5 Water (hydrological models)

5.1 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
Human influence and land-use scenarios	
1860soc	Pre-industrial land use and other 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.
histsoc	Varying historical land use and other human influences.
2005soc	Fixed year-2005 land use and other human influences.
rcp26soc	Varying land use, water abstraction and other human influences 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 land use, water abstraction and other human influences 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	Land use and other human influences 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 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 human influences *at all* 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.

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) will 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.

	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 2*: **2005soc**	Option 1: **histsoc** Option 2*: **2005soc**	**2005soc**	**2005soc**
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 2*: **2005soc**	**2005soc**	**2005soc**
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			**2005soc**	
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**	

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) 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).

5.2.1 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 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	Resolution	Unit (NetCDF format)	Comments

Hydrological Variables				
*Runoff	qtot	daily (0.5°x0.5°)	kg m^{-2} s^{-1}	total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly.
Surface runoff	qs	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff
Subsurface runoff	qsb	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	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	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	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	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	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	daily (0.5°x0.5°)	m^3 s^{-1}	If daily resolution not possible, please provide monthly
Discharge (gauge level)	dis	daily (see website for gauge locations)	m^3 s^{-1}	If daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	maxdis	monthly (0.5°x0.5°)	m^3 s^{-1}	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Monthly minimum of daily discharge	mindis	monthly (0.5°x0.5°)	m^3 s^{-1}	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	evap	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	Sum of transpiration, evaporation, interception losses, and sublimation.

Potential Evapotranspiration	potevap	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	as for *evap*, but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture (= soil water storage)	soilmoist	monthly (0.5°x0.5°)	kg m^{-2}	provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Soil moisture, root zone	rootmoist	monthly (0.5°x0.5°)	kg m^{-2}	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	monthly (0.5°x0.5°)	kg m^{-2}	water content of frozen soil
**Temperature of Soil	tsl	daily (0.5°x0.5°)	K	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	monthly (0.5°x0.5°)	m	Grid cell mean depth of snowpack.
*Snow water equivalent (= snow water storage)	swe	monthly (0.5°x0.5°)	kg m^{-2}	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Total water storage	tws	monthly (0.5°x0.5°)	kg m^{-2}	Mean monthly water storage in all compartments. Please indicate in the netcdf metadata which storage compartments are considered.
Canopy water storage	canopystor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in the canopy.
Glacier storage	glacierstor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in glaciers.
Groundwater storage	groundwstor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in groundwater layer.

Lake storage	lakestor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in lakes (except reservoirs).
Wetland storage	wetlandstor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in wetlands.
Reservoir storage	reservoirstor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in reservoirs.
River storage	riverstor	monthly (0.5°x0.5°)	kg m-2	Mean monthly water storage in rivers.
*Annual maximum daily thaw depth	thawdepth	annual (0.5°x0.5°)	m	calculated from daily thaw depths, which do not need to be submitted themselves.
Rainfall	rainf	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	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	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	
Water management variables (for models that consider water management/human impacts)				
NOTE: 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 **i**rrigation and **l**ivestock sectors would be "pilww"; combined actual water consumption in the **i**rrigation, **d**omestic, **m**anufacturing, **e**lectricity, and **l**ivestock sectors would be "aidmeluse" (see sectjon 2.6 for the latest naming convention regarding file names).				
Irrigation water demand (=potential irrigation water Withdrawal)	pirrww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	airrww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	Irrigation water withdrawal, taking water availability into account; please provide if computed
Potential irrigation water consumption	pirruse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	portion of withdrawal that is evapo-transpired, assuming unlimited water supply

Actual irrigation water consumption	airruse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	portion of withdrawal that is evapotranspired, taking water availability into account; if computed
Actual green water consumption on irrigated cropland	airrusegreen	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	actual evapotranspiration from rain water over irrigated cropland; if computed
Potential green water consumption on irrigated cropland	pirrusegreen	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	potential evapotranspiration from rain water over irrigated cropland; if computed and different from airrusegreen
Actual green water consumption on rainfed cropland	arainfusegreen	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	actual evapotranspiration from rain water over rainfed cropland; if computed
Actual domestic water withdrawal	adomww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual domestic water consumption	adomuse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual manufacturing water withdrawal	amanww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual Manufacturing water consumption	amanuse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual electricity water withdrawal	aelecww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual electricity water consumption	aelecuse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Actual livestock water withdrawal	aliveww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed

Actual livestock water consumption	aliveuse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	if computed
Total (all sectors) actual water consumption	Atotuse	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	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	Atotww	monthly (0.5°x0.5°)	kg m^{-2} s^{-1}	Sum of actual water withdrawal from all sectors in case it is not possible to provide this information sector-specific
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	static (0.5°x0.5°) or monthly (0.5°x0.5°) where appropriate	1	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>	per growing season (0.5°x0.5°)	dry matter (t ha^{-1} per growing season)	irrigation setting = "cirr" for "constraint irrigation" or "noirr" for rainfed
Actual planting dates	plantday-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year	Julian dates

Actual planting year	plantyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Year of planting	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>	per growing season (0.5°x0.5°)	Day of year of anthesis	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>	per growing season (0.5°x0.5°)	year of anthesis	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>	per growing season (0.5°x0.5°)	Day of year of maturity	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>	per growing season (0.5°x0.5°)	year of maturity	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>	per growing season (0.5°x0.5°)	kg ha^{-1} per growing season	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>	per growing season (0.5°x0.5°)	Dry matter (t ha^{-1} per growing season)	
Soil carbon emissions	sco2-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg C ha^{-1}	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	sn2o-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg N_2O-N ha^{-1}	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrogen application rate	initr-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg ha^{-1} per growing season	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

Simulations should be provided for the four major crops (wheat, maize, soy, and rice) but output for other 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.

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 modeling 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).