

# NETLAKE toolbox for the analysis of high-frequency data from lakes



## Factsheet #3

### The General Lake Model (GLM)

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Marieke Frassl, Michael Weber and Louise Bruce

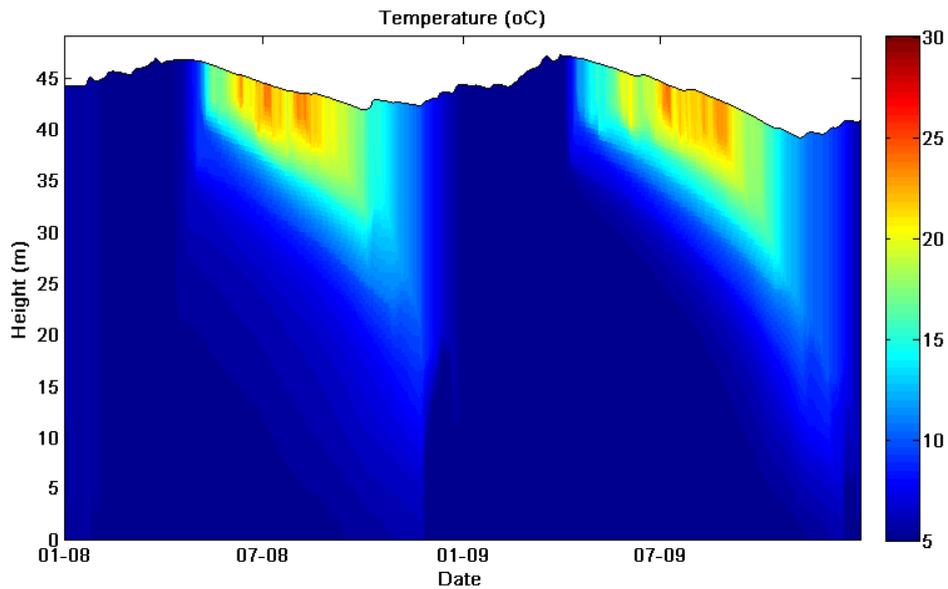
#### *Objective*

Numerical modelling of lakes and reservoirs provides opportunities for addressing research questions beyond those possible with observational monitoring data alone. This is the case when the scientific or management questions are about the ecosystem state in the future, or when a higher resolution in space or time is needed than observed by monitoring. Lake models can serve as tools providing, for example, near real-time forecasting of water quality, scenario analyses of changed external drivers (e.g. climate change) or simulated data on the outcome of different management strategies.

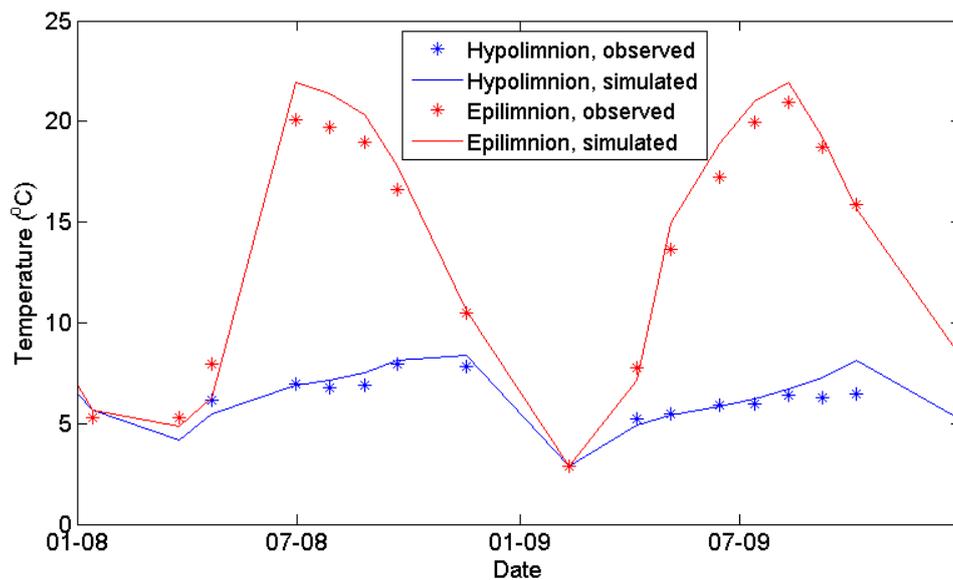
The General Lake Model (GLM) is a one-dimensional hydrodynamics model. Hydrodynamic models describe the thermal properties and the mixing dynamics in water bodies. Based on inflow and outflow data, as well as meteorological data, GLM calculates a water and energy balance resulting in vertical profiles of temperature, salinity and density over time. As a one-dimensional model, GLM simulates the vertical profiles at one spatial point in the lake. Effects of ice cover on thermal properties and mixing of the lake can be included. GLM can also be coupled to biogeochemical models (e.g. AED, FABM), and therefore serves as the basis for models simulating the biological and chemical parameters in the water column. Data from monitoring stations are used as input data and to calibrate and validate the lake model. In combination with the observed data, GLM can be used to explore the role that stratification and vertical mixing play on the dynamics of lakes.

#### *Specific application*

The main usage of GLM is to provide simulated physical data that are coupled to an ecological model to simulate water quality. However, GLM can be used as a stand-alone tool such as using it to assess the outcome of different management strategies on the thermal structure of a reservoir. Figures 1 and 2 show the GLM output for a two-year simulation of the Grosse Dhuenn Reservoir, Germany. Note the change in simulated water level, and water temperature over time.



**Figure 1.** Simulated water temperature in the Grosse Dhuenn Reservoir, Germany (2008-2009).



**Figure 2.** Comparison of simulated and observed epi- and hypolimnetic temperatures in the Grosse Dhuenn Reservoir, Germany (2008-2009).

## Background

The model is written in 'C'. Compiled executables for MS Windows, Mac OS or Linux are freely available at the GLM webpage (see link below). To run a simulation, GLM can be called from the command window. Alternatively, the R-package GLMr can be used to run the model and plot the output. Some knowledge in 'R' or 'Matlab' is helpful to prepare the input files and to analyse the output. A basic knowledge of modelling techniques such as calibration and validation procedures is recommended before applying the model (Bennet et al. 2013). Calibration uses measured data to find the optimum values for selected model parameters;

validation uses different measured data to allow an assessment of model performance for an independent time period to that used to calibrate the model.

### *Type of data and requirements*

GLM input data are specified in .txt and .csv files. The following data are required:

- Morphometric data of the lake as a hypsographic curve. These are in the form of two columns of data, one with depth (m) and the second with the area of the lake at that depth (m<sup>2</sup>).
- The extinction coefficient (1/m), averaged over the simulated time period, e.g. estimated from Secchi depth measurements.
- Meteorological data (mean air temperature (°C), mean wind speed (m/s), mean shortwave radiation (W/m<sup>2</sup>), mean longwave radiation (W/m<sup>2</sup>) or cloud cover (fraction coverage), mean relative humidity (%), total rainfall (m/day) in an hourly or daily resolution.
- Inflow and outflow data in a daily resolution: volume (m<sup>3</sup>/s), salinity (psu) and temperature (°C).
- An initial temperature profile, including the depths of each temperature measurement.

The format and file structure needed to run the model are described in depth in the user manual (see link below). Example files and simulations are provided on the webpage.

For the model validation, a time series of temperature measurements at different depths is needed. The time resolution of the calibration and validation data is not fixed. However, a higher resolution generally reduces the uncertainty in model prediction.

### *Basic procedures*

A detailed description of how to set up and run the model is given in the manual (see link below). The basic steps are:

1. Optional: Run one of the example simulations.
2. Collect and clean-up input data and prepare the input files for your lake (.csv file with meteorological data, .csv files with inflow and outflow data, a master .nml file including lake morphometry and lake location, run time set up and initial conditions).
3. Check the format and units of your input data.
4. Split your input and monitoring data into two time frames.
5. Run the model for the first part of your available data.
6. Compare model results and observations and calibrate model parameters.
7. Use the second part of your available data to validate the model, i.e. compare observations and model results without further calibrating the model. For different metrics to quantify model fit see e.g. Bennet et al. (2013).
8. Optional: Use your model set-up to run scenarios.

## *Pitfalls and tips*

- GLM is a one-dimensional model and is based on the assumption that variation in the vertical direction is more important than the horizontal direction. Check if this assumption applies to your lake or reservoir.
- If your simulation does not start, or shows strange results, check the file format (especially the date format) and the units of your model input (e.g. Kelvin instead of degrees Celsius; mm instead of m – see manual). Wrong units or a wrong format are the main error source and it is worth checking the model input carefully.
- To avoid frustration due to a wrong format of the input files, it is very helpful to start with the example files and to exchange those files step by step with your own data.
- GLM is an open-source community model, therefore different “sources for help” exist from which you can benefit. If you have a question, start by checking the AEMON forum, where model users actively discuss problems and offer solutions (see link below).
- To calibrate and validate the model results a range of metrics and patterns should be analysed such as the epilimnion and hypolimnion temperature, thermocline depth, stratification onset. For an example see Figure 2.
- The R-packages *glmtools* (see link below) and *Lake Analyzer* (Read et al. 2011), which are available in ‘R’ and ‘Matlab’, are useful software packages to analyse the model output.

## *Further reading*

### **GLM Manual:**

Hipsey, M.R., Bruce, L.C., Hamilton, D.P. 2014. GLM – General Lake Model, Model Overview and User Information (<http://aed.see.uwa.edu.au/>)

### **Applications of GLM:**

Read, J.S., Winslow, L.A., Hansen, G.J.A., Van Den Hoek, J., Hanson, P.C., Bruce, L.C., Markfort, C.D. 2014. Simulating 2368 temperate lakes reveals weak coherence in stratification phenology. *Ecological Modelling* 291: 142-150.

Yao, H., Samal, N.R., Joehnk, K.D., Fang, X., Bruce, L.C., Pierson, D.C., Rusak, J.A. James, A. 2014. Comparing ice and temperature simulations by four dynamic lake models in Harp Lake: past performance and future predictions. *Hydrological Processes* 28: 4587-4601.

### **Calibration Techniques:**

Bennett, N.D., Croke, B.F.W., Guariso, G., Guillaume, J.H.A., Hamilton, S.H., Jakeman, A.J., Marsili-Libelli, S., Newham, L.T.H., Norton, J.P., Perrin, C., Pierce, S.A., Robson, B., Seppelt, R., Voinov, A.A., Fath, B.D., Andreassian, V. 2013. Characterising performance of environmental models. *Environmental Modelling & Software* 40: 1-20.

## Code

The model is written in 'C'. Executables are available at:

<http://aed.see.uwa.edu.au/research/models/GLM/>

The R-package *GLMr*, which can be used to run the model and analyse the output is available at: <https://github.com/GLEON>. The package *glmtools* is available at <https://github.com/USGS-R/glmtools>

## Contact details

Lead developers and project owners:

Louise Bruce and Matt Hipsey, Aquatic Ecodynamics Research Group, University of Western Australia, Perth, Australia (<http://aed.see.uwa.edu.au/>)  
[louise.bruce@uwa.edu.au](mailto:louise.bruce@uwa.edu.au) and [matt.hipsey@uwa.edu.au](mailto:matt.hipsey@uwa.edu.au)

GLM users:

Marieke Frassl and Michael Weber, Department of Lake Research, Helmholtz Centre for Environmental Research, UFZ, Magdeburg, Germany ([www.ufz.de](http://www.ufz.de))  
[marieke.frassl@ufz.de](mailto:marieke.frassl@ufz.de) and [michael.weber@ufz.de](mailto:michael.weber@ufz.de)

R tools and Open Source leads:

Jordan Read and Luke Winslow, USGS Center for Integrated Data Analytics, Wisconsin, USA  
[jwinslow@usgs.gov](mailto:jwinslow@usgs.gov) and [jread@usgs.gov](mailto:jread@usgs.gov)

AEMON forum: <https://groups.google.com/forum/#!forum/aquaticmodelling>

## Suggested citation

Frassl, M., Weber, M. and Bruce, L. 2016. The General Lake Model (GLM). In Obrador, B., Jones, I.D. and Jennings, E. (Eds.) *NETLAKE toolbox for the analysis of high-frequency data from lakes* (Factsheet 3). Technical report. NETLAKE COST Action ES1201. pp. 11-15.  
<http://eprints.dkit.ie/id/eprint/534>.

## Acknowledgement

This factsheet is based upon work from the NETLAKE COST Action ES1201, supported by COST (European Cooperation in Science and Technology).