A Multi-agent system (MAS) coupled to the land use model WaSiM-ETH
Technical Description

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1 Running the coupled model as WASIM-ETH standalone application

During the calibration of both MPMAS and WASIM-ETH , it became apparent that both model components need to be run and calibrated as standalone applications: scientists feel more comfortable with the software of their expertise, and the exchange of data considerably complicates model runs, and undermines model transparency.
Thus, we have developed a method to run WASIM-ETH as standalone application: Input data on land use and irrigation are first generated in a coupled run, and then calibrated and investigated further in standalone mode. This allows publication in disciplinary journals, but also technical verification of the coupling setup: If external forcing is used from data exchanged in a coupled run, then model results in standalone mode should be equal to results from a coupled run.
Finally, we run the model in multiple runs:

1. In standalone run, without external forcing, as *Spinup-Run* (see Sec. **??** on page **??**). This spinup is used to stabilize the hydrological model numerically. Model data from the last time step is stored, and used to initialize all further runs.

2. Then, a fully coupled run is used to create the dynamic land use scenario, including irrigation by farm agents. Alternatively, land use may be "controlled" or externally fixed sector-wise: via some Excel sheets, land use is defined for each sector. For each soil type of each sector, MPMAS land use activities are defined. Irrigation is determined by "typical" water requirements, in a way that water suffices for 100% irrigation.

3. The data from the coupled run is processed: monthly output files (statistic files and inflows) are pasted together for the standalone application. Also, an irrigation table covering the full year is created. Based on the TimeHandler input data (`[SCEN]/input/dat/TimeHandler.dat`), it is determined which months are irrigated. The irrigation table is created from a water requirement table. Also, the control file over the full modeling time is automatically generated from the control file template (`[SCEN]/iniFiles/template.str` or as named in `[SCEN]/iniFiles/filenames.ini`), using the routine `xxxx`. All routines mentioned are described in detail in section **??**.

4. Finally, WASIM-ETH can be run as standalone application. WASIM input data have the usual format hydrologists are accustomed to, which facilitates calibration and validation.

5. After the WaSiM model was re-calibrated, it can be re-run in coupled mode: Thus, the control file template has to be updated to all changes, by hand.

More detail on the technical solution is given in section 2

2 Preparing and running a WaSiM-ETH standalone application after a coupled run

As motivated and summarized in section 1 on page 1, is is both usefull and necessary to run a complex coupled model as standalone application, with the same data that was used in a single run. This chapter is a technical, step-by-step description how to create WaSiM-ETH input data that allow standalone runs.
Technically, the following steps have to be taken:

1	**Creation of Inflow files**
	All inflow files (*"zl"*-folder) that were active during the coupled model run are used to create a single inflow file over the full model time, for both dry runs and irrigation runs
	`glueAbstractionInflowFiles.exe` $PATH_OUTPUT — Path for outputs of this routine $PATH_WASIM — Path of WaSiM outputs output — Start of monthly output directories $PATH/TimeHandler.dat — Position and name of time handler data

2	**Creation of abstraction files**
	From all monthly abstraction files created during coupling, full-time abstraction files are created. These data are used only for validation, as they are not inputs.

3	**Creation of statistic files**
	For all statistic files, another routine is used.
	`glueAllStatisticFiles.exe` $PATH_OUTPUT — Path for outputs of this routine $PATH_WASIM — Path of WaSiM outputs output — Start of monthly output directories $PATH/TimeHandler.dat — Position and name of time handler data $PATH/allFilenames_stat.txt — Characteristic letters of statistic files

From monthly irrigation, a full-time irrigation table needs to be created. This table should be consistent with monthly irrigation decisions given by MpMas . Currently, there is a two-step implementation to do so: First, a table has to be created by hand, which contains (a) background irrigation, and (b) the irrigation values consistent with the irrigation grid. Secondly, a routine is used to translate this table into a WASIM -formated irrigation table[1].

4	**Creation of table with irrigation data**
	Creation of table with irrigation values by hand. Two files help here: the background irrigation table (in `[SCEN]/iniFiles`), and a dynamically created extract that DataManager creates every year (in `[SCEN]/temp`). If land use is fixed externally, the irrigation table is automatically exported to directory `$SCENARIODIR/temp/`
	Use output `[SCEN]/temp/standalone_IrrigTable_yyyy.txt`, in [mm/day], and modify it

5	**Creation of table with irrigation data**
	A routine to create an irrigation table from input table created in step 4.
	`createIrrigTableFromFiles.exe` dirINPUT — Directory of input table created in step 4 fnINPUT — Name of input table created in step 4 fnOUTPUT — Name of output: Irrigation table $PATH/TimeHandler.dat — Position and name of time handler data

Finally, all files have to be linked, and written into a new control file for the full application.

6	**Creation of WASIM control file from template**
	A routine uses the control file template (in `[SCEN]/inifiles`, the time information of the time handler, and the irrigation table created in step 5, to create new control files for the full-time run.
	`CreateControlFileFromTemplate.exe` $PATH/fnTEMPLATE — Name of WASIM control file template $PATH/fnCONTROL — Name of output: Wasim control file $PATH/TimeHandler.dat — Position and name of time handler data $DIR_WASIM_IN — Path of requested WASIM inputs, for control file $DIR_WASIM_OUT — Path of requested WASIM output path, for control file [0 / 1] — Flag if irrigation tables should be included into control file [fnTemplateIrrigTable] — Irrigation table, as created in step 5

A script is provided to do all these steps, and consistent directories are already included and explained step-by-step (Appendix **??**).

[1] As some months have no irrigation, only dry run data is created during model coupling. Then, the full-time file contains irrigation-run-inflows during irrigation months, and dry-run-inflows during non-irrigation months.

3 Verification of WaSiM standalone applications

This section aims at technical verification of the coupling setup, in the sense that computer source code does what its supposed to do. We show that the technical realization of the coupling does not influence model outputs beyond deviations that we intentionally do for reasons of runtime. Methodologically, we create a standalone WaSiM model run with the same external forcing as created in the coupled run, and compare it to the "pasted" outputs of the coupled model, which runs at monthly time steps.

Model scenario used We specified land uses as shown in figure 1. Most areas are under staple crops, but the area also contains rice, some horticulture and fruit trees. Irrigation methods are furrow and drip irrigation (fig. 2). Average daily irrigation varies between 2 and 5 mm per day:

CropName* / Month	10	11	12	1	2	3
MAS0100203	1.9908	3.318	3.002	3.318	3.002	0
MAS0900205	3.318	3.318	3.002	0	0	0
MAS1070202	1.3272	0.948	3.318	3.318	3.318	3.318
MAS1090202	1.3272	0.948	3.318	3.318	3.318	3.318
MAS1160202	1.3272	0.948	3.318	3.318	3.318	3.318
MAS1770204	3.2864	4.108	4.108	4.108	4.108	3.002
MAS1800204	3.2864	4.108	4.108	4.108	4.108	3.002
MAS2800305	3.45625	3.456	3.456	3.456	3.014	3.014

**The CropName contains a three numbers, with 3-2-2 digits. The first three digits encode the farmers' cropping activity. Then, two digits describe the irrigation method. The last two are internal use only.*

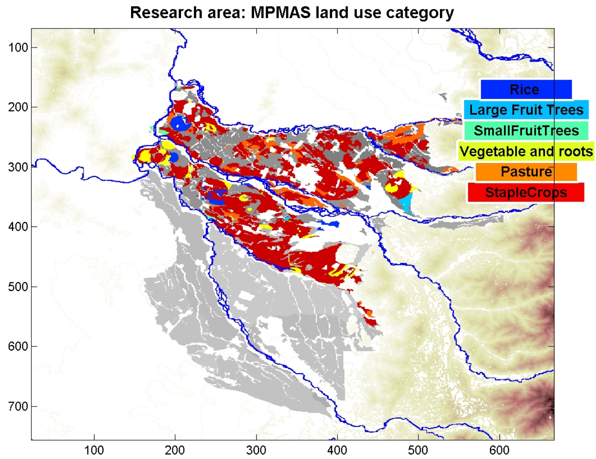

Figure 1: *Land uses as defined for a subset of sectors.*

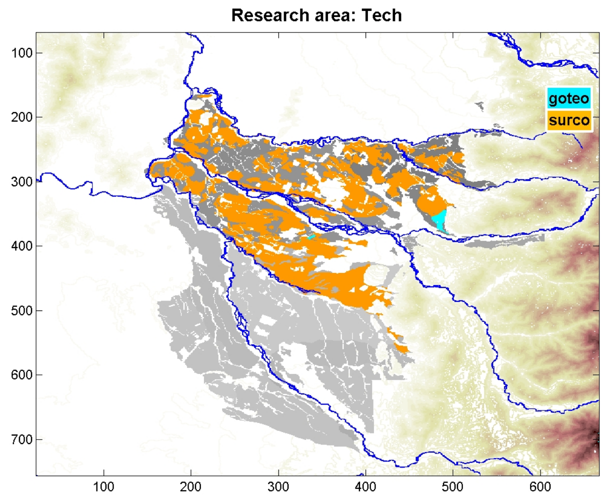

Figure 2: *Irrigation area, and irrigation methods used*

Technical realization WaSiM is re-started every month from a memory dump, then runs for one month without irrigation within the research area, to assess water availability. In the end of the month, the memory is dumped to files, and outputs are evaluated. Water availability in the rivers is analyzed: From river flows, the value of all water rights are determined, and an actual quantity of water is computed and attributed to farmers. Based on the farmer's water endowments, the MpMas model determines the amount of irrigation water they apply to every grid cell, and a map is passed to the WaSiM model (in [l/s]). For the same month, the hydrological application is run for a second time, now with full irrigation as chosen by farmers.
The first "dry" run is initialized from "dry-run-data" of the previous month, and "irrigation runs" are initialized with last-month's irrigation run. Thus, the soil water content is very different in both runs, as the "dry-run-scenario" shows the system without irrigation.

When the irrigation period is over, we decided to continue the model only in dry-run-mode. After finishing the coupled application, the monthly WaSiM outputs (inflows, abstractions and statistic files) from all irrigation runs are pasted together into full-run files. During the wet winter months where no irrigation takes place (April - September), we use dry-run-outputs. This results in a sudden discontinuity of soil moisture from irrigated, wet soil during March, to the dried-out soils in April. This shift is abrupt in the coupling setup, but smooth when running the standalone model: here, soils slowly dry out during end of summer, until winter rainfall starts. At the beginning of the cropping period, the outputs are again equal, as soils have returned to their "natural" moisture.

The graphs in the annex show three types of variables as output in statistic files. The first type is data generated internally in WaSiM-ETH , from external input data and before any dynamics. This type of data includes the spatial map of rainfall as interpolated from measurements (see fig. 3), and likewise air humidity, solar radiation, and wind speed. The statistic file generated from the coupled run ("glued"' or "pasted" together) is exactly the same as the one generated in standalone mode.
The second type of outputs is the one controlled externally during the coupling, mainly through the irrigation table and land use. Figure 4 shows the amount of daily irrigation water that was taken from surface water, averaged over a complete sub basin. This value corresponds to the input table of the control file (see paragraph on model scenario). The outputs do not correspond perfectly, as only a part of the sub basin area is irrigated, and the unit of the statistic file is "average irrigation water abstraction per spatial unit of the full sub basin". In addition, the coupling setup deviates from the standalone setup during the first day of every application. The relative change ($\frac{\Delta q_{irr}}{q_{irr,\, coupl}}$) is very large on this day due to division with zero.
The third type of outputs are "real" or dynamically computed outputs, such as fluxes, moisture levels, and groundwater recharge. The strongest deviation between both model runs is observed, as expected, in April when the coupled model uses dry-run data. Figure **??** shows the time development of soil moisture in the top meter. In the standalone run, the "real" development of soil moisture is reproduced. The coupled run strongly under-estimates soil moisture in April, as dry-run data are used. This error converges to zero at the end of the wet period (September). This phenomenon also translates into direct runoff data (fig. 6), as water during April is absorbed by the dry soil.

A Graphs

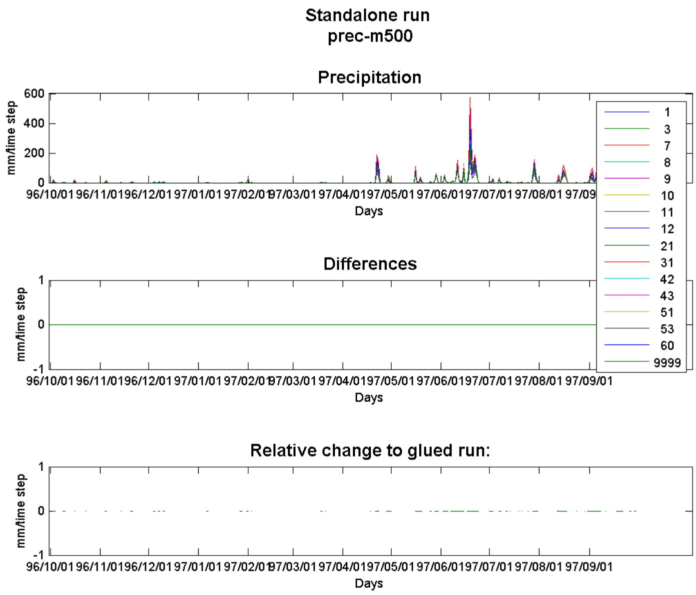

Figure 3: *Comparison of coupled (glued) and standalone* WASIM-ETH *outputs. The graph was generated by comparing statistic files that were generated directly from input files, such as wind speed, or here air humidity. These data was interpolated from input time series only. The top graph shows the daily precipitation, in mm. The system is dominated by heavy rainfalls during winter (Mai-September). The middle graph shows differences between both runs, in absolute terms. The bottom graph shows the relative difference, in percent. Both absolute and relative differences are zero.*

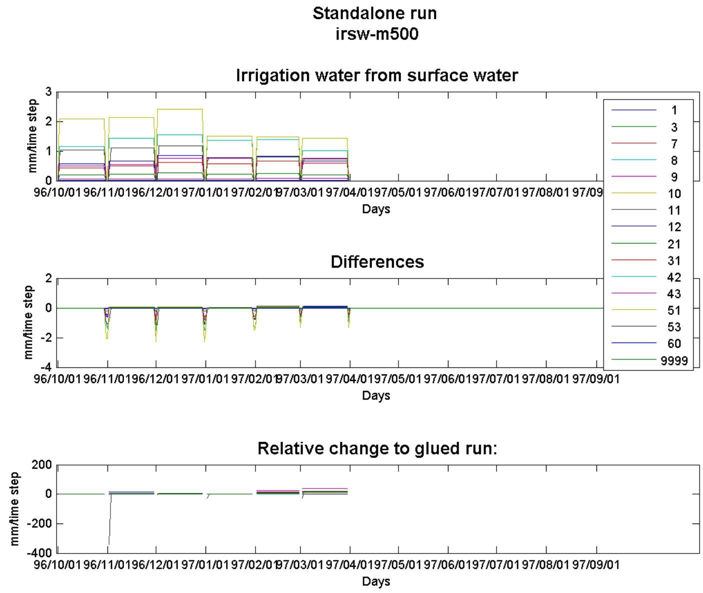

Figure 4: *Comparison of coupled (glued) and standalone* WASIM-ETH *outputs for quantity of irrigation water, averaged over* WASIM *sub basins. This value is bellow the actual irrigation quantity per hectare, as the average also considers non-irrigated areas. The bottom graph shows the relative difference, in percent. Both absolute and relative differences are zero.*

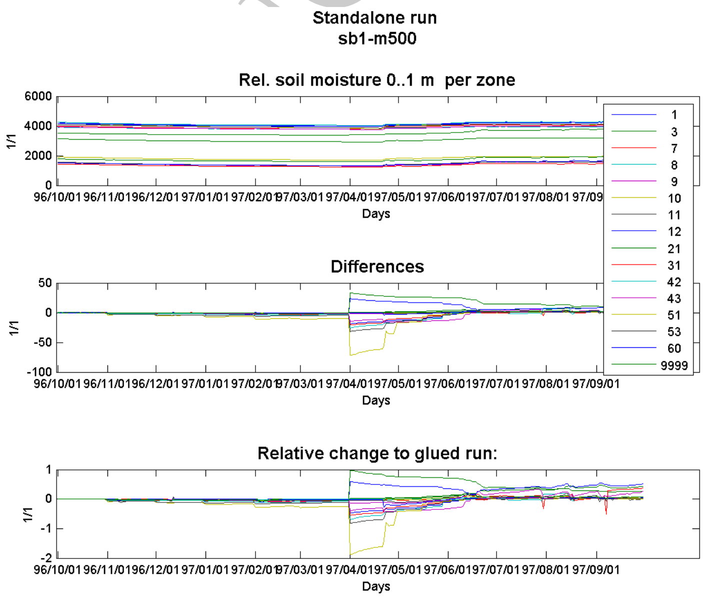

Figure 5: *During the month directly after irrigation, the lack of soil moisture is obvious.*

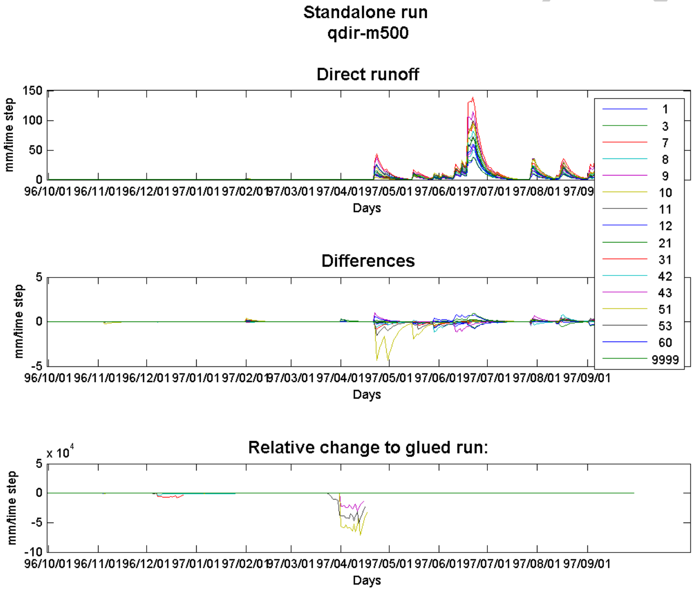

Figure 6: *The dry soil of the coupled run reduces direct surface runoff into the river system in April and May.*