1. You are a geochemist working on the water chemistry at Crater Lake, the deepest lake in North America. There is no surface flow out of the lake, and the lake level is maintained by a balance between evaporation (28 percent) and seepage of water out of the lake through fractures in the lake bottom (72 percent). The 67.8 km^2 drainage basin consists of the lake (53.2 km^2) and the steep walls of the caldera (14.6 km^2). Precipitation averages 172 cm annually. The average depth of the lake is 350 m. The steady state Mg^{2+} concentration in the lake is 200 μM/L.

a. Find the annual input of fresh water from precipitation.

b. Find the annual volume flow of water from seepage and evaporation.

Since it is still an active volcano, there is hydrothermal flow at the bottom of the lake. This flow is a simple circulation cell that returns all the water volume flowing through the hydrothermal cell to the lake at a temperature of 350 K above the lake bottom water temperature. At this temperature, all Mg^{2+} that flows through the hydrothermal cell is removed. Researchers estimate the convective heat flow from hydrothermal circulation is 6.4×10^8 J s^{-1}.

c. What is the rate of hydrothermal flow in kg of water per year? Assume a heat capacity of late water (C_p) of 5.8 J g^{-1} K^{-1}.

d. What is the total hydrothermal uptake of Mg^{2+} in moles per year?

e. What is the residence time of Mg^{2+} with respect to the flux into or out of the lake?

2. You are planning to conduct precise isotopic measurements on O_2 gas extracted from surface seawater and are currently deciding what volume your sample bottles need to be to provide you with the appropriate volume of gas for your measurements. Assume that conditions at your study site and in the laboratory are both close to standard temperature and pressure (i.e. 1 atmosphere and 273.15K). In addition to STP conditions, assume that the concentration of O_2 in your samples is 225 μmol kg^{-1} and that the density of seawater is 1.025 kg l^{-1}. Assume also that you will be able to extract close to 100% of the dissolved O_2 gas in the seawater.

a. What volume of seawater do you need to collect to provide 5 cc (ml) of O_2 gas for your measurements?
b. You will also be collecting samples at a site of vigorous upwelling where concentrations of O_2 at the surface can be as low as 60 μmol kg^{-1}. What is the minimum volume of seawater you will need to collect at this site to guarantee at least 5 cc of extracted O_2 gas for your measurements?

3. What equatorial upwelling rate would be required to maintain the oxygen deficit of ~ 4 mmol m^{-3} in the eastern equatorial Pacific (see figure) if there were no biological production? Assume that the upwelling water has an oxygen deficit of 40 mmol m^{-3} and that the deficit is zero in the waters at either side of the axis of upwelling. Assume a mixed layer of 40m and a gas transfer velocity of 10 cm hr^{-1}.

a. Draw a meridional / depth section of the upwelling system across the equator. Indicate the directions of the mass (water) fluxes and those of oxygen.
b. Derive a mass balance equation for the oxygen in the mixed layer.
c. Assume steady state and solve for the upwelling velocity.