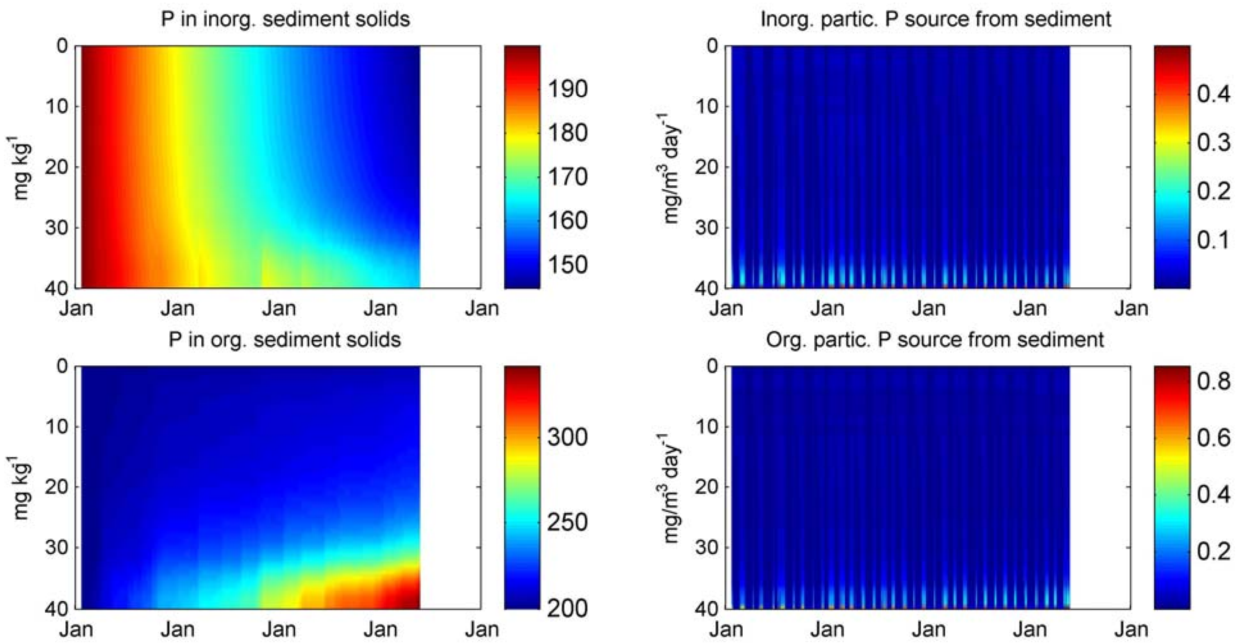
REPORT SNO (unpublished)

MyLake (v.1.2)

Technical model documentation and user's guide for version 1.2



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REPORT

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Abstract

MyLake (Multi-year Lake simulation model) is a one-dimensional process-based model code for simulation of daily 1) vertical distribution of lake water temperature and thus stratification, 2) evolution of seasonal lake ice and snow cover, and 3) phosphorus-phytoplankton dynamics. MyLake has a relatively simple and transparent model structure, it is easy to set up, and is suitable both for making predictions and scenarios, and to be used as an investigative tool. Short runtime allows application of comprehensive sensitivity and uncertainty analysis as well as simulation of a large number of lakes or over long periods (decades). MyLake aims to include only the most significant physical, chemical and biological processes in a well-balanced and robust way. This report gives a description of the updates and developments made to version 1.2 compared to the previous version 1.1 described in details in Saloranta and Andersen (2004).

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1. Modellering	1. modelling
2. Innsjø	2. lake
3. eutrofiering	3. eutrophication
4. MyLake	4. MyLake

Project manager | Research manager | Head of research department

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Preface

We thank the Norwegian Institute for Water Research (NIVA) for funding the MyLake model v.1.2 development work in project “Pcode”. The application and testing of MyLake model (v.1.2) was done mainly within the same project.

Oslo, 5. 10. 2005

Tuomo M. Saloranta

Contents

Summary

MyLake (Multi-year Lake simulation model) is a one-dimensional process-based model code for simulation of daily 1) vertical distribution of lake water temperature and thus stratification, 2) evolution of seasonal lake ice and snow cover, and 3) phosphorus-phytoplankton dynamics. MyLake has a relatively simple and transparent model structure, it is easy to set up, and is suitable both for making predictions and scenarios, and to be used as an investigative tool. Short runtime allows application of comprehensive sensitivity and uncertainty analysis as well as simulation of a large number of lakes or over long periods (decades). MyLake aims to include only the most significant physical, chemical and biological processes in a well-balanced and robust way. This report gives a description of the updates and developments made to version 1.2 compared to the previous version 1.1 described in details in Saloranta and Andersen (2004).

1. Introduction

MyLake (Multi-year Lake simulation model) is a one-dimensional process-based model code for simulation of daily 1) vertical distribution of lake water temperature and thus stratification, 2) evolution of seasonal lake ice and snow cover, and 3) phosphorus-phytoplankton dynamics. The lake water simulation part of the model code is based on Ford and Stefan (1980), Riley and Stefan (1988), and Hondzo and Stefan (1993), while the ice simulation code is based on Leppäranta (1991) and Saloranta (2000). MyLake has been developed at the Norwegian Institute for Water Research (NIVA), and the model has so far (spring 2005) been applied in BMW, THERMOS and EUROLIMPACS projects (Saloranta 2005, Lydersen et al. 2003). The overall structure of MyLake model code is shown in Table 1.

Strengths of MyLake model code include:

- MyLake has a relatively simple and transparent model structure, it is easy to set up, and is suitable both for making predictions and scenarios, and to be used as an investigative tool.
- Short runtime allows application of comprehensive sensitivity and uncertainty analysis as well as simulation of a large number of lakes or over long periods (decades).
- MyLake aims to include only the most significant physical, chemical and biological processes in a well-balanced and robust way.

There are, of course, limitations too. MyLake is a newcomer and only three previous applications are documented so far. More applications are needed before the model code can be said to be thoroughly tested in practise. However, the model building blocks are based on more or less well-established science and have been used previously in numerous applications. Some users may also consider the model too simple for their purposes, as many processes, e.g. zooplankton grazing and fish population dynamics are left out of the current version (v.1.2) of the model code. Other limitations may be the model time step which is preset to 24 hours and cannot be changed, as well as the 1-dimensional vertical resolution approach, which may not be so well suited for some particular types of problems and lakes.

Generally MyLake model code development aims to take into account the following five criteria adapted from Riley and Stefan (1988): 1) that the model code be general for use on different sites with minimum of alterations, 2) that the model code be capable of simulating a wide range of treatment options, 3) that the model code incorporate the dominant physical, chemical and biological processes, especially processes directly affected by various treatment options, 4) that the physical, chemical and biological components be modelled with similar orders of detail to reduce the possibility of a weak link in the modelling process, and 5) that the model be economical enough to run to serve as management tool.

This report gives a description of the updates and developments made to version 1.2, compared to the previous version 1.1 described in details in Saloranta and Andersen (2004).

2. Updates and developments in MyLake (v.1.2)

2.1 New model state variables

The single particulate phosphorus state variable that was used in the previous MyLake version 1.1 is in the current version 1.2 modified to represent only the phosphorus bound to inorganic particles. In addition, dissolved organic phosphorus (DOP) and dissolved organic carbon (DOC) are added as new state variables. Chlorophyll *a* now represents the particulate organic phosphorus fraction. The eight main model state variables, of which vertical profiles are simulated by MyLake v.1.2 are:

T	Temperature [°C]
C	Passive tracer [-]
S	Suspended inorganic particulate matter (functions also as a passive sedimenting tracer) [kg m^{-3}]
P_D	Dissolved inorganic phosphorus (phosphate) [µg l^{-1} = mg m^{-3}]
P_{IP}	Phosphorus bound to inorganic particles [µg l^{-1} = mg m^{-3}]
P_{DO}	Dissolved organic phosphorus [µg l^{-1} = mg m^{-3}]
P_{Chla}	Chlorophyll *a* [µg l^{-1} = mg m^{-3}]
DOC	Dissolved organic carbon [µg l^{-1} = mg m^{-3}]

2.2 Modelling the dissolved and particulate phosphorus fractions

The mass fraction of phosphorus bound to the profile S [kg m^{-3}] of suspended inorganic particulate matter in the water column is denoted by F_{IP} [mg kg^{-1}]. The concentration profile of phosphorus bound to suspended inorganic matter P_{IP} [mg m^{-3}] is thus:

$$P_{IP} = v\rho_{sed} F_{IP} = \frac{S}{\rho_{sed}} \rho_{sed} F_{IP} = SF_{IP} \qquad (1)$$

where v is the volume fraction of inorganic solids in water column or sediment ($v=V_{inorg}/(V_{inorg}+V_{\mathrm{water}})$), and ρ_{sed} [kg m^{-3}] is the density of inorganic solid matter. Similar equation applies also in the sediment and v for sediment can be calculated from the volume fraction of solids in the wet bulk sediment (i.e., 1 – porosity) ϕ [m^3 m^{-3}] and the volume fraction of inorganic matter in these solids υ_{inorg}.

$$v = \frac{\phi\upsilon_{inorg}}{\phi\upsilon_{inorg} + (1-\phi)} \tag{1b}$$

We assume an instant (~ in a timescale of less than a day) equilibrium partitioning between dissolved inorganic phosphorus P_D [mg m^{-3}] and F_{IP} [mg kg^{-1}] (Webster and Grace, 2001). This equilibrium is modelled using Langmuir isotherm approach. The sum of inorganic phosphorus taking part to the equilibrium partitioning P_T is assumed to be known ($P_T = TotP - P_{Chla}/y_c - P_{DO}$), where y_c is the yield coefficient, i.e. chlorophyll *a* to phosphorus ratio (see section 3.2.3), which can be assumed equal to one, i.e. 1 mg m^{-3} chlorophyll *a* = 1 mg m^{-3} phosphorus. The following pair of equations then applies to the system:

$$\begin{cases} P_T = P_{IP} + (1-v)P_D = v\rho_{sed}F_{IP} + (1-v)P_D \\ F_{IP} = F_{\max}\dfrac{P_D}{P_{sat}+P_D} + F_{stable} \end{cases} \tag{2}$$

where F_{max} [mg kg^{-1}] and P_{sat} [mg m^{-3}] are the saturation level and half saturation P_D concentration, respectively, describing the Langmuir isotherm, and F_{stable} [mg kg^{-1}] represents the inactive fraction of phosphorus firmly bound in the particles and not available for desorption. Note that the isotherm parameters F_{max} and P_{sat} should not include the contribution from F_{stable}.

An example: let's assume that F_{max} = 1000 mg kg^{-1}, P_{sat} = 10 mg m^{-3}, F_{stable} = 0 mg kg^{-1}, ρ_{sed} = 2500 kg m^{-3} and that initially the system is in equilibrium with P_D=10 mg m^{-3}, F_{IP}=500 mg kg^{-1}, S=0.067 kg m^{-3}, P_T=43.5 mg m^{-3}. If we now throw inorganic phosphorus-free particles into the water column so that S=0.2 kg m^{-3} (200% increase), then a new equilibrium would be P_D=2.6 mg m^{-3}, F_{IP}=204.5 mg kg^{-1}, P_T=43.5 mg m^{-3}. Thus P_D has been reduced by 74%, while F_{IP} has been reduced by 34%. P_T has, of course, remained the same.

The two remaining phosphorus fractions are P_{Chla} and P_{DO}. The unit of P_{Chla} is the actual chlorophyll *a* concentration [mg m^{-3}] but this is related to phosphorus units via the yield coefficient y_c. P_{DO} is mineralized to P_D (usually very slowly, i.e. the temperature dependent specific rate coefficient $k_{dop}(20)$ ~ 10^{-3}), but does not otherwise take part in any reactions in the water or sediment.

2.3 Dissolved organic carbon (DOC)

To be formulated…

2.4 Sediment-water interaction

We define an active, mixed sediment layer with depth H_{sed}, [m, wet sediment], resuspension rate of dry particles U_{res} [m d^{-1}] and diffusion rate for pore water-water column interaction $k_{seddiff}$ [m d^{-1}]. U_{res} equals the thickness of the daily resuspended layer of dry particles and different resuspension value can be defined in the model for epi- and hypolimnion which are separated by the simulated pycnocline depth. The active sediment layer consists of both inorganic (S) and organic (chlorophyll a) particles sedimenting from the water column, and we further define the volume fraction of dry inorganic matter in the total dry sediment solids, F_{IM}. Similar fraction of dry organic matter will be consequently 1-F_{IM}, and the conversion from P_{Chla} [mg m^{-3}] to concentration of dry particular organic matter S_{org} [kg m^{-3}] is by dividing P_{Chla} by $y_c F_{Porg}$, where F_{Porg}=12346 mg kg^{-1}, assuming a Redfield phosphorus to carbon weight ratio of 1:40 and a 50% carbon content in the organic algal matter.

The resuspended solids are taken as a source for the water column S, P_{IP} and P_{Chla}, while the net sedimenting matter changes concentrations of sediment P_{IP} and P_{Chla} via thickness-weighted averages of the concentrations in the sediment and in the sedimenting matter, where the thickness weights are (H_{sed} - H_{newsed}) and H_{newsed}, respectively, and where H_{newsed} denotes the wet bulk thickness of the newly sedimented inorganic or organic matter (assuming constant volume fraction of solids in the sediment ϕ). This implies also that old sediment of thickness H_{newsed} will be buried to inactive sediment layer.

A similar partitioning, as in the water column, between dissolved P_D in the sediment pore water and F_{IP} in the sediment solids applies also in the sediment. The parameter $k_{seddiff}$ denotes the thickness of the daily diffused pore water layer, and this pore water is mixed with the corresponding water layer above the sediment column. Similar amount of water from the corresponding water layer above the sediment column is mixed with the pore water. The sedimented chlorophyll a is assumed to be mineralised to P_D in the pore water, as in the water column, according to a temperature dependent specific rate coefficient $k(T)$. The concentration of P_{DO} in the pore water is assumed to be the same as in the water column above it, and due to the small volume of the pore water (compared to the water layers) its diffusion is not simulated.

If the active sediment layer is well oxidized, then most of the phosphorus in the sediment is bound to particles and thus particle resuspension (rate U_{res}) usually controls the phosphorus source from sediment to water. However, if the active sediment layer is anoxic then the particles' phosphorus sorption capacity is much lowered (i.e. F_{max} in equation 2 approaches zero) and most of the phosphorus is dissolved in the pore water, and thus pore water diffusion (rate $k_{seddiff}$) becomes the dominant process for the phosphorus source from sediment to water. (In future versions of MyLake the value F_{max} in equation 2, controlling the particles' phosphorus sorption capacity, could be coupled to the oxygen conditions in the sediment, e.g. via the oxygen profile in the water).

The amount of sedimentation for each layer is calculated using the difference between the "funnelling" and "non-funnelling" version of the advective-diffusive equation 30 in Saloranta and Andersen (2004), i.e. the concentration difference $\Delta C_{fun\text{-}nonfun}$ between these two versions of the equation

$$A\frac{\partial(\Delta C_{fun-nonfun})}{\partial t} = A\frac{\partial(wC_{nonfun})}{\partial z} - \frac{\partial(AwC_{fun})}{\partial z} \tag{3}$$

is multiplied by the volume of the corresponding layer to get the total amount sedimented during one time step.

Figure 1 shows a schematic illustration of the flow and transport processes between the different phoshorus fractions.

2.5 Other model code revisions

The structure of the code is somewhat rearranged from the previous version, as shown in Table 1. Also a new code module *convection.m* is introduced, handling the vertical convection due to instable water stratification.

The heat sources/sinks in the water column are now resolved twice during a day, both at day and night. The solar heat input is applied only in the daytime, while the sediment heat and total daily turbulent and long wave heat sources/sinks are first multiplied by the fractions of day when the sun angle is above and below a preset threshold value (currently 15°), respectively, and then applied for day- and nighttime periods. Convection is allowed to mix the water both after day- and nighttime, and thus the water surface temperature and consequently the turbulent and long wave heat fluxes will be somewhat different compared to the v.1.1 code where the whole daily heat flux was applied once a day.

The simulation of the heat flux from water to the ice is changed so that heat is allowed to diffuse into the first water layer, and the daily temperature increase above freezing point in this layer is used to melt ice at each time step at the bottom of the ice layer. The temperature of the first water layer is then set back to the freezing point.

The "sedimentation switch" with which one could switch off sedimentation processes in the model is removed and only the passive dissolved tracer is currently affected by the "tracer switch".

Table 1. Overview of MyLake v.1.2 model code structure

(Start)

For one model time step (24 h):

- Calculate daytime surface heat fluxes and wind stress, light attenuation, and phytoplankton growth and loss rates. Calculate also the heat flux between water and sediment.
- Apply daytime heat sources, allow convection, calculate nighttime surface heat sources and apply them, allow convection.
- Calculate profile of the diffusion coefficient K
- Solve new profile for each state variable taking into account advection, diffusion and local sources/sinks. Solving is done in following order: 1) temperature (after which convection is allowed), 2) tracer, 3) dissolved inorganic phosphorus (P_{DO}), 4) suspended inorganic particulate matter (S) and associated particle bound phosphorus (P_{IP}), 5) chlorophyll *a* (P_{Chla}), 6) dissolved phosphorus (P_D), 7) dissolved inorganic carbon (*DOC*).
- Update phosphorus concentration in the sediment (exchange between pore water and water column, net sedimentation and burial to inactive layer, partitioning of phosphorus between dissolved and particle bound phases).
- Add river inflow and update profiles of the state variables accordingly. Allow partitioning of phosphorus between dissolved and particle bound phases, as well as convection.

    If no ice

    - ❑ Mix water layers with the available turbulent kinetic energy from wind.

    If ice cover

        If T_a<T_f *(freezing)*

        - ♦ Calculate ice surface temperature (depending on snow cover, or ice thickness if snow is absent)
        - ♦ Calculate snow ice formation in case of isostatic imbalance
        - ♦ Calculate congelation ice growth by Stefan's law
        - ♦ Accumulate new snow fall and subtract formed snow ice from snow cover

        If $T_a \geq T_f$ *(melting)*

        - ♦ Melt snow or ice from top with total surface heat flux

    - ❑ Melt ice from bottom with the heat diffused to the surface layer (keeping the surface layer temperature at freezing point)
    - ❑ Update snow density
- Allow partitioning of phosphorus between dissolved and particle bound phases in the water column.
- Check the water column for supercooled layers and turn them into initial ice cover.
- Save results to output matrices.

(Goto Start)

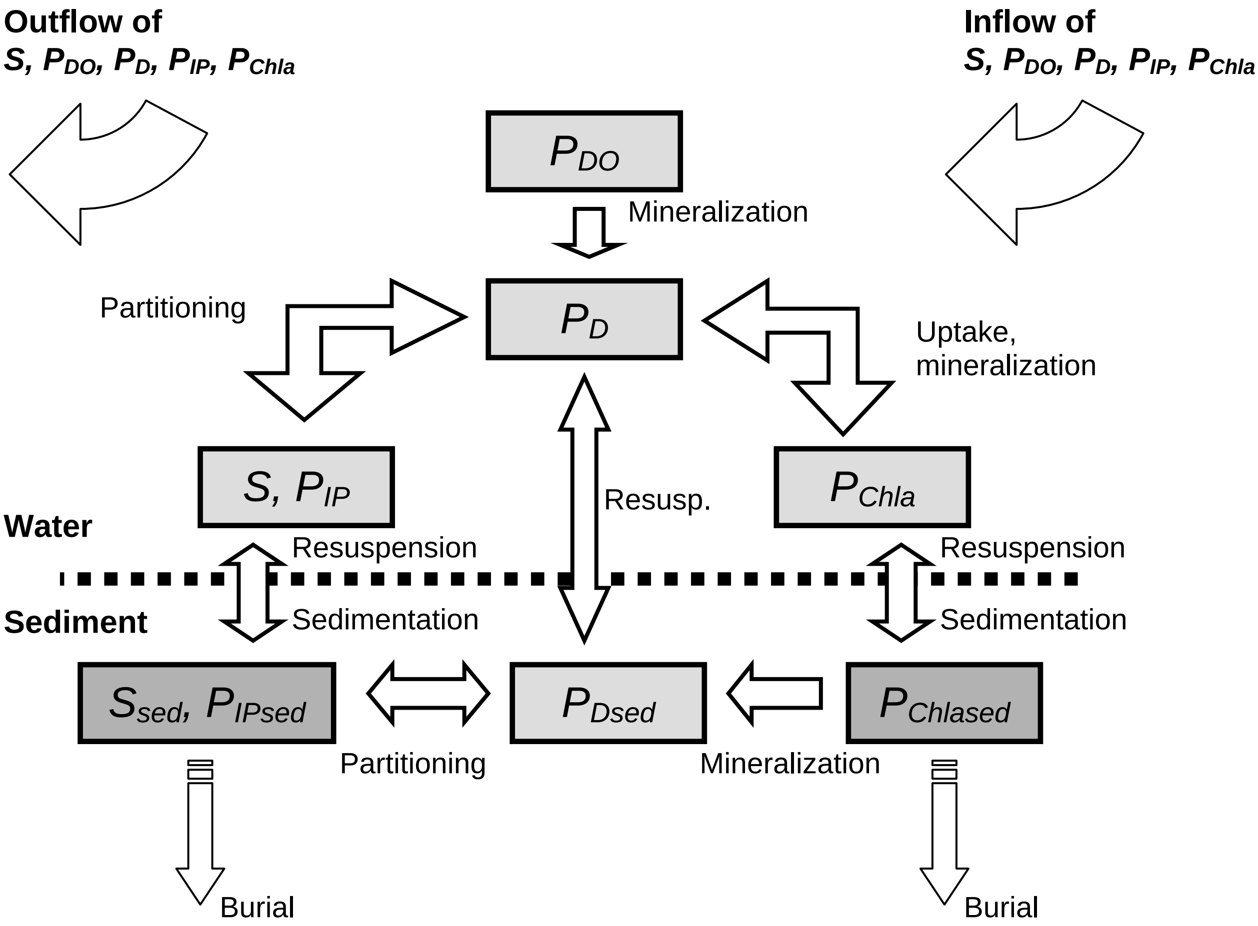


Figure 1. *A schematic illustration of the flows between the main state variables in MyLake v.1.2 model, dissolved inorganic phosphorus (phosphate, P_D), phosphorus bound to inorganic particles (P_{IP}), dissolved organic phosphorus (P_{DO}), chlorophyll a (P_{Chla}), and suspended inorganic matter (S).*

3. Running a MyLake v.1.2 model application

3.1 New code modules

The MyLake v.1.2 model code consists of six modules (MATLAB scripts, ”m-files”), of which one is entirely new (*convection.m*) and two remain unchanged from the previous version (*IOflow_v11.m* and *sedimentheat_v11.m*):

solvemodel_v12.m	Contains most of the model algorithms and numerical solving of the equations. Contains also a number of “switches” with which particular processes can be disabled in the model code;

heatflux_v12.m	Handles calculation of turbulent and radiative heat fluxes, and some other physical and astronomical variables. Utilises MATLAB *Air-Sea Toolbox* (by Rich Pawlowicz, Woods Hole: http://sea-mat.whoi.edu/air_sea-html/);
sedimentheat_v11.m	Calculates the sediment-water heat exchange;
IOflow_v11.m	Handles the addition of river inflow;
modelinputs_v12.m	Handles the reading of input data, initial conditions and parameters from the three Excel files described in sections 3.2.1-3.2.3.
convection_v12.m	Handles the vertical convection due to instable water stratification.

3.2 Revisions to parameter and input file structures

In addition to the model code (including the *Air-Sea Toolbox*), three different parameter and input data files are required to run a MyLake model application. These three files contain 1) time series of meteorological variables and inflow properties, 2) lake morphometry and initial profiles, and 3) model parameter values. These files are formatted in Excel spreadsheet software. File formats and required units (the latter are given in square brackets) are explained below and file templates are shown in Figures 2-4. Note that the first cell in the upper left corner (A1) must contain a dummy number (e.g. -999) so that MATLAB reads in the columns and rows correctly.

3.2.1 Meteorological and inflow time series

Note that time series with daily resolution are required, and that values for missing observations or measurement dates in the meteorological and inflow time series are in MyLake automatically estimated by linear interpolation.

Rows

1-2: Header rows

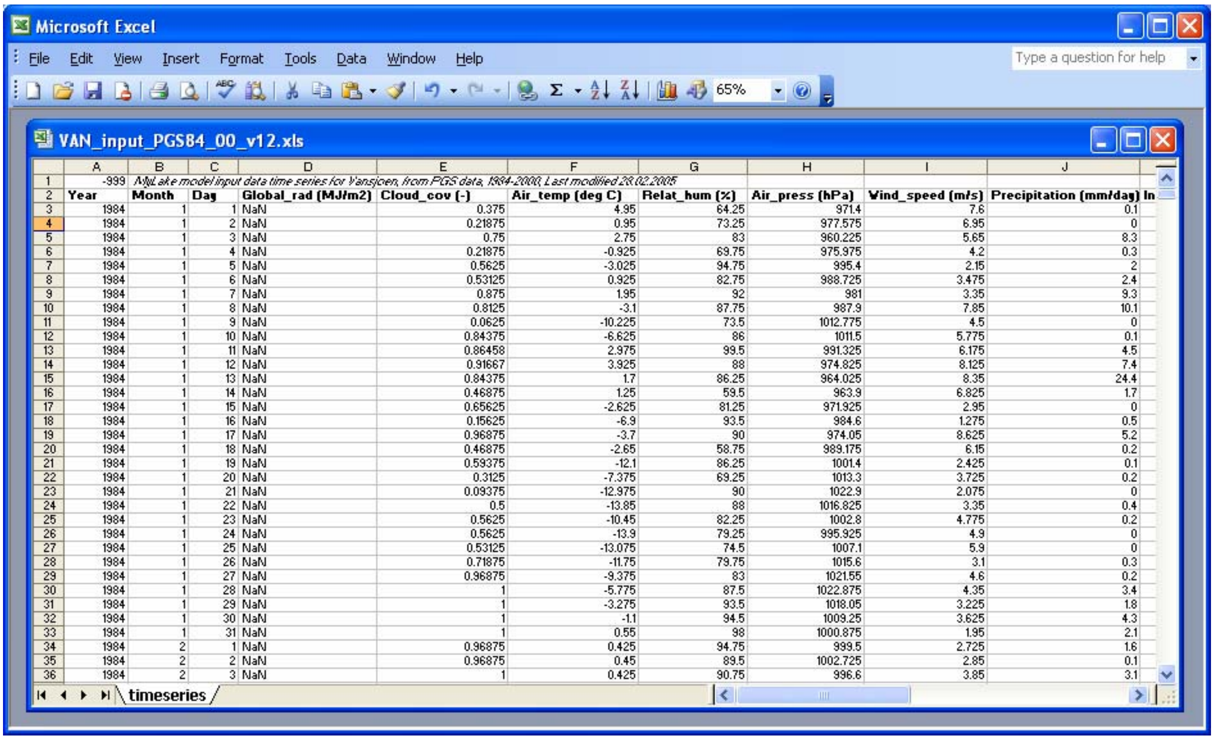
(**Important!** The first cell on the first row (A1) must contain a number, e.g –999)

3-end: Data rows

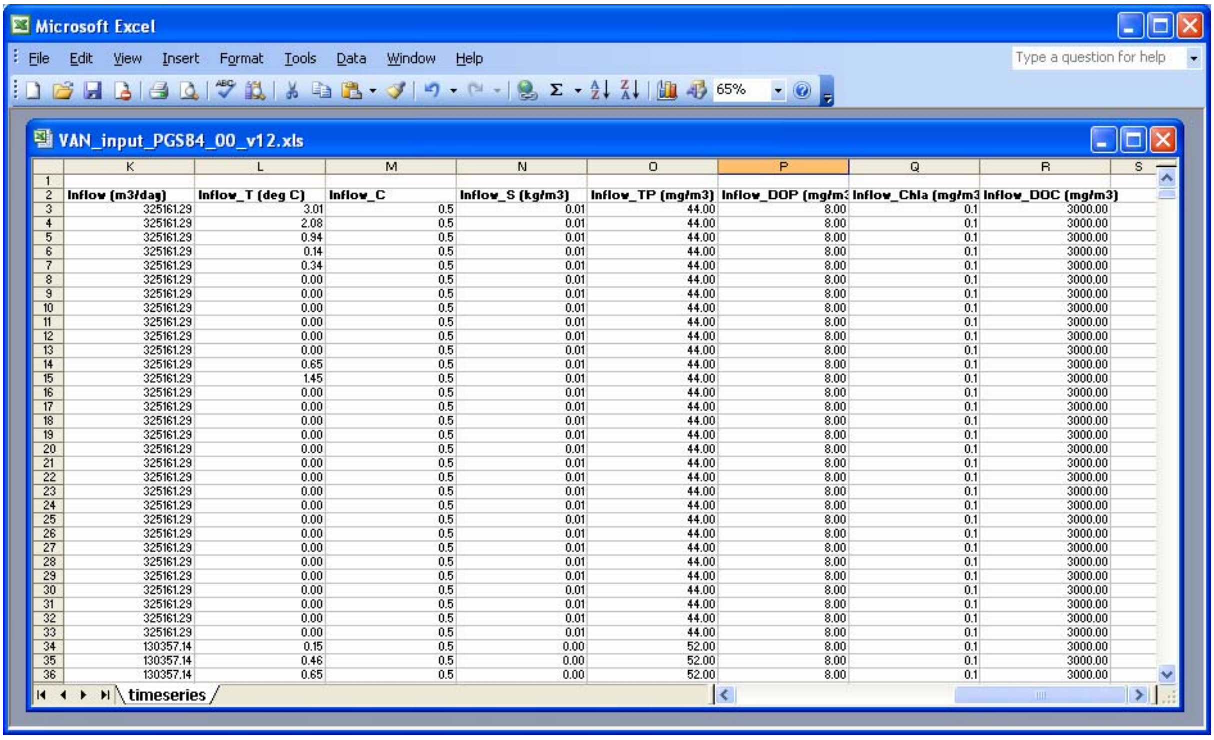
Columns

1. Year
2. Month
3. Day
4. Global radiation [MJ m^{-2} day^{-1}]
5. Cloud cover (0-1)

6. Air temperature at 2 meter height [°C]
7. Relative humidity at 2 meter height [%]
8. Air pressure at station level [hPa]
9. Wind speed at 10 m height [m s^{-1}]
10. Precipitation [mm d^{-1}]
11. Inflow volume [m^3 d^{-1}]
12. Inflow temperature [°C]; if ”NaN” (“Not a Number”, a MATLAB expression for missing value) then the inflow is assumed to mix with the surface layer
13. Inflow concentration of the passive tracer [-]
14. Inflow concentration of the suspended inorganic particulate matter (*S*, functions also as a passive sedimenting tracer) [kg m^{-3}]
15. Inflow concentration of total phosphorus (P_D+P_{IP}+P_{DO}+P_{Chla}) [µg l^{-1} = mg m^{-3}]
16. Inflow concentration of dissolved organic phosphorus (P_{DO}) [µg l^{-1} = mg m^{-3}]
17. Inflow concentration of chlorophyll *a* (P_{Chla}) [µg l^{-1} = mg m^{-3}]
18. Inflow concentration of dissolved organic carbon (*DOC*) [µg l^{-1} = mg m^{-3}]



	A	B	C	D	E	F	G	H	I	J
1	-999	MyLake model input data time series for Vansjoen, from PGS data, 1984-2000, Last modified 28.02.2005								
2	Year	Month	Day	Global_rad (MJ/m2)	Cloud_cov (-)	Air_temp (deg C)	Relat_hum (%)	Air_press (hPa)	Wind_speed (m/s)	Precipitation (mm/day)
3	1984	1	1	NaN	0.375	4.95	64.25	971.4	7.6	0.1
4	1984	1	2	NaN	0.21875	0.95	73.25	977.575	6.95	0
5	1984	1	3	NaN	0.75	2.75	83	960.225	5.65	8.3
6	1984	1	4	NaN	0.21875	-0.925	69.75	975.975	4.2	0.3
7	1984	1	5	NaN	0.5625	-3.025	94.75	995.4	2.15	2
8	1984	1	6	NaN	0.53125	0.925	82.75	988.725	3.475	2.4
9	1984	1	7	NaN	0.875	1.95	92	981	3.35	9.3
10	1984	1	8	NaN	0.8125	-3.1	87.75	987.9	7.85	10.1
11	1984	1	9	NaN	0.0625	-10.225	73.5	1012.775	4.5	0
12	1984	1	10	NaN	0.84375	-6.625	86	1011.5	5.775	0.1
13	1984	1	11	NaN	0.86458	2.975	99.5	991.325	6.175	4.5
14	1984	1	12	NaN	0.91667	3.925	88	974.825	8.125	7.4
15	1984	1	13	NaN	0.84375	1.7	86.25	964.025	8.35	24.4
16	1984	1	14	NaN	0.46875	1.25	59.5	963.9	6.825	1.7
17	1984	1	15	NaN	0.65625	-2.625	81.25	971.925	2.95	0
18	1984	1	16	NaN	0.15625	-6.9	93.5	984.6	1.275	0.5
19	1984	1	17	NaN	0.96875	-3.7	90	974.05	8.625	5.2
20	1984	1	18	NaN	0.46875	-2.65	58.75	989.175	6.15	0.2
21	1984	1	19	NaN	0.59375	-12.1	86.25	1001.4	2.425	0.1
22	1984	1	20	NaN	0.3125	-7.375	69.25	1013.3	3.725	0.2
23	1984	1	21	NaN	0.09375	-12.975	90	1022.9	2.075	0
24	1984	1	22	NaN	0.5	-13.85	88	1016.825	3.35	0.4
25	1984	1	23	NaN	0.5625	-10.45	82.25	1002.8	4.775	0.2
26	1984	1	24	NaN	0.5625	-13.9	79.25	995.925	4.9	0
27	1984	1	25	NaN	0.53125	-13.075	74.5	1007.1	5.9	0
28	1984	1	26	NaN	0.71875	-11.75	79.75	1015.6	3.1	0.3
29	1984	1	27	NaN	0.96875	-9.375	83	1021.55	4.6	0.2
30	1984	1	28	NaN	1	-5.775	87.5	1022.875	4.35	3.4
31	1984	1	29	NaN	1	-3.275	93.5	1018.05	3.225	1.8
32	1984	1	30	NaN	1	-1.1	94.5	1009.25	3.625	4.3
33	1984	1	31	NaN	1	0.55	98	1000.875	1.95	2.1
34	1984	2	1	NaN	0.96875	0.425	94.75	999.5	2.725	1.6
35	1984	2	2	NaN	0.96875	0.45	89.5	1002.725	2.85	0.1
36	1984	2	3	NaN	1	0.425	90.75	996.6	3.85	3.1



	K	L	M	N	O	P	Q	R
1								
2	Inflow (m3/day)	Inflow_T (deg C)	Inflow_C	Inflow_S (kg/m3)	Inflow_TP (mg/m3)	Inflow_DOP (mg/m3	Inflow_Chla (mg/m3	Inflow_DOC (mg/m3)
3	325161.29	3.01	0.5	0.01	44.00	8.00	0.1	3000.00
4	325161.29	2.08	0.5	0.01	44.00	8.00	0.1	3000.00
5	325161.29	0.94	0.5	0.01	44.00	8.00	0.1	3000.00
6	325161.29	0.14	0.5	0.01	44.00	8.00	0.1	3000.00
7	325161.29	0.34	0.5	0.01	44.00	8.00	0.1	3000.00
8	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
9	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
10	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
11	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
12	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
13	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
14	325161.29	0.65	0.5	0.01	44.00	8.00	0.1	3000.00
15	325161.29	1.45	0.5	0.01	44.00	8.00	0.1	3000.00
16	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
17	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
18	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
19	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
20	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
21	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
22	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
23	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
24	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
25	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
26	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
27	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
28	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
29	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
30	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
31	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
32	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
33	325161.29	0.00	0.5	0.01	44.00	8.00	0.1	3000.00
34	130357.14	0.15	0.5	0.00	52.00	8.00	0.1	3000.00
35	130357.14	0.46	0.5	0.00	52.00	8.00	0.1	3000.00
36	130357.14	0.65	0.5	0.00	52.00	8.00	0.1	3000.00

Figure 2. Example of a MyLake input forcing data file.

3.2.2 Bathymetry and initial profiles

Note that linear temperature profile between the lake water temperature and 4 °C is initially assumed in the sediment columns.

Rows

1-2: Header rows

(**Important!** The first cell on the first row (A1) must contain a number, e.g –999)

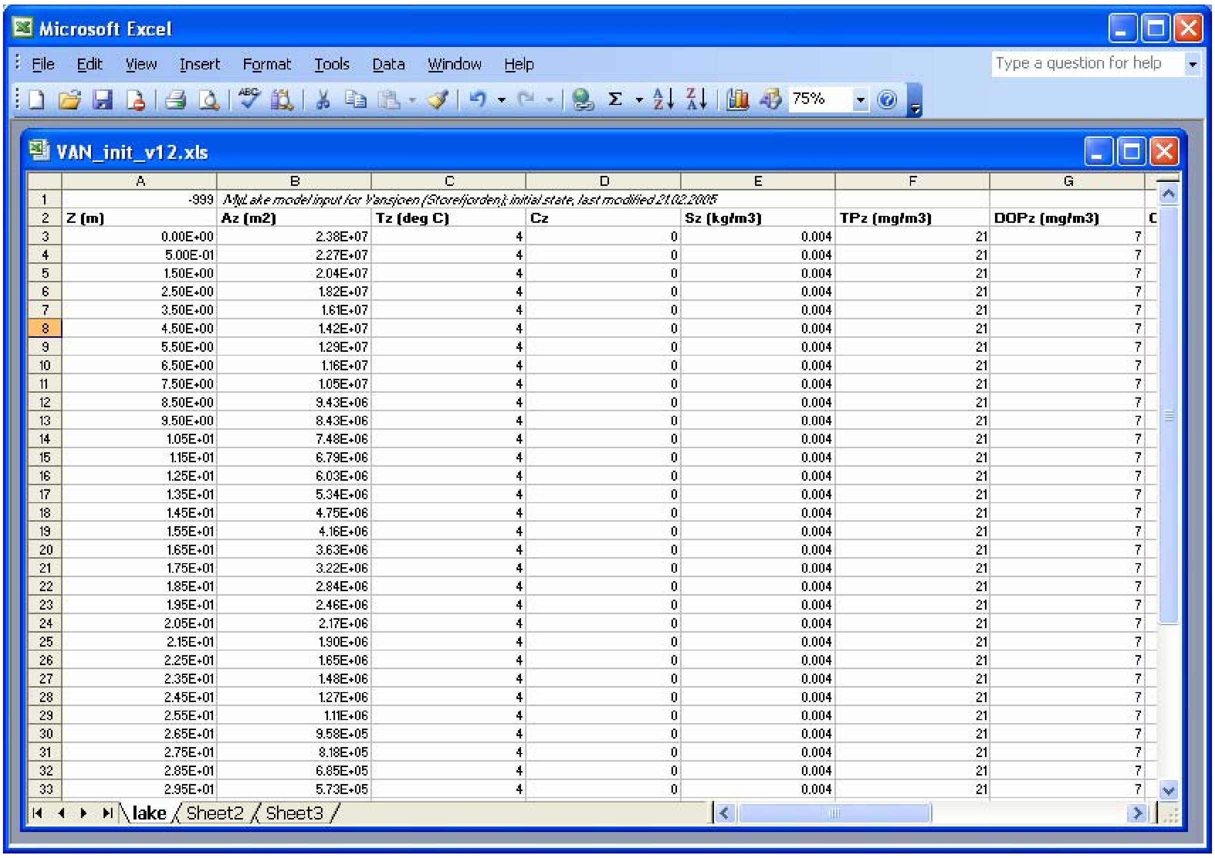
3-end: Data rows

Columns

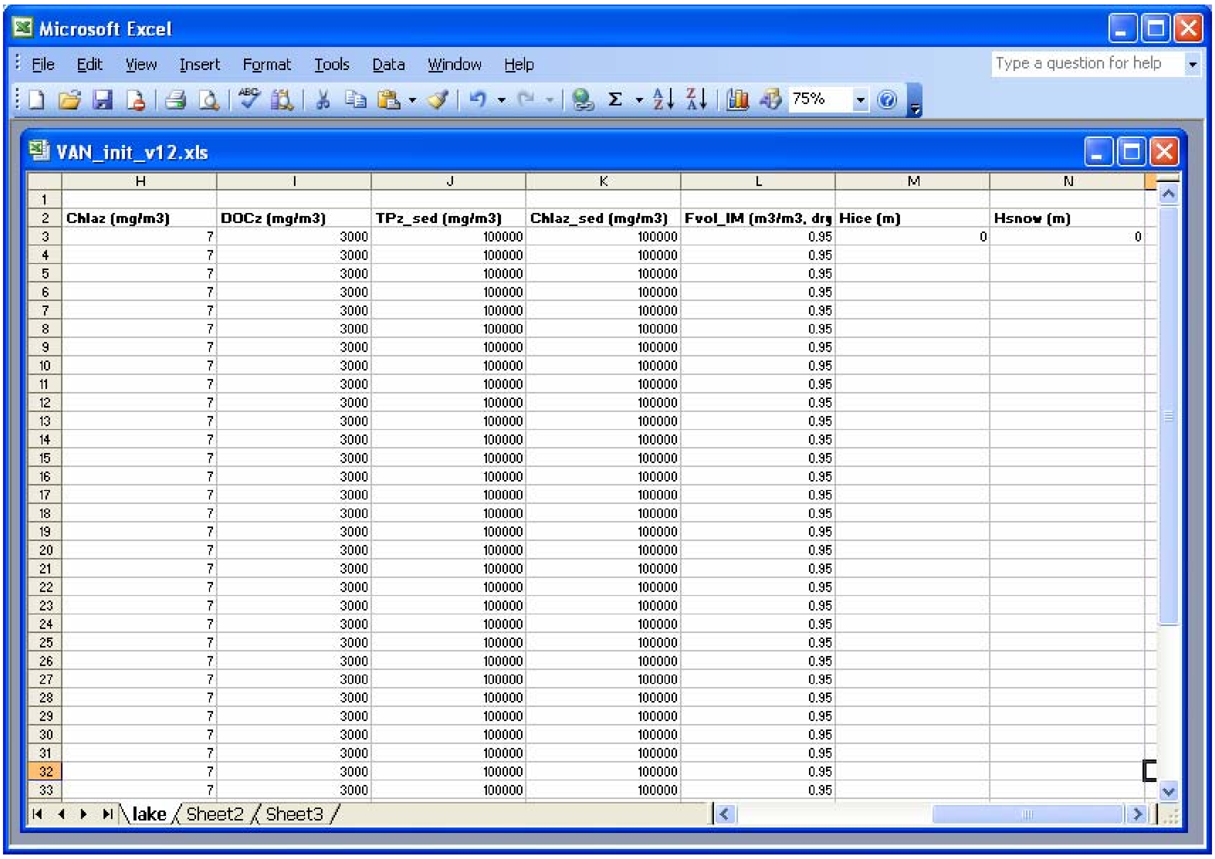
1. Depth levels (meters from surface; positive values); the first and last levels must be zero and the maximum depth, respectively

   (*the following variable values must be given at all depth levels of column 1*)

2. Horizontal areas [m^2]; the first and last levels must be lake surface area and zero, respectively
3. Initial profile of temperature [°C]
4. Initial profile of the passive tracer [-]
5. Initial profile of the suspended inorganic particulate matter (*S*, functions also as a passive sedimenting tracer) [$kg\ m^{-3}$]
6. Initial profile of total phosphorus (P_D+P_{IP}+P_{DO}+P_{Chla}) [$\mu g\ l^{-1}$ = $mg\ m^{-3}$]
7. Initial profile of dissolved organic phosphorus (P_{DO}) [$\mu g\ l^{-1}$ = $mg\ m^{-3}$]
8. Initial profile of of chlorophyll *a* (P_{Chla}) [$\mu g\ l^{-1}$ = $mg\ m^{-3}$]
9. Initial profile of of dissolved organic carbon (*DOC*) [$\mu g\ l^{-1}$ = $mg\ m^{-3}$]
10. Initial profile of sediment bulk concentration of total phosphorus (P_D+P_{IP}+P_{DO}+P_{Chla}) [$\mu g\ l^{-1}$ = $mg\ m^{-3}$ wet weight]
11. Initial profile of sediment bulk concentration of chlorophyll *a* [$\mu g\ l^{-1}$ = $mg\ m^{-3}$ wet weight]
12. Initial profile of sediment volume fraction of inorganic matter [$m^3\ m^{-3}$ dry weight]
13. Initial value of total ice thickness [m]
14. Initial value of snow thickness [m]



	A	B	C	D	E	F	G	C
1	-999	*MyLake model input for Vansjoen (Storefjorden); initial state, last modified 21.02.2005*						
2	Z (m)	Az (m2)	Tz (deg C)	Cz	Sz (kg/m3)	TPz (mg/m3)	DOPz (mg/m3)	C
3	0.00E+00	2.38E+07	4	0	0.004	21	7	
4	5.00E-01	2.27E+07	4	0	0.004	21	7	
5	1.50E+00	2.04E+07	4	0	0.004	21	7	
6	2.50E+00	1.82E+07	4	0	0.004	21	7	
7	3.50E+00	1.61E+07	4	0	0.004	21	7	
8	4.50E+00	1.42E+07	4	0	0.004	21	7	
9	5.50E+00	1.29E+07	4	0	0.004	21	7	
10	6.50E+00	1.16E+07	4	0	0.004	21	7	
11	7.50E+00	1.05E+07	4	0	0.004	21	7	
12	8.50E+00	9.43E+06	4	0	0.004	21	7	
13	9.50E+00	8.43E+06	4	0	0.004	21	7	
14	1.05E+01	7.48E+06	4	0	0.004	21	7	
15	1.15E+01	6.79E+06	4	0	0.004	21	7	
16	1.25E+01	6.03E+06	4	0	0.004	21	7	
17	1.35E+01	5.34E+06	4	0	0.004	21	7	
18	1.45E+01	4.75E+06	4	0	0.004	21	7	
19	1.55E+01	4.16E+06	4	0	0.004	21	7	
20	1.65E+01	3.63E+06	4	0	0.004	21	7	
21	1.75E+01	3.22E+06	4	0	0.004	21	7	
22	1.85E+01	2.84E+06	4	0	0.004	21	7	
23	1.95E+01	2.46E+06	4	0	0.004	21	7	
24	2.05E+01	2.17E+06	4	0	0.004	21	7	
25	2.15E+01	1.90E+06	4	0	0.004	21	7	
26	2.25E+01	1.65E+06	4	0	0.004	21	7	
27	2.35E+01	1.48E+06	4	0	0.004	21	7	
28	2.45E+01	1.27E+06	4	0	0.004	21	7	
29	2.55E+01	1.11E+06	4	0	0.004	21	7	
30	2.65E+01	9.58E+05	4	0	0.004	21	7	
31	2.75E+01	8.18E+05	4	0	0.004	21	7	
32	2.85E+01	6.85E+05	4	0	0.004	21	7	
33	2.95E+01	5.73E+05	4	0	0.004	21	7	



	H	I	J	K	L	M	N
1							
2	Chlaz (mg/m3)	DOCz (mg/m3)	TPz_sed (mg/m3)	Chlaz_sed (mg/m3)	Fvol_IM (m3/m3, dry	Hice (m)	Hsnow (m)
3	7	3000	100000	100000	0.95	0	0
4	7	3000	100000	100000	0.95		
5	7	3000	100000	100000	0.95		
6	7	3000	100000	100000	0.95		
7	7	3000	100000	100000	0.95		
8	7	3000	100000	100000	0.95		
9	7	3000	100000	100000	0.95		
10	7	3000	100000	100000	0.95		
11	7	3000	100000	100000	0.95		
12	7	3000	100000	100000	0.95		
13	7	3000	100000	100000	0.95		
14	7	3000	100000	100000	0.95		
15	7	3000	100000	100000	0.95		
16	7	3000	100000	100000	0.95		
17	7	3000	100000	100000	0.95		
18	7	3000	100000	100000	0.95		
19	7	3000	100000	100000	0.95		
20	7	3000	100000	100000	0.95		
21	7	3000	100000	100000	0.95		
22	7	3000	100000	100000	0.95		
23	7	3000	100000	100000	0.95		
24	7	3000	100000	100000	0.95		
25	7	3000	100000	100000	0.95		
26	7	3000	100000	100000	0.95		
27	7	3000	100000	100000	0.95		
28	7	3000	100000	100000	0.95		
29	7	3000	100000	100000	0.95		
30	7	3000	100000	100000	0.95		
31	7	3000	100000	100000	0.95		
32	7	3000	100000	100000	0.95		
33	7	3000	100000	100000	0.95		

Figure 3. *Example of a MyLake morphometry and initial profile file.*

Note that the initial sediment concentrations of chlorophyll *a* can be estimated by P_{Chla} = (1-F_{IM})·ϕ ·$\rho_{organic}$·F_{Porg}·y_c, where $\rho_{organic}$ is the density of dry organic matter (~1000 kg m^{-3}). The total phosphorus concentration in sediment can be estimated by assuming same P_D and P_{DO} as in the water column, by converting P_{Chla} to phosphorus units by dividing with the yield coefficient y_c, and by estimating $P_{IP} = F_{IP}·F_{IM}·\phi ·\rho_{inorg}·$, where ρ_{inorg} is the density of dry inorganic matter (~2500 kg m^{-3}) and F_{IP} is calculated from P_D using equation 2.

3.2.3 Model parameters

The equation and page numbers below refer to the MyLake v.1.1 documentation (Saloranta and Andersen, 2004).

Rows

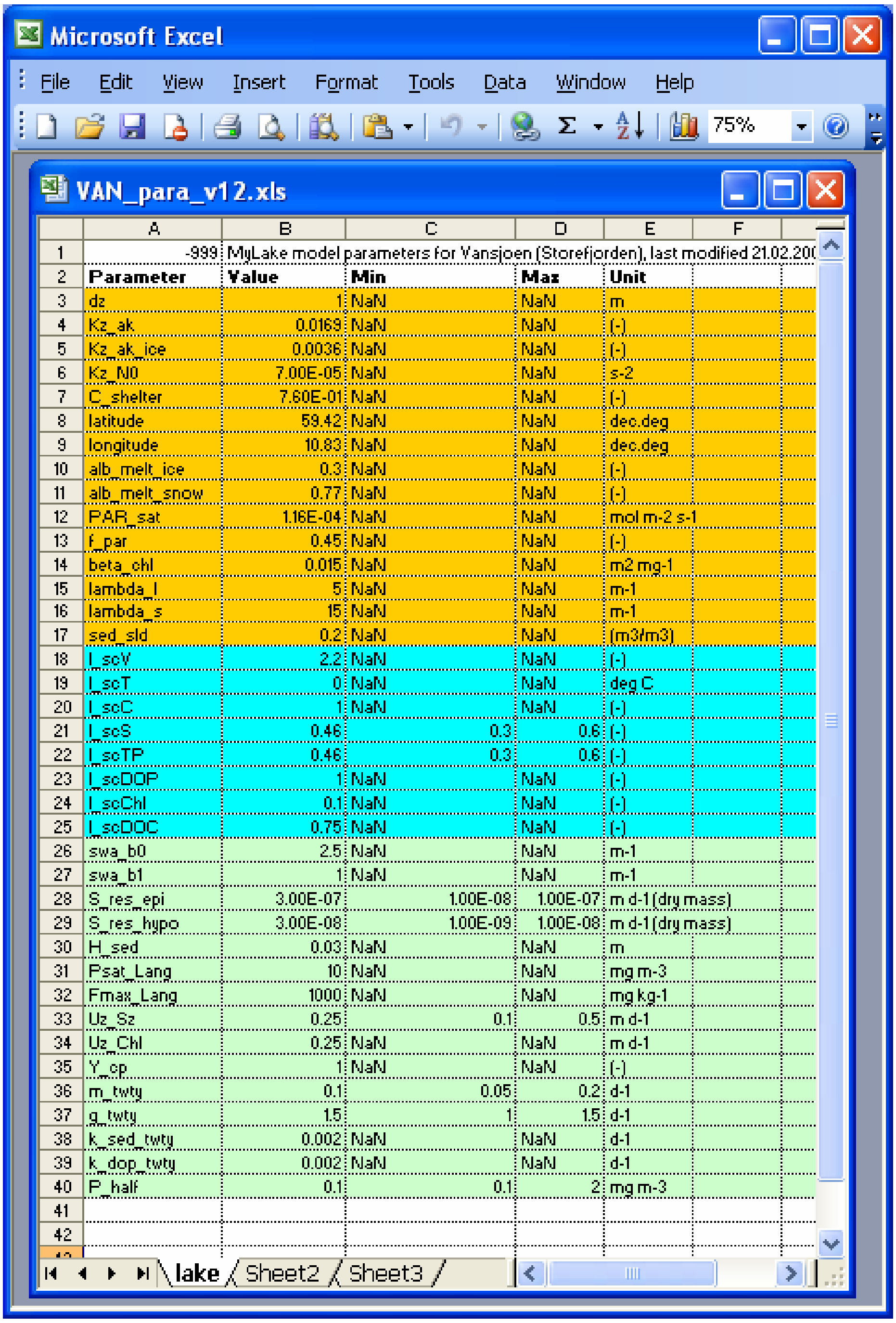
1. Header row
   (**Important!** The first cell on the first row (A1) must contain a number, e.g –999)
2. Header row
3. dz [m], model vertical grid step (i.e., model layer thickness)
4. a_k [-] (equation 18), diffusion parameter during open water periods; if ”NaN” then a_k is calculated from lake surface area (page 13)
5. a_k [-] (equation 18), diffusion parameter during lake ice periods; if ”NaN” then a_k is calculated from lake surface area (page 13)
6. N^2_{min} [s^{-2}] (page 13); if ”NaN” then a default value 7x10^{-5} is assumed (page 13)
7. W_{str} [-] (equations 23, 24); if “NaN” then W_{str} is calculated from lake surface area (eq. 24)
8. Lake latitude [decimal degrees]
9. Lake longitude [decimal degrees]
10. α_{ice} [-], melting ice albedo (page 17)
11. α_{snow} [-], melting snow albedo (page 17)
12. I' [mol (quanta) m^{-2} s^{-1}] (equation 44)
13. f_{PAR} [-] (equation 47)
14. β [m^2 mg^{-1}] (equation 43)
15. λ_{ice} [m^{-1}], PAR light attenuation coefficient for ice
16. λ_{snow} [m^{-1}], PAR light attenuation coefficient for snow
17. ϕ_{sld} [-], volume fraction of solids in the sediment
18. I_scV [-], dimensionless scaling factor for inflow volume
19. I_scT [°C], scaling coefficient for inflow temperature

20. I_scC [-], dimensionless scaling factor for inflow concentration of passive tracer
21. I_scS [-], dimensionless scaling factor for inflow concentration of suspended inorganic particulate matter, (or passive sedimenting tracer)
22. I_scTP [-], dimensionless scaling factor for inflow concentration of total phosphorus
23. I_scP_{DO} [-], dimensionless scaling factor for inflow concentration of dissolved organic phosphorus
24. I_scP_{Chla} [-], dimensionless scaling factor for inflow concentration of chlorophyll *a*
25. I_scDOC [-], dimensionless scaling factor for inflow concentration of dissolved organic carbon (*DOC*)
26. $\hat{\varepsilon}_0$ [m^{-1}] (equations 20, 43), non-PAR light extinction coefficient for water (non-chlorophyll related)
27. ε_0 [m^{-1}] (equations 20, 43), PAR light extinction coefficient for water (non-chlorophyll related)
28. S_{res_epi} [m d^{-1}], resuspension rate of dry sediment particles in the epilimnion
29. S_{res_hypo} [m d^{-1}], resuspension rate of dry sediment particles in the hypolimnion
30. H_{sed} [m], depth of the active (mixed) sediment layer
31. P_{sat} [mg m^{-3}], Langmuir isotherm coefficient, see equation 2 in this document
32. F_{max} [mg kg^{-1}], Langmuir isotherm coefficient, see equation 2 in this document
33. w [m d^{-1}] (equation 30), for inorganic matter (S); must be $w>0$
34. w [m d^{-1}] (equation 30), for organic matter (P_{Chla}); must be $w>0$
35. y_c [-] yield coefficient, i.e. chlorophyll *a* to phosphorus ratio
36. $m(20)$ [d^{-1}] (equation 39)
37. $\mu(20)$ [d^{-1}] (equation 41)
38. $k(20)$ [d^{-1}] as $m(20)$ but in applies in sediment
39. $k_{dop}(20)$ [d^{-1}] specific P_{OD} to P_D mineralization rate coefficient
40. P' [$\mu g\ l^{-1} = mg\ m^{-3}$] (equation 40)

Columns (from 3rd row)

1. Parameter names (optional; used in connection with e.g. plotting of figures)
2. Nominal parameter values
3. Minimum of the parameter value range (optional for normal single model runs, but at least one dummy value (e.g. -9) must be given so that MATLAB can read the file in correctly)
4. Maximum of the parameter value range (optional for normal single model runs, but at least one dummy value (e.g. -9) must be given so that MATLAB can read the file in correctly)

5. Remarks (optional). In the example of Figure 5 this column is used to denote the units in which parameter values are required by MyLake model code (fixed units, see list above). This is highly recommended.
6. Remarks (optional). In the example of Figure 5 this column is used to explain the parameter symbols.



Microsoft Excel

File Edit View Insert Format Tools Data Window Help

VAN_para_v12.xls

	A	B	C	D	E	F
1	-999	MyLake model parameters for Vansjoen (Storefjorden), last modified 21.02.200				
2	Parameter	Value	Min	Max	Unit	
3	dz	1	NaN	NaN	m	
4	Kz_ak	0.0169	NaN	NaN	(-)	
5	Kz_ak_ice	0.0036	NaN	NaN	(-)	
6	Kz_N0	7.00E-05	NaN	NaN	s-2	
7	C_shelter	7.60E-01	NaN	NaN	(-)	
8	latitude	59.42	NaN	NaN	dec.deg	
9	longitude	10.83	NaN	NaN	dec.deg	
10	alb_melt_ice	0.3	NaN	NaN	(-)	
11	alb_melt_snow	0.77	NaN	NaN	(-)	
12	PAR_sat	1.16E-04	NaN	NaN	mol m-2 s-1	
13	f_par	0.45	NaN	NaN	(-)	
14	beta_chl	0.015	NaN	NaN	m2 mg-1	
15	lambda_I	5	NaN	NaN	m-1	
16	lambda_s	15	NaN	NaN	m-1	
17	sed_sld	0.2	NaN	NaN	(m3/m3)	
18	I_scV	2.2	NaN	NaN	(-)	
19	I_scT	0	NaN	NaN	deg C	
20	I_scC	1	NaN	NaN	(-)	
21	I_scS	0.46	0.3	0.6	(-)	
22	I_scTP	0.46	0.3	0.6	(-)	
23	I_scDOP	1	NaN	NaN	(-)	
24	I_scChl	0.1	NaN	NaN	(-)	
25	I_scDOC	0.75	NaN	NaN	(-)	
26	swa_b0	2.5	NaN	NaN	m-1	
27	swa_b1	1	NaN	NaN	m-1	
28	S_res_epi	3.00E-07	1.00E-08	1.00E-07	m d-1 (dry mass)	
29	S_res_hypo	3.00E-08	1.00E-09	1.00E-08	m d-1 (dry mass)	
30	H_sed	0.03	NaN	NaN	m	
31	Psat_Lang	10	NaN	NaN	mg m-3	
32	Fmax_Lang	1000	NaN	NaN	mg kg-1	
33	Uz_Sz	0.25	0.1	0.5	m d-1	
34	Uz_Chl	0.25	NaN	NaN	m d-1	
35	Y_cp	1	NaN	NaN	(-)	
36	m_twty	0.1	0.05	0.2	d-1	
37	g_twty	1.5	1	1.5	d-1	
38	k_sed_twty	0.002	NaN	NaN	d-1	
39	k_dop_twty	0.002	NaN	NaN	d-1	
40	P_half	0.1	0.1	2	mg m-3	
41						
42						

lake / Sheet2 / Sheet3

Figure 4. *Example of a MyLake parameter file.The coulouring highlights the more general, the scaling, and the more site-specififc parameter groups.*

3.3 Switches

The module *solvemodel_v11.m* contains five switches, which can be used to disable some particular model processes. These are:

- snow_compaction_switch (simulation of snow compaction: 0=off, 1=on)
- river_inflow_switch (simulation of river inflow: 0=off, 1=on)
- sediment_heatflux_switch (simulation of heatflux from sediments: 0=off, 1=on)
- selfshading_switch (simulation of light attenuation by chlorophyll *a*: 0=off, 1=on)
- tracer_switch (simulation of tracer state variables: 0=off, 1=on)

3.4 How to execute a MyLake v.1.2 model run

When the parameter and input data files are ready, a MyLake model application can be run by the following MATLAB command:

function [zz,Az,Vz,tt,Qst,Kzt,Tzt,Czt,Szt,Pzt,Chlzt,PPzt,DOPzt,DOCzt,Qzt_sed,lambdazt,...
P3zt_sed,P3zt_sed_sc,His,DoF,DoM,MixStat,Wt] =
solvemodel_v12(M_start,M_stop,Initfile,Initsheet,Inputfile,Inputsheet,Parafile,Parasheet);

where *M_start* and *M_stop* [year, month, day] are row vectors of the model start and stop date; *Initfile, Inputfile,* and *Parafile* are strings containing the file names (full paths) of the three files containg lake morphometry and initial profiles, time series of meteorological variables and inflow properties, and model parameter values, respectively. Similarly, *Initsheet, Inputsheet,* and *Parasheet* are strings containing the Excel worksheet names containing this data.

For example, using the file examples shown in Figures 2-4 and running the model from May 1, 1998 to December 21, 2000, a model execution line would read:

function [zz,Az,Vz,tt,Qst,Kzt,Tzt,Czt,Szt,Pzt,Chlzt,PPzt,DOPzt,DOCzt,Qzt_sed,lambdazt,...
P3zt_sed,P3zt_sed_sc,His,DoF,DoM,MixStat,Wt] =
solvemodel_v12([1998,5,1],[2000,12,31],
’H:\MyLake\Applications\Vansjo\v12_applications\Pcode_Eproject\VAN_init_v12.xls','lake',
’H:\MyLake\Applications\Vansjo\v12_applications\Pcode_Eproject
VAN_input_PGS84_00_v12.xls','timeseries'’H:\MyLake\Applications\Vansjo\v12_applications\Pcode
_Eproject\VAN_para_v12.xls','lake');

Note that the whole set of parameter values, initial profiles and input data read from the Excel files (*Parafile, Initfile, Inputfile*) can also be bypassed by entering these variables in correct order directly in the input list after *Parasheet*, i.e:

...=solvemodel_v12(M_start,M_stop,Initfile,Initsheet,Inputfile,Inputsheet,Parafile,Parasheet, In_Z,In_Az,tt,In_Tz,In_Cz,In_Sz,In_TPz,In_DOPz,In_Chlz,In_DOCz,In_TPz_sed,In_Chlz_sed, In_FIM,Ice0,Wt,Inflw,Phys_par,Phys_par_range,Phys_par_names,Bio_par,Bio_par_range,Bio_par_ names

In other words, the output from model module *modelinputs_v12.m* to *solvemodel_v12.m* is replaced by a similar input directly to *solvemodel_v12.m* given by the user on the command line. The meaning and structure of the output variables from *modelinputs_v12.m* are not explained here, but the user is referred to the header code of that module for detailed information. The possibility to bypass model parameters and other input variables facilitates easier writing of MATLAB scripts for running the model numerous times with different parameter values, e.g. in connection with Monte Carlo simulations and sensitivity analysis.

The model output variables (i.e., from *solvemodel_v12.m*) are listed below with units indicated in square brackets. Output matrix dimensions are indicated in parentheses.

zz	Solution depth domain array (length N) [m], i.e. depths at the top of the layers
Az	Layer interface area [m^2] (N)
Vz	Layer volume [m^3] (N)
tt	Solution time domain array (length M), i.e. model day number, starting from 1 [d]
Qst	Estimated surface heat fluxes [W m^{-2}] ([Q_{sw}, Q_{lw}, Q_{turb}] × M)
Kzt	Predicted vertical diffusion coefficient [m^2 d^{-1}] (N × M)
Tzt	Predicted temperature profile [°C] (N × M)
Czt	Predicted passive tracer profile [-] (N × M)
Szt	Predicted suspended inorganic particulate matter profile (*S*, functions also as a passive sedimenting tracer) [kg m^{-3}] (N × M)
Pzt	Predicted dissolved inorganic phosphorus (P_D, phosphate) profile [μg l^{-1} = mg m^{-3}] (N × M)
Chlzt	Predicted chlorophyll *a* profile (P_{Chla}) [μg l^{-1} = mg m^{-3}] (N × M)
PPzt	Predicted profile of phosphorus bound to inorganic particles (P_{IP}) [μg l^{-1} = mg m^{-3}] (N × M)
DOPzt	Predicted dissolved organic phosphorus profile (P_{DO}) [μg l^{-1} = mg m^{-3}] (N × M)
DOCzt	Predicted dissolved organic carbon profile (*DOC*) [μg l^{-1} = mg m^{-3}] (N × M)

Qz_sed Predicted sediment-water heat flux (normalised values, see page 13) [W m^{-2}] (N × M)

lambdazt Predicted average total light attenuation coefficient down to depth z [m^{-1}] (N × M)

P3zt_sed Predicted concentrations of P_D, $P_{IP,}$ and P_{Chla} in the sediment, as well as amount of inorganic and organic net sedimentation (dry matter), and the volume fraction of dry inorganic matter in dry sediment solids [mg m^{-3}, mg kg^{-1}, mg kg^{-1}, m d^{-1}, m d^{-1}, -] (N × M × 6)

P3zt_sed_sc Predicted phosphorus resuspension sources for P_D, $P_{IP,}$ and P_{Chla} from the sediment [mg m^{-3} d^{-1}] (N × M × 3)

His Ice and snow simulation matrix [m, m, m, °C, °C, kg m^{-3}, boolean] ([h_{ice} h_s h_{si} T_{ice} T_a ρ_s *IceOn/Off*] × M)

DoF Predicted days of freezing [model day number]

DoM Predicted days of melting [model day number]

MixStat Temporary variables used in model testing, see model code (X × M)

Wt Meteorological forcing data (M × variables in columns 4-10 described in section 3.2.1)

Note that the model execution time can easily be reduced by supplying the table for albedo calculation routine via function call, and by optimizing an iteration loop in the turbulent heatflux function (hfbulktc.m) in the *Air-Sea Toolbox* (contact the report authors for more details on this optimization). Increasing vertical grid step size, and turning off e.g. simulation of the tracers and/or calculation of sediment-water heat fluxes, by using the switches described in section 3.3, will also contribute to shorter model execution times.

4. Application example from Lake Vansjø

The functioning of MyLake v.1.2 was tested with an application in the Storefjorden subbasin of Lake Vansjø. Daily meteorological time series from Rygge and Ås stations, as well as monthly mean time series of water flow, total phosphorus concentration and suspended solids at Kure station of River Hobøl (Stålnacke et al., 2005; Figures 5-7) were used as model forcing in 1984-2000. Evaluation of model results was done against observed data of monthly mean time series of chlorophyll *a* and total phosphorus (Stålnacke et al., 2005), as well as suspended solids in the 0-4 m water column of Storefjorden subbasin.

Although the time series at Kure provide good data of the long term variability in the main river inflowing to Storefjorden, the distance from Kure station to Vansjø is ~10 km and thus the transports estimated at Kure may not always well represent the actual loads of phosphorus and suspended matter into Storefjorden subbasin, due to, e.g., sedimentation and resuspension processes taking place downstream of Kure. Moreover, the inflow of Hobølelva is not the only input of water into Storefjorden subbasin. Therefore the time series measured at Kure were scaled for model input to account for estimated yearly loads into and outflow from Storefjorden subbasin. The flow measured at Kure was multiplied by 2.2 to account for the mean estimated outflow of $3.18 \cdot 10^8$ m^3 from Storefjorden in 1984-2000 (measured outflow from the whole Vansjø multiplied by the Storefjorden part of the whole Vansjø catchment, 0.9). To retain the yearly load of total phosphorus at the level ~17 tons per year, estimated in Lyche Solheim et al. (2001), its concentration in the inflow was correspondingly divided by 2.2. Similar scaling was also done for the suspended solids concentration. The concentration of P_{DO} in the inflow was assumed constant 8 mg m^{-3}. Parameter values shown in Figure 4 were applied (the model was not calibrated for this test application in any systematic way). Figures 8-13 show various model results from the Vansjø-Storefjorden application for the period 1984-2000.

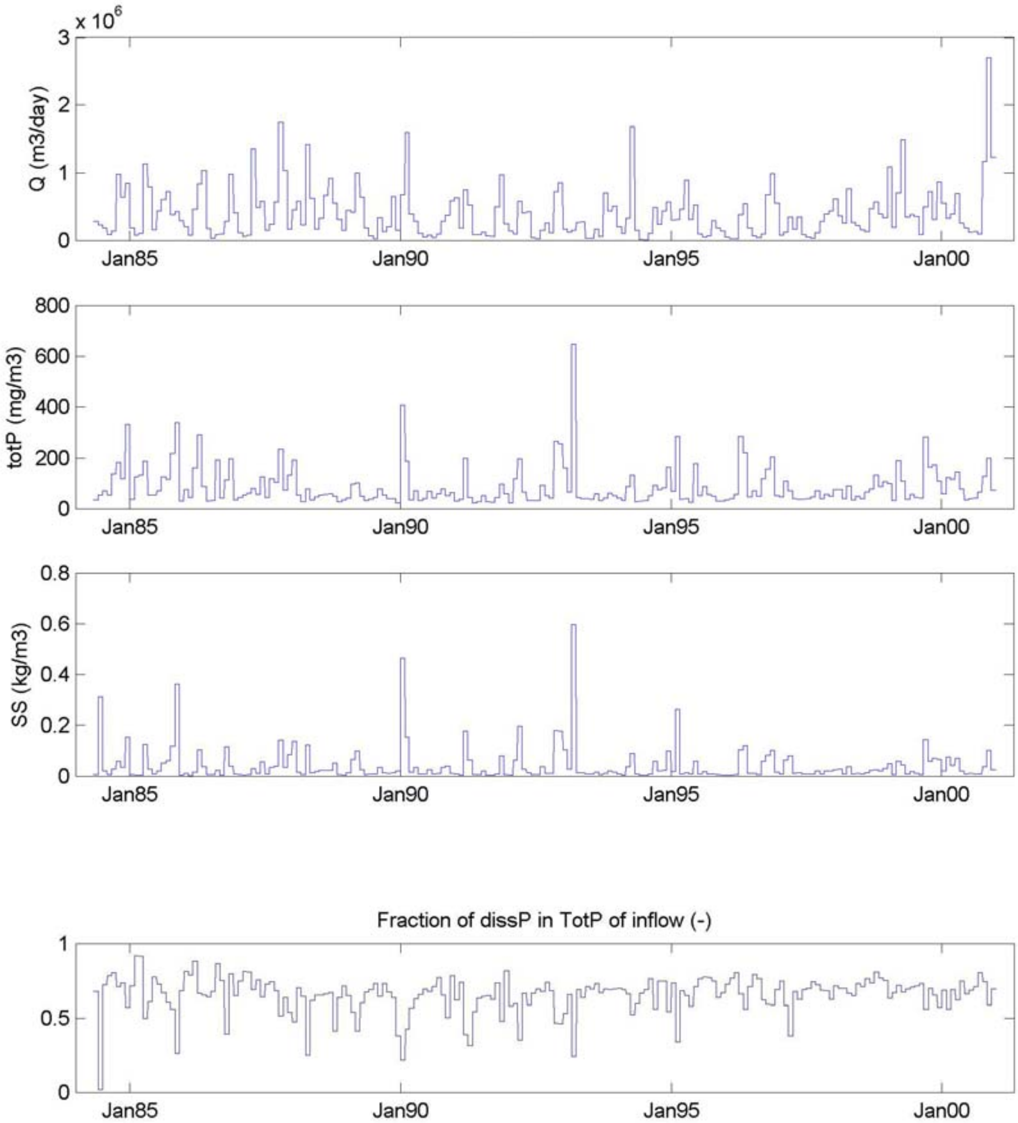


Figure 5. *Time series of water flow, as well as concentration of total phosphorus and suspended solids at Kure station of River Hobøl in 1984-2000. Yearly mean water flow is $1.45 \cdot 10^8$ m^3, and the mean concentrations of total phosphorus and suspended solids are 88 mg m^{-3} and 0.042 kg m^{-3}, respectively. The lowermost figure shows the calculated (equation 2) fraction of dissolved phosphorus in total phosphorus concentration (0.65 in the mean).*

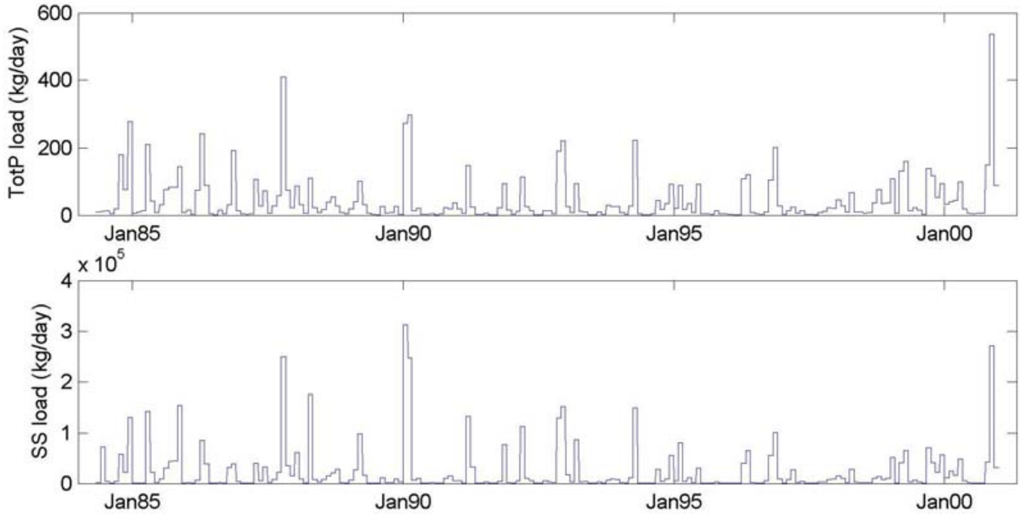


Figure 6. *Time series of daily transports of total phosphorus and suspended solids at Kure station of River Hobøl in 1984-2000. Mean loads are 16.7 and 9000 tons per year, respectively.*

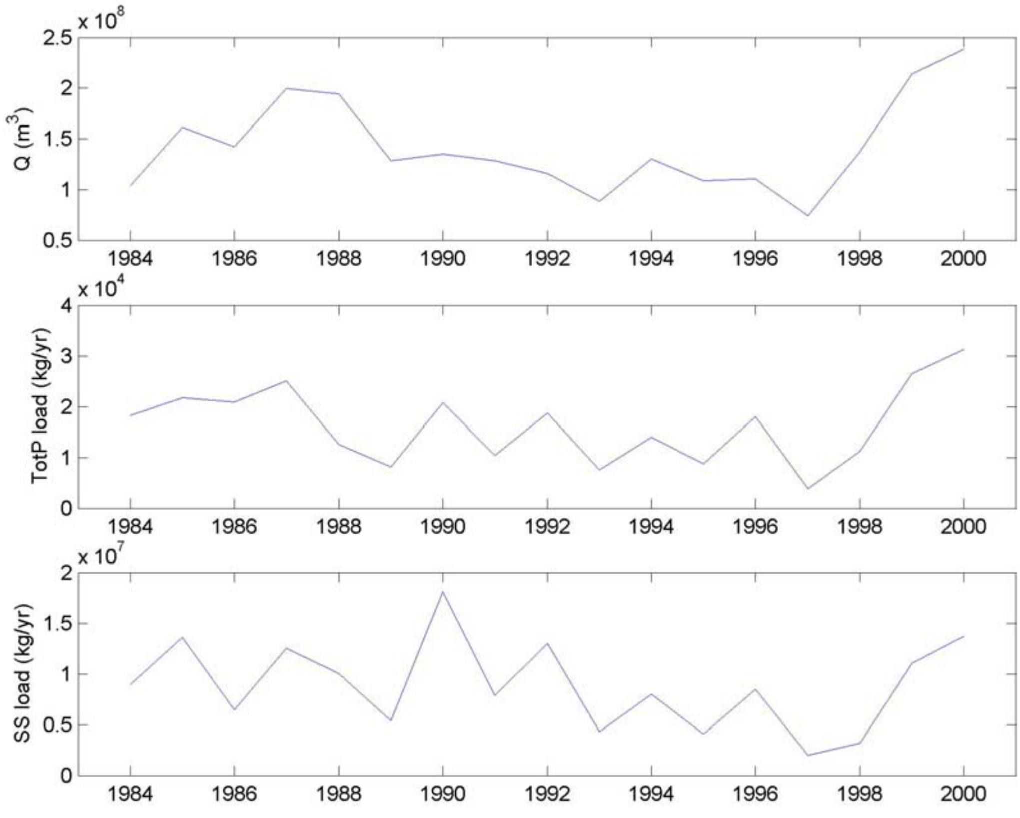


Figure 7. *Time series of yearly loads of water, total phosphorus and chlorophyll a at Kure station of River Hobøl in 1984-2000.*

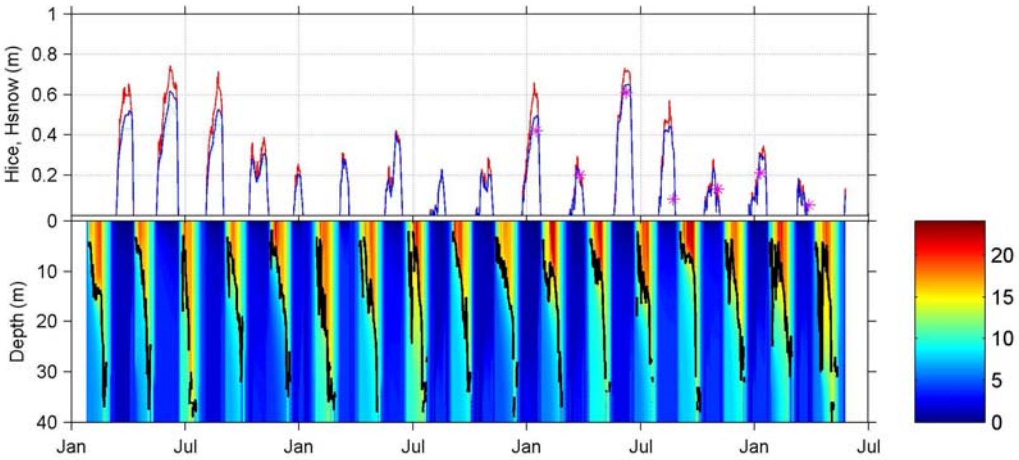


Figure 8. *Measured vs. simulated temperature and ice conditions in 1984-2000 in Vansjø-Storefjorden.*

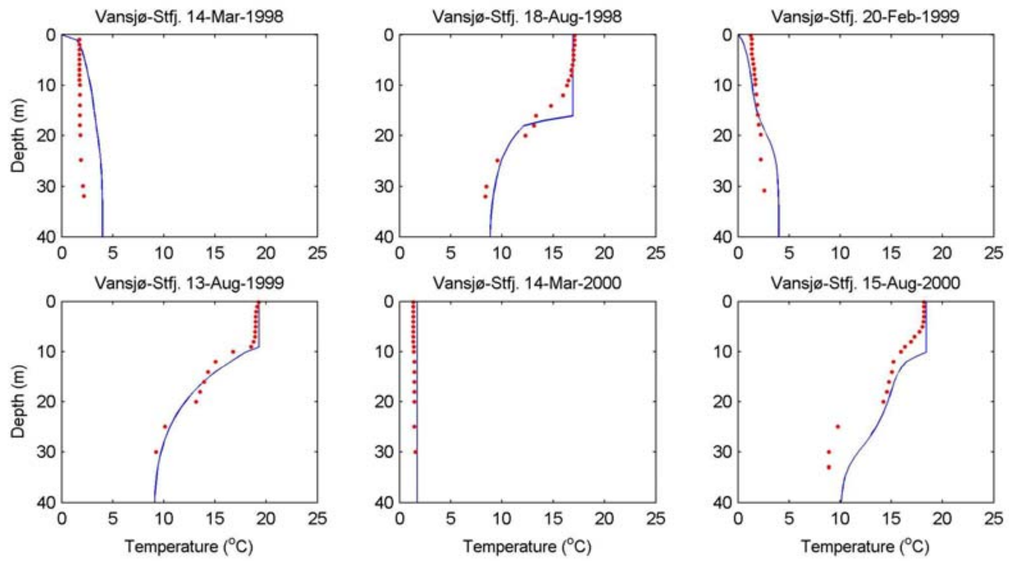


Figure 9. *Measured (red dots) vs. simulated temperature in 1998-2000 in Vansjø-Storefjorden.*

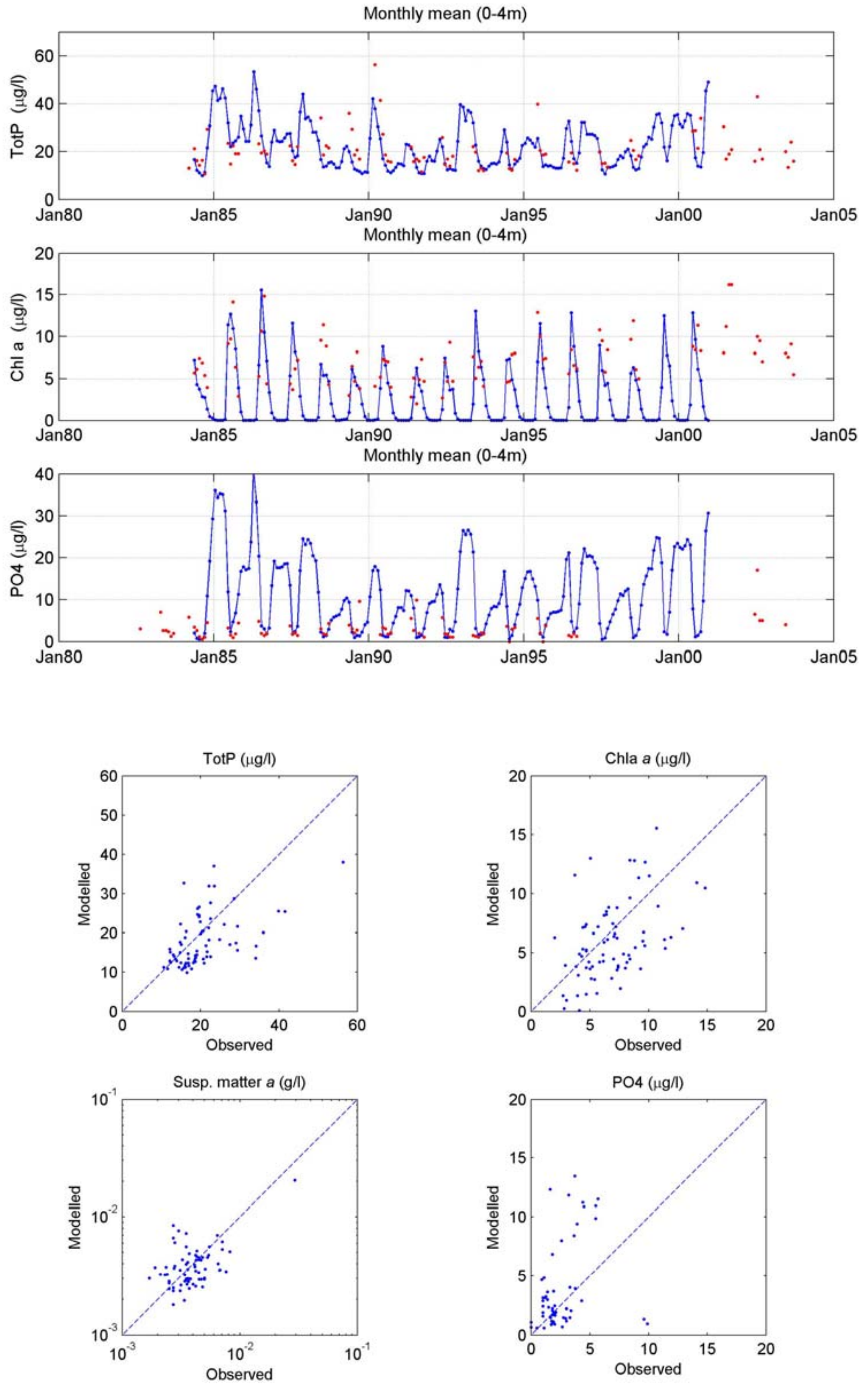


Figure 10. *Measured (red dots in the upper panel) vs. simulated total phosphorus (P_D+P_{IP}+P_{DO}+P_{Chla}), $P_{Chla,}$ P_D (PO_4) and suspended matter (S+$S_{org,}$ lower panel only) in 1984-2000 in Vansjø-Storefjorden.*

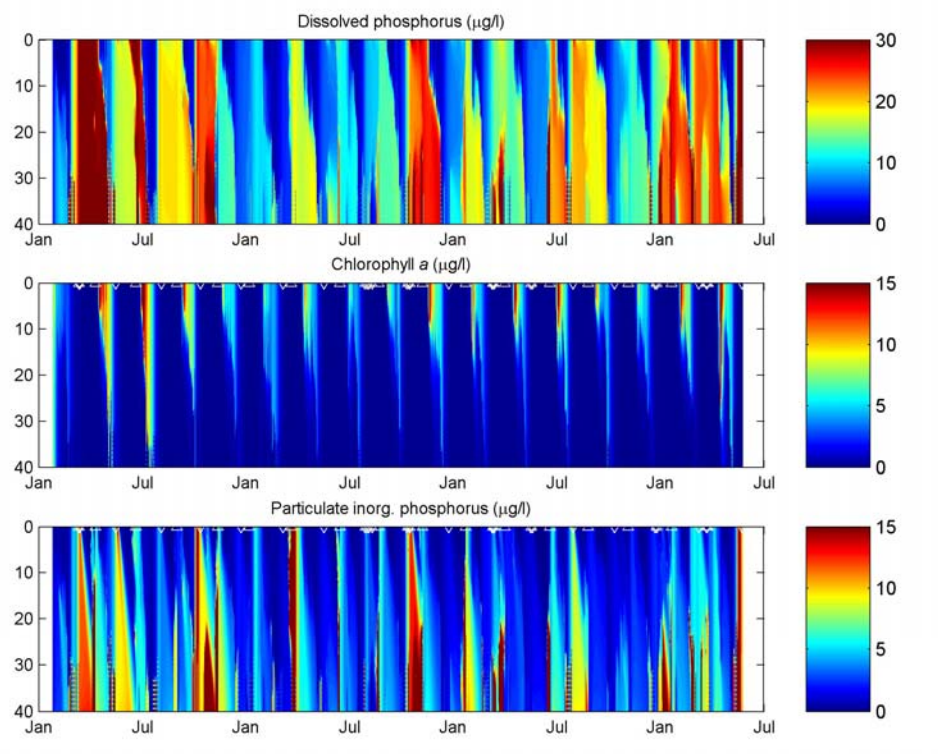


Figure 11. *Simulated profiles of P_D, P_{Chla}, and P_{IP} in 1984-2000 in Vansjø-Storefjorden.*

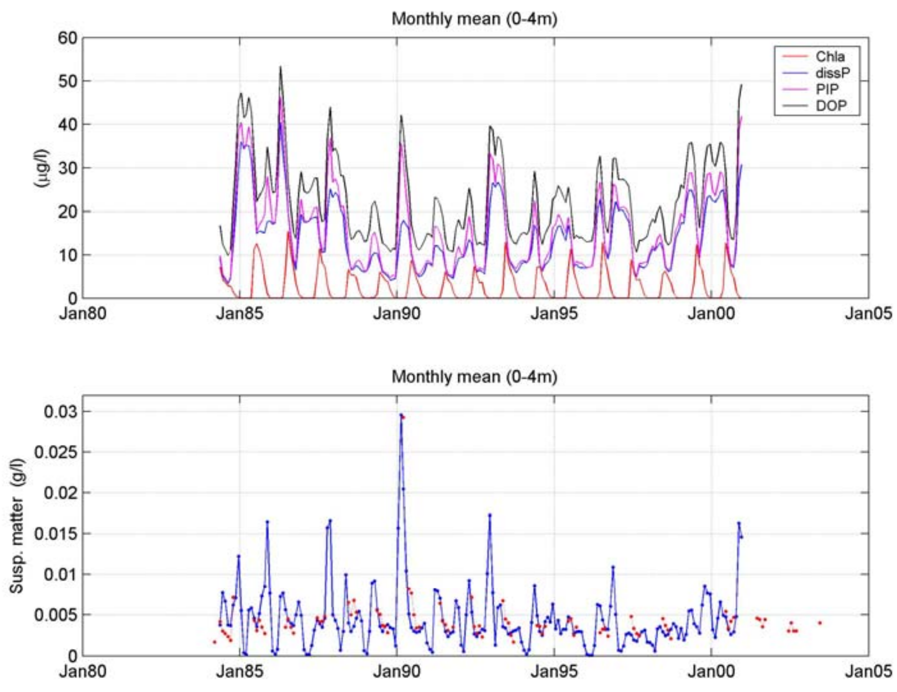


Figure 12. *Simulated phosphorus fractions (cumulative sum of P_{Chla},P_D, P_{IP}, and P_{DO}, upper panel), and simulated vs. observed (red dots) suspended matter concentration (S+$S_{org,}$, lower panel; see also Figure 10) in 1984-2000 in Vansjø-Storefjorden.*

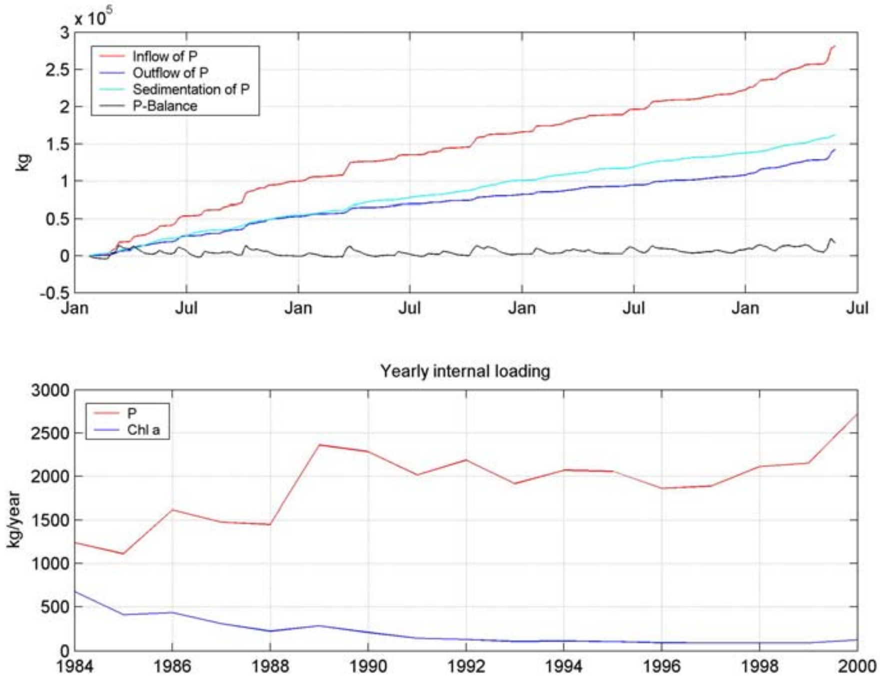


Figure 13. *Simulated cumulative phosphorus balance in the water column (upper panel), and yearly resuspension of phoshorus and chlorophyll a from the sediments (lower panel) in 1984-2000 in Vansjø-Storefjorden* ***(NB! P-balance curve is wrongly plotted).***

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