Topic 1: Simulating two scenarios for counteracting eutrophication in a lake: extraction of deep water and reduction of inflow concentration.

Motivation

High nutrient inputs to a lake (from agricultural activities or wastewater) can lead to eutrophication. The increased growth of algae and subsequent degradation of dead organic matter can lead to a severe oxygen depletion in the hypolimnion of a stratified lake. Currently, many lakes on the Swiss plateau (e.g. Zugersee, Sempacher See, Lago di Lugano, Balderggersee, Murtensee) do not fulfil the legal requirements regarding oxygen concentrations in the hypolimnion (min 4 mg/L O_2) and phosphorus concentrations, which do not lead to an exceedance of "a moderate production of biomass". The goal here is to assess the potential effects of different management measures to counteract the effects of eutrophication.

Typical lake management measures are:

1. Tackling the source of the problem by reducing the phosphate input to the lake to reduce algae production
2. A measure to increase the transport of dissolved oxygen into the hypolimnion and reducing dissolved nutrients by extracting water from the hypolimnion (deep water extraction)
3. Supplying compressed air to the hypolimnion to increase circulation in winter and to increase the oxygen concentration.

All three measures have been applied in Switzerland. The first has been applied in all catchments of Swiss lakes by installing sewage treatment plants and increasing their phosphorus elimination rate and by trying to reduce phosphate inputs from agriculture. The second measure has been discussed for several lakes (e.g. Lake Zug[1]), but rarely implemented. Examples for an implementation are Lake Hüttwil[2], Mauensee LU and Wilersee ZG. The third measure has been implemented in Lake Baldegg and Lake Hallwil[3] and will soon be implemented in Lake Zug.

The intention of this assignment is to compare the measures 1 and 2 for a hypothetical (not strongly eutrophic) lake.

Assignment

First, add a deep water extraction line (outflow) from the hypolimnion in the model definition of model 11.4 (see Figure 1). For this, you have to make some changes to the water fluxes of the model and you have to introduce **one** new parameter: the outflow from the hypolimnion as a fraction of the inflow to the lake. The modification you make must not affect the total outflow from the lake, so that it remains

---

[1]See page 6 in https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiP-cjEhfnvAhWMGewKHWhwBcYQFjABegQIBRAD&url=https%3A%2F%2Fwww.bafu.admin.ch%2Fdam%2Fbafu%2Fde%2Fdokumente%2Fwasser%2Ffachinfo-daten%2FWasserqualit%25C3%25A4t_Seen_Zugersee.pdf.download.pdf%2FWasserqualit%25C3%25A4t_Seen_Zugersee.pdf&usg=AOvVaw0_ImirmsnB1i_FPlLzEMpF

[2] https://www.e-periodica.ch/cntmng?pid=tng-001:2010:64::290

[3] https://www.ag.ch/de/bvu/umwelt_natur_landschaft/umwelt_1/oberflaechengewaesser/hallwilersee/sanierung_hallwilersee_1/sanierung_hallwilersee.jsp, http://www.seetal-plus.ch/Natur/SeeSanierung.html

equal to the inflow. The volumes of the two boxes should stay constant, therefore you need to introduce an advective flux from the epilimnion to the hypolimnion and plot the volume to check if it works.

Once you implemented the model, investigate the efficiency of the two measures **individually**:

- Reduction of the inflow concentration of phosphorus by 50%
- Outflow of the deep water extraction is 50% of the inflow to the lake

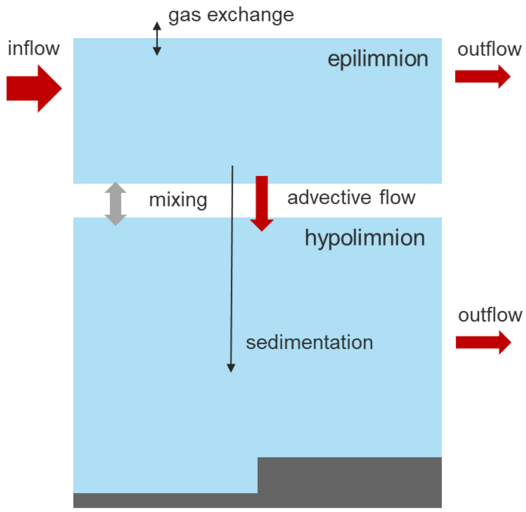

Figure 1: Illustration of the two box model with an additional outflow of the hypolimnion.

Especially, look at the behaviour of the phosphate concentration in winter, the minimal oxygen concentration during the summer in the hypolimnion and the concentration of algae. Compare the effect of the two measures with the original situation.

Oftentimes, we have a considerable reservoir of degradable organic matter stored in the sediments of eutrophic lakes that is degraded only slowly over multiple years. This was not the case in the model studied so far. To consider this, increase the initial surface density of degradable organic matter in the sediment from 0 g_{DM}/m^2 to 300 g_{DM}/m^2 and decrease the rate constant for oxic and anoxic degradation of organic matter in the sediment from 5 $g_{DM}/m^2/d$ to 1 $g_{DM}/m^2/d$.

Now perform the exact same analysis as before, but with the new system. What is the effect of the two measures now? How does it compare to the effect for the other system and what might be the reason for the differences? How long does it take in each case to fulfil the legal oxygen requirements?

In your analysis, consider that the system might need considerable time to reach a periodic equilibrium depending on the initial conditions, i.e. choose simulation times that allow you to fully discuss the temporal dynamics, including the dependence on the initial density of sedimented degradable organic particles.

Finally, think about the most important shortcomings of this model that could lead to differences to what happens in real lakes.