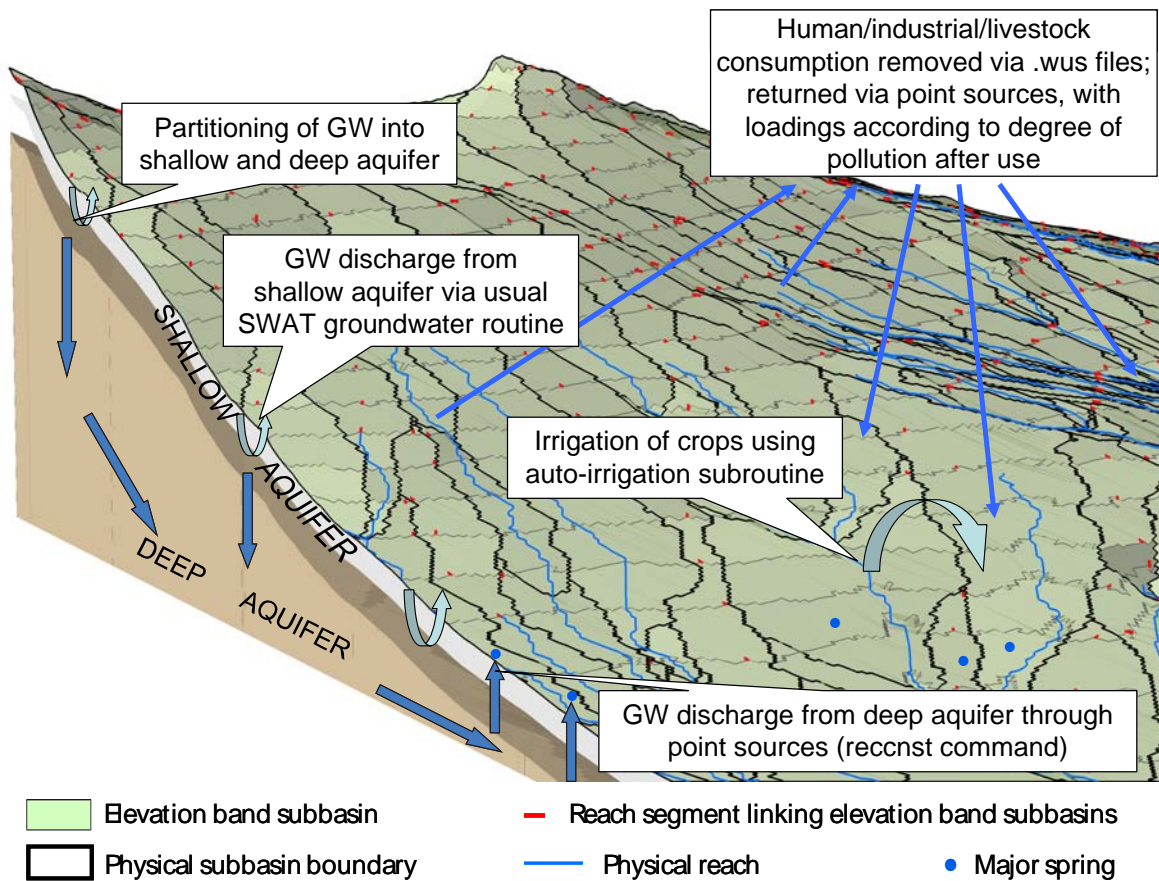


# SWAT-P Hydrological Model

## Documentation of changes with respect to SWAT2005

Benedikt Notter

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# 1. INTRODUCTION

SWAT-P is a modified version of the hydrological model SWAT (Soil and Water Assessment Tool), a distributed, physically-based, river-basin scale hydrological model originally developed for the US Department of Agriculture (Arnold et al. 1998), and now used world-wide for the assessment of impacts of watershed management practices on water, sediments, and chemical yields. It simulates a number of physical processes in a watershed, ranging from runoff generation and water routing to plant growth and nutrient cycling.

SWAT-P has been developed in the course of a study carried out within the NCCR North-South research programme<sup>1</sup>. The study aimed at the physical quantification of water-related ecosystem services in the East African Pangani Basin. For the application in Pangani Basin, several modifications to the source code of the official SWAT model version SWAT2005 became necessary:

- a) Since the auto-irrigation routine was used to simulate irrigation, an error in the auto-irrigation routine was detected and corrected. The error caused all flow in a river to be set to zero if only a part of it was removed for irrigation;
- b) As plants in the tropics do not go dormant based on decreasing daylength as in temperate latitudes, the threshold for dormancy for tropical latitudes (20°N – 20°S) was decreased. This way, unintended dormancy of plants in the simulation, which would have caused plant water demand to be underestimated, can be avoided;
- c) Pangani River crosses a large wetland, the Kirua Swamp, in its middle reaches. The swamp attenuates flood peaks and receives natural irrigation. Since SWAT2005 is not able to simulate the spilling of water from a river channel onto adjacent areas, a simple floodplain routine was introduced to simulate this process;
- d) Since some model input data with a high influence on simulation results (rainfall, temperature, spring discharge, and maximum allowed diversion amounts) for Pangani Basin are of low reliability, correction factors for these inputs were introduced. These correction factors could then be varied during the calibration and uncertainty assessment with SUFI-2 (see below) like other model parameters, and their uncertainty could be included in the modelling result;
- e) As the Pangani Basin was modelled at high spatial resolution, a high number of spatial modelling units (> 20'000) resulted. Therefore the need to remove some limitations on the number of input files arose;
- f) Some additional output variables were introduced, e.g. actual water removal for "consumptive" (domestic/industrial/livestock) use, days with flooding, or plant water stress.

The thus modified model version was called SWAT-P.

This documentation covers only the differences between SWAT-P and the version SWAT2005. The documentation for SWAT2005 can be downloaded from <http://www.brc.tamus.edu/swat/doc.html>

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<sup>1</sup> NCCR stands for "National Centre of Competence in Research". NCCR's are consortia of academic research groups (institutes, departments) from Swiss Universities targeting research questions of national importance. They are partly funded by the Swiss National Science Foundation (SNF). Currently there are 20 NCCR's in Switzerland.

For more information on the NCCR North-South, visit <http://www.north-south.ch>; for information on the NCCR programme in general, visit <http://www.snf.ch/E/targetedresearch/centres/Seiten/default.aspx>.

and should be used alongside the present document. For explanations on the SWAT parameters mentioned in this document, please consult these documentations.

## 2. CONDITIONS OF USE OF SWAT-P

SWAT is an open-source application. The official SWAT executables, the code, and documentation files can be downloaded from [http://www.brc.tamus.edu/swat/soft\\_model.html](http://www.brc.tamus.edu/swat/soft_model.html). There is no limitation on the use of the software, but it is good practice to cite the developers if study results obtained with SWAT are published.

For the use of SWAT-P, both the official SWAT developers and the developers of the modified version SWAT-P should be cited. Two publications that can be cited include:

For the official SWAT2005 version:

Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R., 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. *Journal of the American Water Resources Association*, 34(1): 73-89.

For the modified version SWAT-P:

Notter, B., Abbaspour, K., Hurni, H., 2009. Setting up SWAT to quantify water-related ecosystem services in a large data-scarce watershed in East Africa. *Proceedings of the 5th International SWAT Conference*, Boulder, Colorado.

## 3. DIFFERENCES FROM SWAT2005 TO SWAT-P

The following sections list the changes from SWAT2005 to SWAT-P in detail and specify the Fortran source files affected by the changes. In the source files, a comment starting with "!! BN:" has been added to all lines that have been changed; therefore, the code changes can be searched by searching for the string "!! BN:".

### 3.1. Correction of auto-irrigation

Two problems exist with the auto-irrigation routine in SWAT2005. On one hand, in SWAT2005 the variables "vol" and "wtrin" got confused between lines 197 and 208 in the source file `irr_rch.f` where the irrigation water is subtracted from the reach water. If executed that way, the remaining water in the reach is always 0. The fix for this problem included only changing the variable `wtrin` to the variable `vol`.

On the other hand, auto-irrigation in SWAT is triggered by the variable describing water stress; the variable `wstrs` in SWAT2005, however, includes not only stress induced by too little water, but also by too much water (aeration stress, i.e. plants not getting any air due to too much water around the roots). Aeration stress should not trigger auto-irrigation. Therefore a new variable "strsw\_irr"

was introduced that only describes stress from too little water (not taking into account aeration stress), and auto-irrigation was set to be triggered by this variable.

Affected source files:

- allocate\_parms.f
- autoirr.f
- dormant.f
- harvkillop.f
- hruday.f
- header.f
- headout.f
- irr.rch.f
- modparm.f
- sim\_initday.f
- swu.f

### 3.2. Continuous growing period in tropical latitudes

The growing period in SWAT2005 is interrupted as the actual daylength for the day nears the minimum daylength for the latitude, if the latitude specified in the .sub file is farther away from the equator than the latitude in the corresponding .wgn file. This is OK for temperate latitudes, but in the tropics it can lead to an unintended interruption of the growing period, which will lead to an underestimation of plant water demand. Therefore, the variable "dl" was changed from 0 to -1 in readwgn.f, affecting tropical latitudes (20°S – 20°N).

Affected source files:

- readwgn.f

### 3.3. Irrigation efficiency parameter

In SWAT2005, an irrigation efficiency of 100% is assumed, i.e. if the auto-irrigation routine is invoked, it is assumed that all water abstracted from a stream will be applied to the plants. This is not the case in reality in Pangani Basin, and therefore a new input parameter "irr\_eff" describing irrigation efficiency was introduced in SWAT-P. The parameter is optional and can be added to the auto-irrigation initialization command line in the .mgt input files. If it is not entered, a value of 1.0 (=100% irrigation efficiency) is assumed as in SWAT2005. The values of "irr\_eff" can range from 0 to 1, where 0 means none of the water abstracted from the source reaches the destination, and 1 means all water reaches the destination. How much water is actually abstracted from the source is determined by the demand, i.e. if "irr\_eff" is set to 0.5, twice as much water as is needed to satisfy the demand is abstracted from the source – but only as long as water is available in the source, and as long as the abstracted amount does not exceed the limits set by the parameters "DIVMAX" (absolute maximum amount to abstract for this area), "FLOWMIN" (minimum flow requirement in the stream) and "FLOWFR" (maximum fraction of flow that can be abstracted). The water not applied to the destination area is assumed to be lost from the system.

NOTE: "irr\_eff" does not describe overall irrigation efficiency! In the ecosystem services assessment, the following concept was used to model irrigation efficiency:

$$\text{IrrEff\_Total} = (1 - \text{SeepBackFraction}) * (1 - \text{TransmissionLoss}) * (1 - \text{ApplicationLoss})$$

The term  $(1 - \text{TransmissionLoss})$  is what is described by the parameter "irr\_eff".

The SeepBackFraction is the fraction of water that seeps right back to the stream through the furrow walls and bed in the uppermost sections of the furrow. As this process is not simulated in SWAT-P, the fraction of water abstracted and returned to the stream again by this process is regarded as not being abstracted in the first place.

The ApplicationLoss is the portion of water that goes to other plants or areas than where it is intended to go. In the ecosystem services assessment, this part of irrigation inefficiency was included through a characteristic of the AfriCover land use data: Many areas are not classified as 100% crop, but maybe only 60% or 40%. In the assessment, it was assumed that the non-crop fraction if these areas are unintendedly irrigated together with the crop fraction.

Source files affected by the changes:

- allocate\_parms.f
- autoirr.f
- irr\_rch.f
- irr\_res.f
- modparm.f
- readmgt.f
- zero0.f

### 3.4. Correction factors for measured inputs

The calibration procedure of SWAT with the SUFI-2 algorithm (Abbaspour et al. 2007) allows varying input parameters in order to assess their uncertainty. As measured input factors in Pangani Basin are partly of questionable reliability, and interpolation of meteorological inputs introduces additional uncertainty, correction factors for rainfall, temperature, point source, and maximum diversion inputs were introduced in SWAT-P, so that uncertainty in these parameters could be quantified.

The new parameters are:

- PCOR: correction factor for precipitation; precipitation inputs will be varied by a relative change value, i.e.

$$\text{modifiedPrecipitation} = \text{inputPrecipitation} * (1 + \text{PCOR})$$

This implies if PCOR is 0, no change takes place.

- TCOR: correction factor for temperature. Maximum and minimum temperatures will be varied by the value of TCOR in °C, i.e.

$$\text{modifiedTemperature} = \text{inputTemperature} + \text{TCOR}$$

- PSCOR: correction factor for point source inputs. All loadings input as point sources will be varied by a relative change as with PCOR.
- DIVCOR: correction factor for maximum diversions (DIVMAX). All input maximum diversion amounts will be varied by a relative change as with PCOR.

As for practical reasons, the existing format of the SWAT input files could not be changed (as these have to be created by GIS interfaces like ArcSWAT or MapWindowSWAT which could not be modified), the new correction factors are entered in the input files in the place of other existing surrogate SWAT parameters that were not used in the ecosystem services assessment:

- PCOR is entered as SNO\_SUB in the .sub file
- TCOR is entered as CO2 in the .sub file
- PSCOR is entered as SEDPST\_CONC in the .swq file
- DIVCOR is entered as RSDIN in the .mgt file

This means that changes to the values of the surrogate parameters will not be effective in SWAT-P as described in the official SWAT documentation, but they will apply to the new correction factors described here! Therefore a warning message about this characteristic of the application appears in the command window when SWAT is run.

Affected source files:

- allocate\_parms.f
- clicon.f
- main.f
- modparm.f
- readfig.f
- readhru.f
- readmgt.f
- readsub.f
- readswq.f
- reccnst.f
- zero.f

### 3.5. Floodplain simulation

SWAT2005 features a very simple floodplain simulation: if water cannot run off within the given channel dimensions, it spills into a floodplain five times as wide as the river channel. The width of the floodplain cannot be varied from this factor, and water spilling over to adjacent HRUs (hydrological response units) is not modelled.

In Kirua swamp in Pangani Basin, flood water spills over the river banks into a very extensive floodplain. SWAT-P simulates this in the following way: The variable FLD\_FR in the .hru file (already available in SWAT2005 but not used yet) is used under a slightly different meaning than foreseen – instead of "fraction of HRU draining into floodplain" it is used as "fraction of HRU belonging to floodplain" in SWAT-P. If water in a reach with associated floodplain exceeds the channel dimensions, the surplus water is moved to the HRUs with FLD\_FR > 0, dividing its depth over the floodplain area. The floodplain area is the area of the HRUs in the subbasin multiplied by their FLD\_FR.

The water in the floodplain is then treated the same way as water entering the wetland routine in SWAT2005 (the new source file floodplain.f is in fact more or less a copy of wetland.f except for few changes), the only difference being that water seeping through the floodplain bottom

percolates first through the underlying soils instead of going to the shallow aquifer directly as in the wetland routine.

It should be noted that the extended flood plain simulation is not possible at the hourly time step, as also the simple floodplain simulation in SWAT2005 is not implemented at the hourly time step.

Source files affected:

- allocate\_parms.f
- floodplain.f (new in SWAT-P)
- modparm.f
- rchinit.f
- rtday.f
- rteinit.f
- rtmusk.f
- rtout.f

### 3.6. Additional output variables

SWAT-P writes additional variables to the output files:

- the simulation year is written to each line of the outputs in output.hru, output.rch, and output.sub under the column YEAR;
- effective water use from ponds, shallow and deep aquifer to output.sub: column WUSUB10<sup>4</sup>m<sup>3</sup> (unit: 10<sup>4</sup> m<sup>3</sup> per time step, i.e. per day in most cases);
- effective water use from reaches to output.rch: column WURCH10<sup>4</sup>m<sup>3</sup> (unit: 10<sup>4</sup> m<sup>3</sup> per time step, i.e. per day in most cases);
- whether flooding took place (water spilling over channel banks) in a time step to output.rch: column FLOODING (number of days with flooding);
- Maximum and actual plant evaporation (columns EP\_MAX, EP\_DAY, in mm) and water stress not including aeration stress (column STRSW\_IRR, dimensionless factor with values 0 – 1 at daily resolution, summed up at monthly resolution) to output.hru.

Affected source files:

- allocate\_parms.f
- header.f
- headout.f
- hruday.f, hrumon.f, hrubr.f, hrubaa.f
- modparm.f
- rchday.f, rchmon.f, rchyr.f, rchaaf
- rchuse.f
- subday.f, submon.f, subyr.f, subbaaf
- sumv.f
- watuse.f
- virtual.f



### 3.7. Simulation of large or complex watersheds

In large or complex watersheds, a large number of spatial units or climate stations may become necessary; this was the case in the ecosystem services assessment. Therefore, the following changes were made:

- > 10'000 (theoretically up to 99'999) HRUs (hydrological response units) can be simulated. In SWAT2005, only up to 9999 HRUs were possible. Changes were made to output file formats, where an additional digit had to be allowed for 5-digit HRU numbers,
- up to 30 files of rainfall and temperature gauge records can be read in; the limit was 18 files in SWAT2005. Each rainfall gauge file can hold records from up to 300 gauges, and each temperature gauge file holds records from up to 150 gauges; therefore, in SWAT-P, records from 9000 rain and 4500 temperature gauges can be used in a simulation.
- a limitation to a maximum of 6300 subbasins was also removed.

Source files affected:

- getallo.f
- getallo2.f
- modparm.f
- readfile.f

### 3.8. Further changes

Further changes in SWAT-P with respect to SWAT2005 are:

- In readmgt.f: The limit of 3500 PHU (potential heat units) was removed.
- In readwus.f: the input format was changed so that .wus files can be read in in free format (with any number of digits – in SWAT2005 only 1 digit was possible, which did not allow small amounts to be read in).
- In grow.f: Maximum biomass can be specified for all plant types (only for trees in SWAT2005).
- In rteinit.f: plant-related variables are not read anymore for urban land cover types (caused error in SWAT2005).
- In writed.f: flow velocities are not written to output file tempvel.out in SWAT-P, as this does not make sense, and even causes overflow errors, in the simulation of a large watershed with thousands of reaches.

## 4. REFERENCES

- Abbaspour, K.C. et al. 2007. Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of Hydrology*, 333: 413-430.
- Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R., 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. *Journal of the American Water Resources Association*, 34(1): 73-89.
- Notter, B., Abbaspour, K., Hurni, H., 2009. Setting up SWAT to quantify water-related ecosystem services in a large data-scarce watershed in East Africa. *Proceedings of the 5th International SWAT Conference*, Boulder, Colorado.