4 Water (hydrological models)

4.1 Scenarios

Climate & CO_2 concentration scenarios	
picontrol	Pre-industrial climate and 286ppm CO_2 concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO_2 concentration.
rcp26	Future climate and CO_2 concentration from RCP2.6.
rcp60	Future climate and CO_2 concentration from RCP6.0.
rcp85	Future climate and CO_2 concentration from RCP8.5.
Human influence and land use	
1860soc	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. Please indicate in the metadata of the file and the model description on the ISIMIP website which option you used.
histsoc	Varying historical land use and other human influences.
2005soc	Fixed year-2005 land use and other human influences.
nosoc	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.
rcp26soc	Varying water abstraction and land use 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.
rcp60soc	Varying water abstraction and land use 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.
2100rcp26soc	Human influences and land use 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.

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.

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 **Figure 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).

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 2.8. We also provide bias-corrected meteorological forcing data for regional-scale simulations, see Section 2.1.

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 1661-1860	historical 1861-2005	future 2006-2099	extended future 2100-2299
I	no climate change, pre-industrial CO_2	Climate & CO_2	**picontrol**	**picontrol**	**picontrol**	**picontrol**
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU	Option 1: **1860soc**	Option 1: **histsoc**	Option 1: **2005soc**	Option 1: **2005soc**
			Option 2*: **2005soc**	Option 2*: **2005soc****	Option 2*: **2005soc****	Option 2*: **2005soc****
			Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**
II	RCP2.6 climate & CO_2	Climate & CO_2	Experiment I	**historical**	**rcp26**	**rcp26**
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU		Option 1: **histsoc**	Option 1/2*: **2005soc**	Option 1/2*: **2005soc**
				Option 2*: **2005soc**		
				Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**
III	RCP6.0 climate & CO_2	Climate & CO_2	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*: **2005soc**	
					Option 3*: **nosoc**	

IV	no climate change, pre-industrial CO_2	Climate & CO_2	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_2	Climate & CO_2	Experiment I	Experiment I	**picontrol**	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			**rcp60soc**	
VI	RCP2.6 climate & CO_2	Climate & CO_2	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_2	Climate & CO_2	Experiment I	Experiment II	**rcp60**	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			**rcp60soc**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	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**	

4.1.1 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) 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).

4.2 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	**qtot**	kg m-2 s-1	daily (0.5°x0.5°)	Total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly.
Surface runoff	**qs**	kg m-2 s-1	monthly (0.5°x0.5°)	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff
Subsurface runoff	**qsb**	kg m-2 s-1	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	**qr**	kg m-2 s-1	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 recharge	**qr**	kg m-2 s-1	monthly (average for basin until gauge location)	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	**qg**	kg m-2 s-1	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)	**dis**	m3 s-1	daily (0.5°x0.5°)	If daily resolution not possible, please provide monthly
Discharge (gauge level)	**dis**	m3 s-1	daily (see website for gauge locations)	If daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	**maxdis**	m3 s-1	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	**mindis**	m3 s-1	monthly (0.5°x0.5°)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	**evap**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of transpiration, evaporation, interception losses, and sublimation.
Evapotranspiration	**evap**	kg m-2 s-1	monthly (average for basin until gauge location)	Sum of transpiration, evaporation, interception losses, and sublimation.
Potential Evapotranspiration	**potevap**	kg m-2 s-1	monthly (0.5°x0.5°)	As for *evap*, but with all resistances set to zero, except the aerodynamic resistance.
Potential Evapotranspiration	**potevap**	kg m-2 s-1	monthly (average for basin until gauge location)	As for *evap*, but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture (= soil water storage)	**soilmoist**	kg m-2	monthly (0.5°x0.5°)	Please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. If depth varies over time

				or space, see instructions for depth layers on https://www.isimip.org/protocol/preparing-simulation-files.
*Soil moisture (= soil water storage)	**soilmoist**	kg m-2	monthly (average for basin until gauge location)	Please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. If depth varies over time or space, see instructions for depth layers on https://www.isimip.org/protocol/preparing-simulation-files.
Soil moisture, root zone	**rootmoist**	kg m-2	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	**soilmoistfroz**	kg m-2	monthly (0.5°x0.5°)	Water content of frozen soil
**Temperature of Soil	**tsl**	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	**snd**	m	monthly (0.5°x0.5°)	Grid cell mean depth of snowpack.
*Snow water equivalent (= snow water storage)	**swe**	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	**tws**	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	**canopystor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in the canopy.
Glacier storage	**glacierstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in glaciers.
Groundwater storage	**groundwstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in groundwater layer.
Lake storage	**lakestor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in lakes (except reservoirs).
Wetland storage	**wetlandstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in wetlands.
Reservoir storage	**reservoirstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in reservoirs.
River storage	**riverstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in rivers.

*Annual maximum daily thaw depth	**thawdepth**	m	annual (0.5°x0.5°)	Calculated from daily thaw depths, which do not need to be submitted themselves.
River temperature	**triver**	K	monthly (0.5°x0.5°)	Mean monthly water temperature in river (representative of the average temperature across the channel volume).
Rainfall	**rainf**	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	**snowf**	kg m-2 s-1	monthly (0.5°x0.5°)	
Water management variables (for models that consider water management/human impacts)				
Irrigation water demand (=potential irrigation water Withdrawal)	**pirrww**	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	**airrww**	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	**pirruse**	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	**airruse**	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	**airrusegreen**	kg m-2 s-1	monthly (0.5°x0.5°)	Actual evapotranspiration from rain water over irrigated cropland; if computed
Potential green water consumption on irrigated cropland	**pirrusegreen**	kg m-2 s-1	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	**arainfusegreen**	kg m-2 s-1	monthly (0.5°x0.5°)	Actual evapotranspiration from rain water over rainfed cropland; if computed
Actual domestic water withdrawal	**adomww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual domestic water consumption	**adomuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual manufacturing water withdrawal	**amanww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual manufacturing water consumption	**amanuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed

Actual electricity water withdrawal	**aelecww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual electricity water consumption	**aelecuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual livestock water withdrawal	**aliveww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual livestock water consumption	**aliveuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Total (all sectors) actual water consumption	**atotuse**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of actual water consumption from all sectors. Please indicate in metadata which sectors are included
Total (all sectors) actual water withdrawal	**atotww**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of actual water withdrawal from all sectors. Please indicate in metadata which sectors are included
Total (all sectors) water demand (=potential water withdrawal)	**ptotww**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of potential (i.e., assuming unlimited water supply) water withdrawal from all sectors. Please indicate in metadata which sectors are included
Total (all sectors) potential water consumption	**ptotuse**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of potential (i.e., assuming unlimited water supply) water consumption from all sectors. Please indicate in metadata which sectors are included
Other				
Potential manufacturing water consumption	**pmanuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Potential manufacturing water withdrawal	**pmanww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Potential domestic water consumption	**pdomuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Potential domestic water withdrawal	**pdomww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual industrial wáter consumption	**ainduse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Actual industrial water withdrawal	**aindww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed
Static output				
Soil types	**soil**		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	**lai**	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	**yield-<crop>-<irrigation setting>**	dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	Irrigation setting = “cirr” for “constraint irrigation” or “noirr” for rainfed
Actual planting dates	**plantday-<crop>-<irrigation setting>**	Day of year	per growing season (0.5°x0.5°)	Julian dates
Actual planting year	**plantyear-<crop>-<irrigation setting>**	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	**anthday-<crop>-<irrigation setting>**	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	**anthyear-<crop>-<irrigation setting>**	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	**matyday-<crop>-<irrigation setting>**	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	**matyyear-<crop>-<irrigation setting>**	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	**initr-<crop>-<irrigation setting>**	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).
Biomass yields	**biom-<crop>-<irrigation setting>**	Dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	
Soil carbon emissions	**sco2-<crop>-<irrigation setting>**	kg C ha-1	per growing season (0.5°x0.5°)	Ideally should be modelled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	**sn2o-<crop>-<irrigation setting>**	kg N2O-N ha-1	per growing season (0.5°x0.5°)	Ideally should be modelled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrogen application rate	**initr-<crop>-<irrigation setting>**	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).

If storage issues keep you from reporting daily data, please contact the ISIMIP team to discuss potential solutions.

Comments related to the optional agricultural outputs

Simulations should be provided for the four major crops (wheat, maize, soy, and rice) but output for other crops and also bioenergy crops are highly welcome, too. See **Section 9.2** for more information on crop priority and naming list**.** 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 9). Yields simulations provided in the water sector should account for irrigation water constraints and have to be labelled by the “cirr” to highlight the difference.

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 GGCMI 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 9).

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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