Demonstrating the Stratification of Dimictic and Meromictic Lakes in a Fish Tank

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ABSTRACT
The demonstration described in this paper attempts to illustrate the main controls on the vertical circulation of lake water. This phenomenon integrates the effects of annual air temperature cycles, fetch, and possible groundwater sources to a lake. Because the nature of a lake's circulation pattern has an effect on the "quality" of the sediment record preserved, it is among the most important limnological processes for students to understand.

This demonstration involves a fish tank, colored water, salty water, and artificial sun and wind. The water in the tank "evolves" through the seasons of a typical meromictic lake, beginning with Spring turnover and ending with Fall turnover. The demonstration requires several hours to complete, and students measure water temperature and conductivity through the model year. I have found this demonstration to be a helpful illustration of dimictic and meromictic lakes; it is especially helpful to illustrate the seasonal evolution of lake water, which is not apparent during winter field studies of local northeastern US lakes.

INTRODUCTION
The turnover of lakes is a fundamental limnologic process that integrates the effects of seasonal climate change, wind fetch, water chemistry, and the unusual relationship that exists between the density and temperature of water (Cohen, 2003). Additionally, the nature of a lake's stratification can have a big impact on the mode of delivery of fine-grained sediment to lakes, the dissolved gas content of lake bottom water, and the potential of lakes to contain annually resolvable sediment records.

Water achieves its maximum density at ~4°C and lakes turn over when water columns approach an isothermal state and wind mixing is sufficient to overcome any remaining density stratification. The warming of surface water above 4°C creates a low density surface water known as the epilimnion that is superimposed on a higher density bottom water termed the hypolimnion. The interval of the water column between the epilimnion and the hypolimnion that contains the thermal gradient is known as the metalimnion, and the portion of the metalimnion with the maximum thermal gradient is the thermocline. Wind mixing of the epilimnion maintains its isothermal state, and the thickness of the epilimnion is approximated by the depth to wave base, which, in turn, is controlled by wind velocity and fetch.

Most mid-latitude lakes turn over twice a year and are termed dimictic. Near isothermal water columns occur in the late fall when the epilimnion cools to approach the temperature of the hypolimnion, and again in the early spring when the epilimnion warms to approach the temperature of the hypolimnion. During these intervals, oxygenated waters circulate to lake bottoms and any accumulated byproducts of aerobic and anaerobic respiration (e.g., CO₂ and CH₄, respectively) degas to the atmosphere. Cooling of the epilimnion below 4°C in the winter and warming above 4°C in the summer create the biannual stratification that characterize a dimictic lake. During these intervals ventilation of bottom waters ceases, and anoxia of hypolimnia commonly develops in eutrophic lakes.

The presence of salty, dense bottom water in meromictic lakes precludes the full turn over a lakes' water column. Such a lake will turnover to the top of the salty layer, which is known as the monimolimnion; the interval of water possessing the gradient in salt content is the chemocline. These lakes are termed meromictic, and their near-permanent dysoxia to anoxia promotes the preservation of annually resolvable sediment records that are a prime target of many paleoclimate studies (e.g., Dean et al., 2002).

In the course, Lakes and Environmental Change (Rodbell and Gremillion, 2005), that I teach at Union College, I have found that explanations of the complex interplay among the aforementioned variables that control how a lake is stratified and when and to what depth a lake will turnover can be difficult to make in ways that promote real understanding by students. I report here a simple, inexpensive model that can be built with commonly available materials that illustrates the stratification and turnover of lakes with an emphasis on mid-latitude dimictic lakes, and on the effects of meromixis in lake stratification and ventilation.

MATERIALS AND METHODS
The main ingredients in this model (Table 1; Figure 1) are a fish tank, heat lamps, a fan, yellow and blue food coloring, a funnel with rubber hose, salt, a thermometer, and a conductivity meter. The heat source should be ~20 cm above the water surface, and the fan should stand high enough to blow down and across the water surface parallel to the long-axis of the fish tank. It is useful but not essential to build a rack from which to mount the lamp outlets (Figure 1). The entire apparatus should fit on a lab cart so that it can be wheeled into classrooms.

I fill a fish tank with tap water, and then remove approximately 1/3rd of the water and placed it in a separate container. I then add yellow food coloring to the water in the in the separate container, and mix it to saturation with inexpensive MgCl salt that is commonly available for deicing sidewalks, though any salt will serve the purposes of this demonstration. This salty, yellow water is then "injected" into the lake bottom (Figure 1) to form a monimolimnion using a funnel with a ~50-cm long plastic hose.

At this point, I generally wheel the demonstration apparatus into the classroom, and ask one student to measure an initial temperature and conductivity profile, and another student to enter the data into EXCEL and plot the down profile variation of these variables (Figure 2A). The resultant plots are projected onto a screen for all students to see; these initial plots reveal an isothermal profile and a strong chemocline that separates the salty,
dense deep water from the low conductivity surface water.

I then turn on the heat lamps to simulate the "sun". This step takes some time to have a measurable effect, so I generally try and arrange for this step to coincide with the time between a morning lecture and an afternoon lab, which is about 2 hours. When students reconvene, we measure the temperature and conductivity profiles of the water columns, which at this stage show a strong metalimnion, a very thin to non-existent epilimnion, and the same chemocline as was recorded in the first measurement (Figure 2B).

The next step is to turn on the "wind", which is directed down the long axis of the "lake" to maximize fetch. After about 30 minutes, we re-measure the temperature and conductivity profiles, and these show the development of an epilimnion that thickens in a down-lake direction, reflecting the role of fetch and resultant depth to wave base as a main control on determining the depth to the top of the metalimnion (Figure 2C). At this point we add about 250 ml of a mixture of very hot water with a high concentration of blue food coloring. Because a strong metalimnion exists, the hot, blue water only mixes with the epilimnion; the hypolimnion, which is located between the chemocline
and the metalimnion should only become pale blue at this point in the demonstration (Figure 3A.).

The final stage of the demonstration is to illustrate Fall turnover, which is a defining event for most middle-high latitude lakes. At this point, I turn off the "sun" and add several frozen freezer packs to the water surface to cool it. Freezer packs are superior to ice because the former do not dilute the blue coloring of the epilimnion. It is best to use a dozen or so small ones, around 3 cm³, rather than few large ones so that the epilimnion can continue to mix with the wind. As the thermal gradient in the metalimnion weakens (Figure 2D), the stability of the stratified water column weakens to the point where wind or any other mechanical disturbance that promotes mixing will cause the epilimnion to mix with the hypolimnion. This turnover is seen as a gradual leakage of the blue epilimnial waters throughout the hypolimnion; the entire upper part of the "lake" becomes dark blue. Because the density stratification of the chemocline and monimolimnion are unaffected by the mixing of the epilimnion with the hypolimnion, the bottom of the fish tank remains salty and yellow (Figures 2E and 3B). Further, because the chemocline marks the salinity gradient that separates the low salinity blue water from the high salinity yellow water, the chemocline can be seen as a green layer of water that grades from blue-green, green, yellow green (Figure 3). At this point in the exercise, we measure the thermal and chemical profiles of the water columns and plot these against the spring and summer profiles (Figure 2).

**DISCUSSION AND CONCLUSIONS**

I coordinate this demonstration with a laboratory study of a local lake that is meromictic (Rodbell and Gremillion, 2005). The laboratory study requires that the students determine the nature of the lakes' stratification after a single visit in January with limited data. The demonstration described here helps students see the likely evolution in stratification that their lake experiences annually. While I do not have any quantitative assessment data on the effectiveness of this demonstration, I have noticed anecdotally an improved understanding of lake stratification in lab reports from students. Furthermore, because the fish tank demonstration lasts several hours, it is ideal to have in the class while lecturing on the variety of patterns of circulation that lakes can possess.
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REFERENCES