

## 5 Water (hydrological models)

### 5.1 Scenarios

Climate & CO <sub>2</sub> concentration scenarios	
<b>picontrol</b>	Pre-industrial climate and 286ppm CO <sub>2</sub> concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
<b>historical</b>	Historical climate and CO <sub>2</sub> concentration.
<b>rcp26</b>	Future climate and CO <sub>2</sub> concentration from RCP2.6.
<b>rcp60</b>	Future climate and CO <sub>2</sub> concentration from RCP6.0.
<b>rcp85</b>	Future climate and CO <sub>2</sub> concentration from RCP8.5.
Human influence and land use	
<b>1860soc</b>	Pre-industrial human influences. Given the small effect of dams & reservoirs before 1900, modellers may apply the 1901 dam/reservoir configuration during the pre-industrial period and the 1861-1900 part of the historical period if that is significantly easier than applying the 1861 configuration. <b>Please indicate in the metadata of the file and the model description on the ISIMIP website which option you used.</b>
<b>histoc</b>	Varying historical land use and other human influences.
<b>2005soc</b>	Fixed year-2005 land use and other human influences.
<b>nosoc</b>	<b>No direct human influences on the water cycle. This is only for models that do not represent any water abstraction. Such model simulations should be labeled “nosoc” even if human land-use is represented.</b>
<b>rcp26soc</b>	Varying water abstraction <b>and land use</b> according to SSP2 and RCP2.6; fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.

<b>rcp60soc</b>	Varying water abstraction <b>and land use</b> according to SSP2 and RCP6.0, fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.
<b>2100rcp26soc</b>	Human influences <b>and land use</b> fixed at year 2100 levels according to RCP2.6.

For the historical period, groups that have limited computational capacities may choose to report only part of the full period, but including at least 1961-2005. All other periods should be reported completely.

5 For the purpose of the global water sector, “**human influences**” is defined as human interference directly with the hydrological fluxes of the water cycle for the purposes of any one or several of: water management (e.g. dams/reservoirs), irrigation, domestic water use, manufacturing and livestock production. I.e. human land use alone does not represent a human influence.

10 For those models that do not represent *changes* in human influences, those influences should be held fixed at 2005 levels throughout all Group 1 (cf. **2005soc** marked as dashed blue lines in Fig. 1) and Group 2 simulations. Group 3 will be identical to Group 2 for these models and thus does not require additional simulations. Models that do not include **any** human influences *at all* (**as defined above**) should nevertheless run the Group 1 and Group 2 simulation, since these simulations will still allow for an exploration of the effects of climate change compare to pre-industrial climate, and will also allow for a better assessment of the relative importance of human impacts versus climate impacts. These runs should be named as **nosoc** simulations (**even if human land use is included**).

15 The regional-scale simulations are performed for 12 large river basins. In six river basins (Tagus, Niger, Blue Nile, Ganges, Upper Yangtze and Darling) water management (dams/reservoirs, water abstraction) **should** be implemented. In the other six river basins, human influences such as LU changes, dams and reservoirs, and water abstraction is not relevant (Upper Yellow, Upper Amazon) or negligible (Rhine, Lena, Upper Mississippi), and can be ignored. Apart from this, regional water simulations should follow the global water simulations to allow for a cross-scale comparison of the simulations. The focus lakes for the local lake models are located within the focus river basins and listed in section 5.2.

**Table 9** ISIMIP2b scenarios for global and regional water simulations. \*Option 2 only if option 1 not possible. Option 3 only if neither option 1 nor option 2 are possible. Simulations must follow a single row for each experiment; mixing of different options is not possible! \*\*If you can only run simulations with 2005soc, then it is sufficient to provide only 200 years worth of picontrol climate (1661-1860).

Experiment	Input	pre-industrial	historical	future	extended future	
		1661-1860	1861-2005	2006-2099	2100-2299	
I	no climate change, pre-industrial CO <sub>2</sub>	Climate & CO <sub>2</sub>	<b>picontrol</b>	<b>picontrol</b>	<b>picontrol</b>	<b>picontrol</b>

	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU	Option 1: <b>1860soc</b>	Option 1: <b>histsoc</b>	Option 1: <b>2005soc</b>	Option 1: <b>2005soc</b>
			Option 2*: <b>2005soc</b>	Option 2*: <b>2005soc**</b>	Option 2*: <b>2005soc**</b>	Option 2*: <b>2005soc**</b>
			Option 3*: <b>nosoc</b>	Option 3*: <b>nosoc</b>	Option 3*: <b>nosoc</b>	Option 3*: <b>nosoc</b>
II	RCP2.6 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	historical	rcp26	rcp26
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU		Option 1: <b>histsoc</b>	Option 1/2*: <b>2005soc</b>	Option 1/2*: <b>2005soc</b>
				Option 2*: <b>2005soc</b>	Option 3*: <b>nosoc</b>	Option 3*: <b>nosoc</b>
III	RCP6.0 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp60	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			Option 1/2*: <b>2005soc</b>	
					Option 3*: <b>nosoc</b>	
IV	no climate change, pre-industrial CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment I	picontrol	picontrol
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
V	no climate change, pre-industrial CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment I	picontrol	not simulated

	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	
VI	RCP2.6 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp26	rcp26
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp60	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	
VIII	RCP8.5 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp85	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			Option 1/2*: 2005soc	
					Option 3*: nosoc	
IX	Optional: RCP6.0 climate & CO <sub>2</sub> with improved bias-correction and statistical downscaling of climate variables (ewembi-improved)	Climate & CO <sub>2</sub>	picontrol	historical	rcp60	not simulated
	LU & human influences fixed at 2005 levels	Human & LU	Option 1: 1860soc	Option 1: histsoc	Option 1/2*: 2005soc	
			Option 2*: 2005soc	Option 2*: 2005soc		
			Option 3*: nosoc	Option 3*: nosoc	Option 3*: nosoc	

## 5.2 Global and regional hydrological models

Variable names are chosen to comply, where feasible, with the ALMA convention ([www.lmd.jussieu.fr/~polcher/ALMA/convention\\_output\\_3.html](http://www.lmd.jussieu.fr/~polcher/ALMA/convention_output_3.html)) and the names used in WATCH/WaterMIP. All variables are to be reported as time-averages with the indicated resolution; do not report instantaneous values ('snapshots'). Exceptions are **maxdis** and **mindis**, which are the maximum and minimum daily-average discharge in a given month, respectively, to be reported on a monthly basis (see below).

### 5 5.2.1 Output data

**Table 10** Output variables to be reported by water sector models. Variables highlighted in orange are requested from both global and regional models; discharge at gauge level (highlighted in purple) is requested only from regional models; other (i.e. not shaded) variables are requested only from global models. Variables marked by \* are also relevant for the permafrost sector and also listed there. Variables marked by \*\* are **only** relevant for the permafrost sector.

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Hydrological Variables				
*Runoff	<b>qtot</b>	kg m <sup>-2</sup> s <sup>-1</sup>	daily (0.5°x0.5°)	total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly.
Surface runoff	<b>qs</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff
Subsurface runoff	<b>qsb</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Sum of water that flows out from subsurface layer(s) including the groundwater layer (if present). Equals qg in case of a groundwater layer below only one soil layer
Groundwater recharge	<b>qr</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Water that percolates through the soil layer(s) into the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.

Groundwater runoff	<b>qg</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Water that leaves the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Discharge (gridded)	<b>dis</b>	m <sup>3</sup> s <sup>-1</sup>	daily (0.5°x0.5°)	If daily resolution not possible, please provide monthly
Discharge (gauge level)	<b>dis</b>	m <sup>3</sup> s <sup>-1</sup>	daily (see website for gauge locations)	If daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	<b>maxdis</b>	m <sup>3</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Monthly minimum of daily discharge	<b>mindis</b>	m <sup>3</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	<b>evap</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Sum of transpiration, evaporation, interception losses, and sublimation.
Evapotranspiration	<b>evap</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (average for basin until gauge location)	Sum of transpiration, evaporation, interception losses, and sublimation.
Potential Evapotranspiration	<b>potevap</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	as for <i>evap</i> , but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture (= soil water storage)	<b>soilmoist</b>	kg m <sup>-2</sup>	monthly (0.5°x0.5°)	provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Soil moisture, root zone	<b>rootmoist</b>	kg m <sup>-2</sup>	monthly (0.5°x0.5°)	Total simulated soil moisture available for evapotranspiration. If simulated by the model. Please indicate the depth of the root zone for each vegetation type in your model

**Frozen soil moisture for each layer	<b>soilmoistfroz</b>	kg m-2	monthly (0.5°x0.5°)	water content of frozen soil
**Temperature of Soil	<b>tsl</b>	K	daily (0.5°x0.5°)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". Also need depths in meters. Daily would be great, but otherwise monthly would work. **if daily resolution not possible, please provide monthly
**Snow depth	<b>snd</b>	m	monthly (0.5°x0.5°)	Grid cell mean depth of snowpack.
*Snow water equivalent (= snow water storage)	<b>swe</b>	kg m-2	monthly (0.5°x0.5°)	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Total water storage	<b>tws</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in all compartments. Please indicate in the netcdf metadata which storage compartments are considered.
Canopy water storage	<b>canopystor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in the canopy.
Glacier storage	<b>glacierstor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in glaciers.
Groundwater storage	<b>groundwstor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in groundwater layer.
Lake storage	<b>lakestor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in lakes (except reservoirs).
Wetland storage	<b>wetlandstor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in wetlands.
Reservoir storage	<b>reservoirstor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in reservoirs.
River storage	<b>riverstor</b>	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in rivers.

*Annual maximum daily thaw depth	<b>thawdepth</b>	m	annual (0.5°x0.5°)	calculated from daily thaw depths, which do not need to be submitted themselves.
Rainfall	<b>rainf</b>	kg m-2 s-1	monthly (0.5°x0.5°)	These variables are required for test purposes only. If you need to reduce output data volumes, please provide these variables only once, with the first (test) data set you submit, e.g. for the first decade of each experiment. NOTE: rainf + snowf = total precipitation
Snowfall	<b>snowf</b>	kg m-2 s-1	monthly (0.5°x0.5°)	
Water management variables (for models that consider water management/human impacts)				
<b>NOTE:</b> Models that cannot differentiate between water-use sectors may report the respective totals and include the first letter of each sector included in the filenames. E.g. combined potential water withdrawal in the irrigation and livestock sectors would be “pi <sub>l</sub> ww”; combined actual water consumption in the irrigation, domestic, manufacturing, electricity, and livestock sectors would be “ai <sub>dme</sub> luse” (see section 2.6 for the latest naming convention regarding file names).				
Irrigation water demand (=potential irrigation water Withdrawal)	<b>pirrww</b>	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	<b>airrww</b>	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, taking water availability into account; please provide if computed
Potential irrigation water consumption	<b>pirruse</b>	kg m-2 s-1	monthly (0.5°x0.5°)	portion of withdrawal that is evapo-transpired, assuming unlimited water supply
Actual irrigation water consumption	<b>airruse</b>	kg m-2 s-1	monthly (0.5°x0.5°)	portion of withdrawal that is evapotranspired, taking water availability into account; if computed



Actual green water consumption on irrigated cropland	<b>airrusegreen</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	actual evapotranspiration from rain water over irrigated cropland; if computed
Potential green water consumption on irrigated cropland	<b>prrusegreen</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	potential evapotranspiration from rain water over irrigated cropland; if computed and different from airrusegreen
Actual green water consumption on rainfed cropland	<b>arainfusegreen</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	actual evapotranspiration from rain water over rainfed cropland; if computed
Actual domestic water withdrawal	<b>adomww</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual domestic water consumption	<b>adomuse</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual manufacturing water withdrawal	<b>amanww</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual Manufacturing water consumption	<b>amanuse</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual electricity water withdrawal	<b>aelecww</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual electricity water consumption	<b>aelecuse</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed

Actual livestock water withdrawal	<b>aliveww</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Actual livestock water consumption	<b>aliveuse</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	if computed
Total (all sectors) actual water consumption	<b>Atotuse</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Sum of actual water consumption from all sectors in case it is not possible to provide this information sector-specific.
Total (all sectors) actual water withdrawal	<b>Atotww</b>	kg m <sup>-2</sup> s <sup>-1</sup>	monthly (0.5°x0.5°)	Sum of actual water withdrawal from all sectors in case it is not possible to provide this information sector-specific
Static output				
Soil types	<b>Soil</b>		static (0.5°x0.5°)	Soil types or texture classes as used by your model. Please include a description of each type or class, especially if these are different from the standard HSWD and GSWP3 soil types. Please also include a description of the parameters and values associated with these soil types (parameter values could be submitted as spatial fields where appropriate).
Leaf Area Index	<b>lai</b>	1	static (0.5°x0.5°) or monthly (0.5°x0.5°) where appropriate	if used by, or computed by the model
Agricultural variables (optional output for all water models that also simulate crop yields)				
Crop yields	<b>yield-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	dry matter (t ha <sup>-1</sup> per growing season)	per growing season (0.5°x0.5°)	irrigation setting = "cirr" for "constraint irrigation" or "noirr" for rainfed

Actual planting dates	<b>plantday-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	Day of year	per growing season (0.5°x0.5°)	Julian dates
Actual planting year	<b>plantyear-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	Year of planting	per growing season (0.5°x0.5°)	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of planting that is also easy to follow for potential users from outside the project.
Anthesis dates	<b>Anthday-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	Day of year of anthesis	per growing season (0.5°x0.5°)	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of anthesis added to the list of outputs (see below) it allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Year of anthesis	<b>anthyear-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	year of anthesis	per growing season (0.5°x0.5°)	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Maturity dates	<b>matyday-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	Day of year of maturity	per growing season (0.5°x0.5°)	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of maturity added to the list of outputs (see below) it allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Year of maturity	<b>matyyear-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	year of maturity	per growing season (0.5°x0.5°)	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Nitrogen application rate	<b>initr-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	kg ha <sup>-1</sup> per growing season	per growing season (0.5°x0.5°)	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).

Biomass yields	<b>biom-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	Dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	
Soil carbon emissions	<b>sco2-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	kg C ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	<b>sn2o-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	kg N2O-N ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrogen application rate	<b>initr-&lt;crop&gt;-&lt;irrigation setting&gt;</b>	kg ha-1 per growing season	per growing season (0.5°x0.5°)	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).

### Comments related to the optional agricultural outputs

5 Simulations should be provided for the four major crops (wheat, maize, soy, and rice) but output for other crops **and also bioenergy crops** is highly welcome, too. For each crop, yields should be reported separately for irrigated land (cirr for “constraint irrigation”) and rainfed conditions (noirr). This complements the full irrigation (firr) pure crop runs requested in the agriculture part of the protocol (section 10). Yields simulations provided in the water sector should account for irrigation water constraints and have to be labeled by the “cirr” to highlight the difference.

10 The reporting of the crop yield-related outputs differs from the reporting of other variables in the water sector, as it is not done according to time but according to growing seasons to resolve potential multiple harvests. The unit of the time dimension of the NetCDF v4 output file is thus “growing seasons since YYYY-01-01 00:00:00”. The first season in the file (with value time=1) is then the first complete growing season of the time period provided by the input data without any assumed spin-up data, which equates to the growing season with the first planting after this date. To ensure that data can be matched to individual years in post-processing, it is essential to also provide the actual planting dates (as day of the year), actual planting years (year), anthesis dates (as day of the year), year of anthesis (year), maturity dates (day of the year), and year of maturity (year). This procedure is identical to the GGCM convention (Elliott et al. 2015: The Global Gridded Crop Model intercomparison: data and modelling protocols for Phase 1) and part of this agricultural protocol (section 10).

Those models that cannot simulate time varying management/human impacts/fertilizer input should keep these fixed at year 2005 levels throughout the simulations (“2005soc” scenario in Group 1 (dashed line in **Figure 1**) and “2005soc” scenario in Group 2). They only need to run the first preindustrial period of Experiment I (1661-1860). Group 3 runs refer to models that are able to represent future changes in human management (varying crop varieties or fertilizer input). Assumptions about historical (Group 1) and future (Group 3) fertilizer inputs are harmonized and centrally provided within ISIMIP2b (Frieler et al., GMD, 2017).

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