7 Lakes

7.1 Experiments

Simulations of climate-change effects on lakes will be made using coupled lake-hydrodynamic and water-quality models. Models can operate on the global scale (uncalibrated) or on a number of case-study lakes (calibrated). Both global and local models will conduct the same set of simulations.

Table 14: Summary of experiments for lake models.

Climate Data	Scenario	Human Impacts	Other settings (sens-scenario)	# runs
WATCH-WFDEI	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3-W5E5	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3-EWEMBI	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
PGMFD v2.1 (Princeton)	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
WATCH (WFD)	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3

See **Table** 6 and **Table** 7 for an explanation of the nosoc, pressoc, and varsoc experiments. Depending on whether and how human influences are included, a given model may not be able to run all three experiments.

7.2 Sector-specific input data

Global lake models

Global-scale simulations should be performed either assuming a lake present in every pixel or using grid-scale lake fraction based on the Global Lake and Wetland Database (GLWD) (Lehner & Döll, 2004) and available on the DKRZ input data repository at /work/bb0820/ISIMIP/ISIMIP2a/InputData/lakes/pctlake.nc4 (Subin, Riley, & Mironov, 2012). Since a 0.5°x0.5° pixel potentially contains multiple lakes with different characteristics (e.g. in terms of bathymetry, transparency, fetch), it is not possible to fully represent this subgrid-scale heterogeneity. Instead, the global-scale lake simulations should represent a 'representative lake' for a given pixel. Consequently, no stringent requirement is imposed with respect to lake depth, light extinction coefficient or initial conditions.

For lake depth, modellers are encouraged to use the data from the Global Lake Data Base (GLDB). A regridded lake depth field based on GLDBv1 (Kourzeneva, 2010) is available at 0.5°x0.5° resolution on the DKRZ input data repository at /work/bb0820/ISIMIP/ISIMIP2a/InputData/lakes/lakedepth.nc4; this field was aggregated from 30 arc sec to 1.9°x2.5° and then interpolated again to 0.5°x0.5° (Subin, Riley, & Mironov, 2012), but modellers may choose to use the more recent GLDBv2 available at 30 arc sec (http://www.flake.igb-berlin.de/ep-data.shtml) (Choulga, Kourzeneva, Zakharova, & Doganovsky, 2014). Modellers are requested to document their approach regarding lake depth, light extinction coefficient and initial conditions in the ISIMIP Impact Model Database (www.isimip.org/impactmodels). In case the lake model has no built-in calculation of the light extinction coefficient, modellers may consider using the parameterisation proposed by (Shatwell, Thiery, & Kirillin, 2019): extcoeff = 5.681 * max(depth,1) ^(-0.795), derived from a collection of 1258 lakes, or the parameterisation proposed by (Håkanson, 1995): extcoeff = 1.1925 * max(lakedepth,1)^(-0.424), derived from 88 Swedish glacial lakes. Yet it should be noted that modellers are free to decide how to represent extinction coefficient.

Local lake models

Simulations will be made for case-study lakes selected based on the availability of high-quality meteorological and limnological observations, thereby aiming for a good spread across climates and lake types. Model inputs consist of the meteorological variables given in **Table** 1, water inputs from hydrological model simulations, and nutrient loads estimated using simple loading function (Haith & Shoemaker., 1987) (Schneiderman, Pierson, Lounsbury, & Zion, 2002) or statistical estimation procedures. In addition, site-specific data will be needed such as lake bathymetry data. Direct climate effects on lakes that influence factors such as water temperature stratification period, mixing depth etc. will be simulated using climate scenarios shown in **Table** 14, and water inflows from hydrologic model simulations based on the experiments described in Section 6. Lake water quality simulations, which affect factors such as phytoplankton and nutrient levels, will also need to include simple nutrient loading inputs linked to the hydrologic model simulations.

Reporting

All variables are to be reported as time-averages with the indicated resolution.

For depth-varying variables, data should be provided either as fully resolved vertical profiles, or, if that is not possible, as a mean of the epilimnion or mixed layer ("mean epi") and mean of the hypolimnion ("mean hypo"). When the lake is simulated as completely mixed or isothermal, the mean of the entire water column is assigned to the epilimnion, and the hyolimnion concentration is set to a missing value.

See section 5.1.5 for further information on file formatting.

Diagnostic for lake stratification

As density is a non-linear function of temperature and a global analysis requires examination of a wide range of lake temperatures it is preferable to use a density-derived definition of stratification to a purely temperature-related definition, as follows:

Calculate density (ρ) from temperature using the formula (Millero & Poisson, 1981):

ρ = 999.842594 + (6.793952 x 10-2 t) – (9.095290 x 10-3 t2) + (1.001685 x 10-4 t3) – (1.120083 x 10-6 t4) + (6.536336 x 10-9 t5),

where t is water temperature of the lake layer in °C.

Define the lake to be stratified whenever the density difference between the surface and the bottom of the lake is greater than 0.1 kg m-3. Note this definition does not distinguish between 'normal' and 'reverse' stratification. Reverse stratification means that the surface is colder than the bottom, but the surface water density is less than the maximum density of water, found particularly under ice. While a separate step can be used to distinguish these events by assessing whether the surface temperature is greater than or less than 3.98 °C, this separation is not requested by the protocol.

Note that the range of model outputs will vary from model to model. Below are generic outputs that capture the basic information provided by most lake-eutrophication models. Modelling groups whose models do not provide all information listed here are invited to report on the reduced set of variables implemented in their models.

7.3 Output Data

Table 15: Output variables to be reported by lake models.

Variable (long name)	Variable name	Unit (NetCDF format)	Spatial Resolution	Temporal Resolution	Depth Resolution	Comments
Hydrothermal Variables						
Thermal	**strat**	*unitless*	Representative lake	Daily	None	1 if lake grid cell is thermally stratified

stratification			associated with grid cell			0 if lake grid cell is not thermally stratified
Depth of Thermocline	**thermodepth**	m	Representative lake associated with grid cell	Daily	None	Depth corresponding the maximum water density gradient
Water temperature	**watertemp**	K	Representative lake associated with grid cell	Daily	Full Profile	Simulated water temperature. Layer averages and full profiles. See Section 5.1.5 for details on reporting
Surface temperature	**surftemp**	K	Representative lake associated with grid cell	Daily (monthly)	None	Average of the upper layer in case not simulated directly
Bottom temperature	**bottemp**	K	Representative lake associated with grid cell	Daily (monthly)	None	Average of the lowest layer in case not simulated directly
Lake ice cover	**ice**	*unitless*	Representative lake associated with grid cell	Daily	None	1 if ice cover is present in lake grid cell 0 if no ice cover is present in lake grid cell
Lake layer ice mass fraction	**lakeicefrac**	*unitless*	Representative lake associated with grid cell	Daily (monthly)	Mean Epi	Fraction of mass of a given layer taken up by ice
Ice thickness	**icethick**	m	Representative lake associated with grid cell	Daily (monthly)	None	
Snow thickness	**snowthick**	m	Representative lake associated with grid cell	Daily (monthly)	None	
Temperature at the ice upper surface	**icetemp**	K	Representative lake associated with grid cell	Monthly	None	
Temperature at the snow upper surface	**snowtemp**	K	Representative lake associated with grid	Monthly	None	

			cell			
Sensible heat flux at the lake-atmosphere interface	**sensheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	At the surface of snow, ice or water depending on the layer in contact with the atmosphere. **Positive if upwards.**
Latent heat flux at the lake-atmosphere interface	**latentheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	**See sensible heat flux**
Momentum flux at the lake-atmosphere interface	**momf**	kg m-1 s-2	Representative lake associated with grid cell	Daily (monthly)	None	**See sensible heat flux**
Upward shortwave radiation flux at the lake-atmosphere interface	**swup**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	**See sensible heat flux.** Not to be confused with net shortwave radiation
Upward longwave radiation flux at the lake-atmosphere interface	**lwup**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	**See sensible heat flux.** Not to be confused with net longwave radiation
Downward heat flux at the lake-atmosphere interface	**lakeheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	**See sensible heat flux** the residual term of the surface energy balance, i.e. the net amount of energy that enters the lake on daily time scale: lakeheatf = swdown - swup + lwdown - lwup - sensheatf - latenheatf (terms defined positive when directed upwards)
Turbulent diffusivity of heat	**turbdiffheat**	m2 s-1	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and	Only if computed by the model. See Section 5.1.5 for details on reporting

					mean hypo	
Surface albedo	**albedo**	*unitless*	Representative lake associated with grid cell	Daily (monthly)	None	Albedo of the surface interacting with the atmosphere (water, ice or snow)
Light extinction coefficient	**extcoeff**	m-1	Representative lake associated with grid cell	Constant	None	only to be reported for global models, local models should use extcoeff as input
Sediment upward heat flux at the lake-sediment interface	**sedheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	Positive if upwards. Only if computed by the model
Water Quality Variables						
Chlorophyll Concentration	**chl**	g-3 m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Total water chlorophyll concentration – indicator of phytoplankton. See Section 5.1.5 for details on reporting
Phytoplankton Functional group biomass	**phytobio**	mole m-3 as carbon	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Different models will have different numbers of functional groups so that the reporting of these will vary by model. See Section 5.1.5 for details on reporting
Zoo plankton biomass	**zoobio**	mole m-3 as carbon	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Total simulated Zooplankton biomass. See Section 5.1.5 for details on reporting
Total Phosphorus	**tp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	See Section 5.1.5 for details on reporting
Particulate Phosphorus	**pp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	See Section 5.1.5 for details on reporting

Total Dissolved Phosphorus	**tpd**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Some models may also output data for soluble reactive phosphorus (SRP). See Section 5.1.5 for details on reporting
Total Nitrogen	**tn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	See Section 5.1.5 for details on reporting
Particulate Nitrogen	**pn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	See Section 5.1.5 for details on reporting
Total Dissolved Nitrogen	**tdn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Some models may also output data for Nitrate (N02) nitrite (NO3) and ammonium (NH4). See Section 5.1.5 for details on reporting
Dissolved Oxygen	**do**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	See Section 5.1.5 for details on reporting
Dissolved Organic Carbon	**doc**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Not always available. See Section 5.1.5 for details on reporting
Dissolved Silica	**si**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Not always available. See Section 5.1.5 for details on reporting

7.4 Additional information for local lake models

7.4.1 Lake sites

Table 16: Lake site specifications for local lake models. A document with additional information is maintained by the sector coordinators and provided at https://docs.google.com/spreadsheets/d/1UY_KSR02o7LtmNoOs6jOgOxdcFEKrf7MmhR2BYDlm-Q/edit#gid=555498854.

Lake name	Lake name in file name (reporting)	Reservoir or lake?	Country	Latitude (dec deg)	Longitude (dec deg)
Allequash Lake	allequash	lake	USA	46,04	-89,62
Alqueva Reservoir	alqueva	reservoir	Portugal	38,20	-7,49
Lake Annecy	annecy	lake	France	45,87	6,17
Lake Annie	annie	lake	USA	27,21	-81,35
Lake Argyle	argyle	reservoir	Australia	-16,31	128,68
Lake Biel	biel	lake	Switzerland	47,08	7,16
Big Muskellunge Lake	big-muskellunge	lake	USA	46,02	-89,61
Black Oak Lake	black-oak	lake	USA	46,16	-89,32
Lake Bourget	bourget	lake	France	45,76	5,86
Lake Burley Griffin	burley-griffin	reservoir	Australia	-35,30	149,07
Crystal Lake	crystal-lake	lake	USA	46,00	-89,61

Crystal Bog	crystal-bog	lake	USA	46,01	-89,61
Delavan Lake	delavan	lake	USA	42,61	-88,60
Dickie Lake	dickie	lake	Canada	45,15	-79,09
Eagle Lake	eagle	lake	Canada	44,68	-76,70
Ekoln basin of Mälaren	ekoln	lake	Sweden	59,75	17,62
Lake Erken	erken	lake	Sweden	59,84	18,63
Esthwaite Water	esthwaite-water	lake	United Kingdom	54,37	-2,99
Falling Creek Reservoir	falling-creek	reservoir	USA	37,31	-79,84
Lake Feeagh	feeagh	lake	Ireland	53,90	-9,50
Fish Lake	fish	lake	USA	43,29	-89,65
Lake Geneva	geneva	lake	France/Switzerland	46,45	6,59
Great Pond	great	lake	USA	44,53	-69,89
Green Lake	green	lake	USA	43,81	-89,00
Harp Lake	harp	lake	Canada	45,38	-79,13

Kilpisjärvi	kilpisjarvi	lake	Finland	69,03	20,77
Lake Kinneret	kinneret	lake	Israel	32,49	35,35
Lake Kivu	kivu	lake	Rwanda/DR Congo	-1,73	29,24
Klicava Reservoir	klicava	reservoir	Czechia	50,07	13,93
Lake Kuivajarvi	kuivajarvi	lake	Finland	60,47	23,51
Lake Langtjern	langtjern	lake	Norway	60,37	9,73
Laramie Lake	laramie	lake	USA	40,62	-105,84
Lower Lake Zurich	lower-zurich	lake	Switzerland	47,28	8,58
Lake Mendota	mendota	lake	USA	43,10	-89,41
Lake Monona	monona	lake	USA	43,06	-89,36
Mozhaysk reservoir	mozhaysk	reservoir	Russia	55,59	35,82
Mt Bold	mt-bold	reservoir	Australia	-35,12	138,71
Lake Müggelsee	mueggelsee	lake	Germany	52,43	13,65
Lake Neuchâtel	neuchatel	lake	Switzerland	46.54	6.52
Ngoring	ngoring	lake	China	34,90	97,70

Lake Nohipalo Mustjärv	nohipalo-mustjaerv	lake	Estonia	57,93	27,34
Lake Nohipalo Valgejärv	nohipalo-valgejaerv	lake	Estonia	57,94	27,35
Okauchee Lake	okauchee	lake	USA	43,13	-88,43
Lake Pääjärvi	paajarvi	lake	Finland	61,07	25,13
Rappbode Reservoir	rappbode	reservoir	Germany	51,74	10,89
Rimov Reservoir	rimov	reservoir	Czechia	48,85	14,49
Lake Rotorua	rotorua	lake	New Zealand	-38.08	176.28
Lake Sammamish	sammamish	lake	USA	47,59	-122,10
Sau Reservoir	sau	reservoir	Spain	41,97	2,40
Sparkling Lake	sparkling	lake	USA	46,01	-89,70
Lake Stechlin	stechlin	lake	Germany	53,17	13,03
Lake Sunapee	sunapee	lake	USA	43,23	-72,50
Lake Tahoe	tahoe	reservoir	USA	39,09	-120,03
Lake Tarawera	tarawera	lake	New Zealand	-38,21	176,43

Lake Taupo	taupo	lake	New Zealand	-38,80	175,89
Toolik Lake	toolik	lake	USA	68,63	-149,60
Trout Lake	trout-lake	lake	USA	46,03	-89,67
Trout Bog	trout-bog	lake	USA	46,04	-89,69
Two Sisters Lake	two-sisters	lake	USA	45,77	-89,53
Lake Vendyurskoe	vendyurskoe	lake	Russia	62,10	33,10
lake Võrtsjärv	vortsjaerv	lake	Estonia	58,31	26,01
Lake Waahi	waahi	lake	New Zealand	37,33	175,07
Lake Washington	washington	lake	USA	47,64	-122,27
Windermere	windermere	lake	United Kingdom	54,31	-2,95
Lake Wingra	wingra	lake	USA	43,05	-89,43
Zlutice Reservoir	zlutice	reservoir	Czechia	50,09	13,11

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