1. Although GLM is a new model code written in C, the core layer structure and mixing algorithms have been based on equations summarized in
    1. Hamilton, D.P. & Schladow, S.G. 1997. Water quality in lakes and reservoirs. Part I Model description. Ecological Modelling, 96: 91–110.
    2. Imberger, J. and Patterson, J.C., 1981. A dynamic reservoir simulation model-DYRESM: 5. In: H.B. Fisher (ed.), Transport Models for Inland and Coastal Waters. Academic Press, New York: 310-361.
2. GLM adopts a one-dimension solution processes of vertical mixing by incorporating a series of vertical layers that are used to describe the variation in water column properties.
3. Excerpt from Hamilton, D.P. & Schladow, S.G. 1997 in which the first water quality model that utilizes the final incarnation of DYRESM as the hydrodynamic component:
    1. Early approaches to predictive modeling of water quality in order to limit eutrophication were oversimplifications based on continuously-stirred or two component vertical systems
    2. Many early attempts *were not process based (?)* and instead solve the 1-D thermal advection-diffusion equation (?)
        1. Dake & Harleman, 1977
        2. Orlob & Selna, 1970
    3. These efforts were improved on by three groups (Imberger et al 1978, Stefan & Ford, 1975, and Bloss & Harleman, 1978) who created process based approaches and, among these, two were coupled to ecological models, thus creating full fledged water quality models called MINLAKE (Riley & Stefan 1978, 1979) and CE-QUAL (USCE, 1986)
    4. All three represent transport and mixing process as a product of inflow, outflow, diffusion, and mixed layer dynamics. The model adopts a flexible Lagrangian structure of <100 layers that are free to move vertically, expand, and contract in response to the four previously mentioned forces.
    5. Three separate algorithms are used to control individual mixed layer processes, inflows (riverine & groundwater), outflows (man-made and natural), and hypolimnetic mixing.
    6. The Lagrangian formulation precludes the necessity of calculating vertical velocities, which speeds up computation and minimized numerical diffusion.
        1. Numerical diffusion is a difficulty with computer simulations of continua (such as fluids) wherein the simulated medium exhibits a higher diffusivity than the true medium.
    7. Mixing is represented as the **amalgamation of layers**. Properties of the amalgamated layer are volumetrically averaged and the total number of model layers are decreased, as necessary. The maximum number of layers and the maximum & minimum thickness of a given layer are specified a priori. When a layer falls below the minimum required size, as is common after an outflow withdrawal, it is merged with the smaller of adjacent bounding layers.
    8. In recent modifications, the true one-dimensional representation of **inflow** was modified to allow for a quasi-two dimensional representation, comprised of three stages:
        1. The inflowing volume is propagated horizontally until buoyancy forces arrest the flow.
        2. The newly introduced volume then moves vertically depending on the relative densities of proximal layers, entraining ambient water until it achieves neutral buoyancy
        3. Finally it will resume horizontal migration until either a gravitational-inertial or gravitational viscous balance is achieved (as quantified by the Grashof Number and the Froude number criterion, Imberger 1976)

9. For reasons spelled out in (Jokela & Patterson, 1985), this inflow volume is not added to the 1D layer structure until it has intruded across the full length of the lake (?)
10. Ground flows may be modeled in the same manner, but without an entrained volume
11. **Outflows** are modeled by modifying layer thicknesses at the vertical position one or more offtakes
    1. Simple surface off takes are only proportional to observed discharge
    2. Submerged off takes are the volume of water removed is determined by the amount of stratification, observed discharge, the type of off take (point sink or line), and is governed by the same Froude & Grashof number criterion as described for inflows.
    3. Outflow dynamics are described in Imberger and Patterson, 1990.
12. To correctly model the influence of wind and solar heating on mixing, a daily and a possibly **sub-daily time step** are required:
    1. A daily (24 hr) time step is used for inflows and outflows
    2. A sub daily time step is used to represent mixing processes, solar heating, and wind shear processes.
    3. Three calculations are made to determine the length of this time step and the minimum among them is used.
        1. The photoperiod (defined by latitude & hemisphere),
        2. The length of time needed to heat the upper layer 3 degrees C (defined by longwave & albedo corrected shortwave flux, layer volume, layer surface area, specific heat capacity, surface layer depth, evaporative & sensible heat flux, and light extinction coefficient)
        3. the amount of time needed to limit the shear velocity of the surface layer of the model to 0.1 m/s.
13. All three differ in how they represent the production of **turbulent kinetic energy**, which is the mechanism by the mixed layer move along the vertical dimension. One is dependent on user input, another is dependent on thermal stratification and wind stress and the third, which is the one the GLM is based on, represents mixing as an empirically observed product of four phenomena, described in Imberger & Patterson 1981
    1. Surface layer dynamics is are based on the integral of TKE model specified by Sherman et al 1978.
    2. The TKE budget is partitioned between the forces of wind stirring, convective overturn, interfacial shear production, and Kelvin-Helmholtz billowing. The energy available through each of these processes is compared with the potential energy required to combine two adjacent layers.
    3. If there is sufficient TKE, then the layers are combined and the available TKE is reduced by the amount of potential energy that was gained and the process is repeated for the layer below until insufficient energy remains to within the present time step to continue the deepening process.
14. **Hypolimnetic mixing** is modelled by the turbulent diffusivity coefficient.
    1. Weinstock, 1981 describes that this coefficient depends directly on the dissipation of TKE and inversely on thermal stratification
    2. Dissipation is equivalent to the energy input by wind and decays exponentially from the region of most severe stratification (Imberger, 1982)
    3.
15. The MAJOR advantage of the ultimate approach is that only data is required to simulate mixing and calibrations supposedly is not.
16. This also implies that it is ultimately correct and as such it has been shown to be based on a multi-lake comparison study (Imberger & Patterson 1990)

    17. As such, this advantage is entirely discarded by the current implementation of the GLM. Based on my project there is no apparent advantage to this added process parameterizations.
    18. According to Vincent et al 1991, hydrodynamics is one of the dominant factors in lake ecology
    19. A full description of a water quality model involves a hydrodynamic model, a particle settling model, and an ecological model
    20. The state equations for the ecological model are explicitly stated in the paper by Schadlow and Hamilton
4. Imberger, J. and Patterson, J.C., 1981. A dynamic reservoir simulation model-DYRESM:5. In: H.B. Fisher (ed.), Transport Models for Inland and Coastal Waters. Academic Press, New York: 310-361.
5. DYRESM Description is split across the following papers:
    1. Imberger and Patterson, 1990
    2. Imberger, J. and Patterson, J.C., 1981. A dynamic reservoir simulation model-DYRESM: 5. In: H.B. Fisher (ed.), Transport Models for Inland and Coastal Waters. Academic Press, New York: 310-361.
    3. Imberger, 1982
    4. Imberger, J., Thompson, R., and Fandry, C. (1976) Selective withdrawal from a finite rectangular tank. Journal of Fluid Mechanics, 78 (3):
    5. Quasi-Two-Dimensional Reservoir Simulation Model