Tracers in the Hydrologic Cycle: A Jigsaw Activity

Peter Lea
Geology Department
Bowdoin College
plea@bowdoin.edu

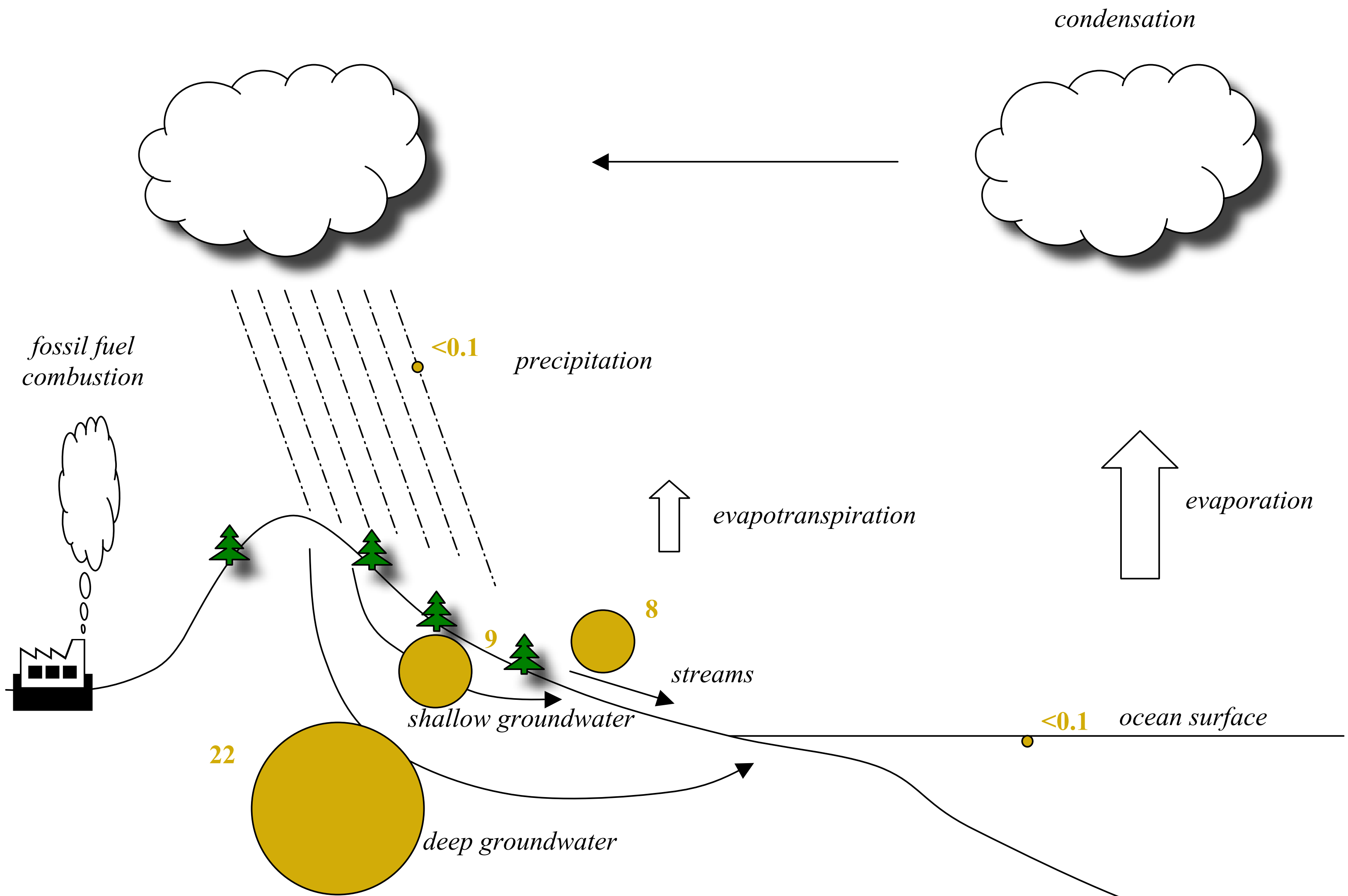
Background: Although most students have encountered the hydrologic or water cycle multiple times beginning in their K-12 years, it is commonly presented in a generalized context that only looks at the physical flux of water through the overall system, and which glosses over the true origins of stream flow as primarily reflecting groundwater contributions even during storms (e.g., Buttle, J.M., 1994. Hydrograph separations and rapid delivery of pre-event water from drainage basins. *Progress in Physical Geography* **18,** 16–41).

This exercise adds biogeochemical data to typical water-cycle diagrams, and asks students (A) to describe variations in (1) nitrate, (2) silica, (3) pH and (4) conductivity within the cycle, (B) to interpret these variations in terms of processes and to link these processes to flow paths, and (C) to look for commonalities in how flow paths impact the water-quality variables.

Instructions:
First, divide students up into four equal-sized groups and distribute copies of the diagrams so that each group gets a different one of the variables. Tell students that the values are typical averages for watersheds that are not highly developed (stream and groundwater data were obtained from the NAWQA database: *water.usgs.gov/**nawqa/data***). Concentrations are represented visually by circles with appropriately scaled diameters. Ask students first to describe variations around the cycle, and second to hypothesize on controls for these variations given the supplemental information provided in each text box. Remind them that they will each be responsible for explaining their group's "story" to other students who have not seen their variable. With students are discussing, I move around the room, listening and if necessary asking clarifying questions and supplying terms (e.g., weathering reactions").

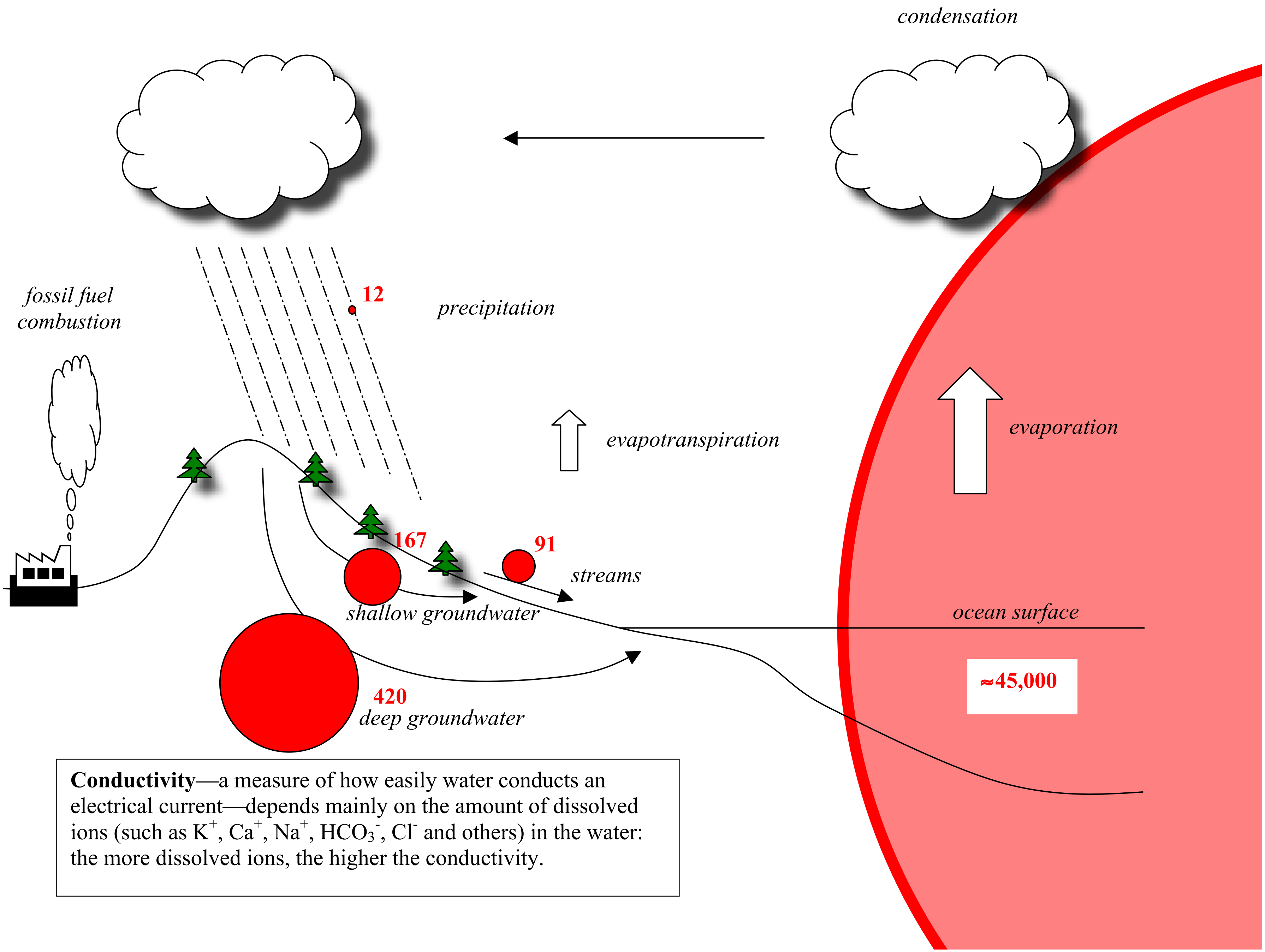
After students have come up with reasonable interpretations (I typically ask each group to explain these to mean before proceeding), recombine the students into groups that have one member from each variable. Ask students (A) to describe and explain the pattern for their own variable within the cycle, and (B) to look for process-related commonalities among the different variables within the cycle (e.g., distillation during evapotranspiration tends to leave behind dissolved ions, weathering within soils/groundwater zones increases concentrations of silica and conductivity while buffering acid rain, biological organisms extract nitrate and silica from waters, stream flow is a mixture of precipitation and groundwater inputs). I usually highlight these big-picture patterns via whole-class discussion, and then discuss how we can use these measurements as tracers [albeit non-conservative ones] to examine surface-groundwater interactions and the sources of stream flow, as well as the value of applying multiple tracers to answer such questions.

Dissolved silica (mg/L)



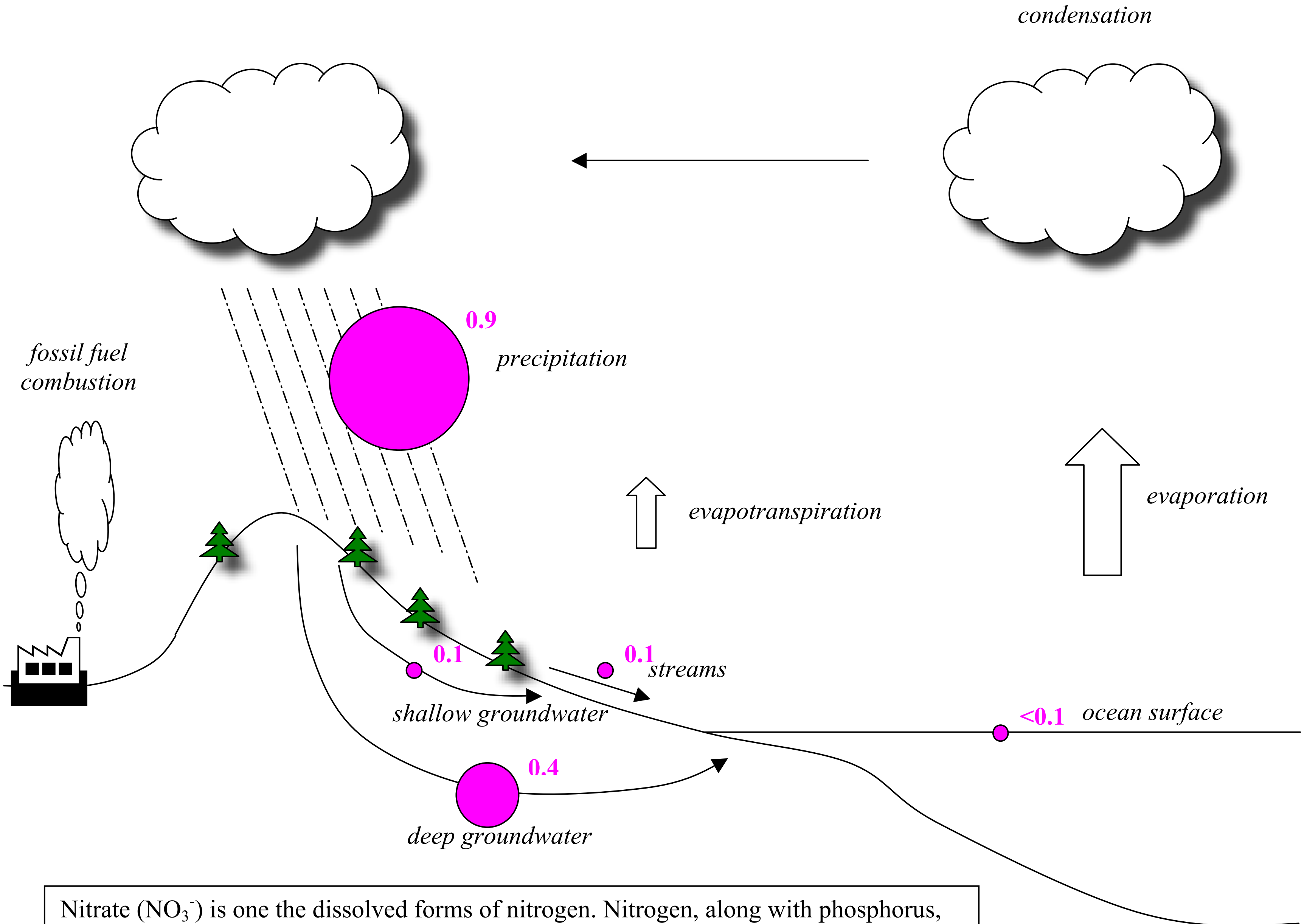
In its solid form, silica (SiO_2) is the most common compound in the earth's crust, either as the mineral quartz (SiO_2) or, more typically, bound with other ions to form minerals such as feldspar ($NaAlSi_3O_8$). Some micro-organisms (e.g., diatoms) construct hard parts out of silica. Dissolved silica is commonly represented as H_4SiO_4.

Conductivity (µS/cm)



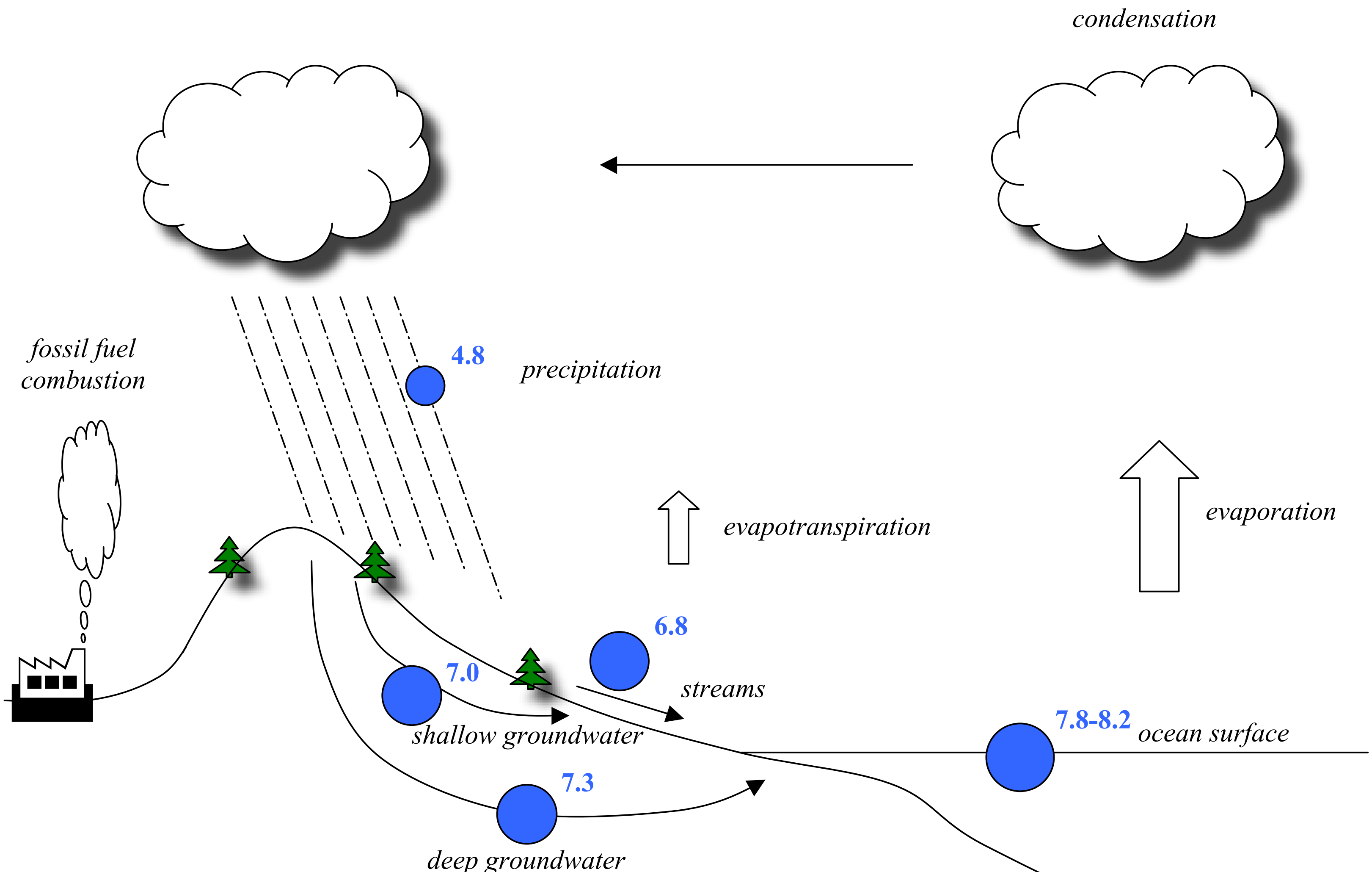
Conductivity—a measure of how easily water conducts an electrical current—depends mainly on the amount of dissolved ions (such as K^+, Ca^+, Na^+, HCO_3^-, Cl^- and others) in the water: the more dissolved ions, the higher the conductivity.

Nitrate (mg/L)



Nitrate (NO_3^-) is one the dissolved forms of nitrogen. Nitrogen, along with phosphorus, is a limiting nutrient in many biological systems (organic material contains not only carbon but also nitrogen and phosphorus). For example, excess runoff of nitrogen-bearing waters to lakes or estuaries can cause blooms of algae and adversely affect water

pH



pH is a measure of the acid-base status of water. A pH of 7 indicates neutral conditions, with equal concentrations (10^{-7} M) of acidic H^+ ions and basic OH^- ions in pure water. Compounds that react with water to create pH's <u>lower</u> than 7 (i.e., more H^+ ions) are termed acids (e.g., sulfuric, nitric or carbonic acid). Solutions with pH higher than 7 (i.e., fewer H^+ ions) are termed basic. The pH scale changes by a factor of ten for each unit (e.g., water of pH 6 is 10 times more acidic than water of pH 7).