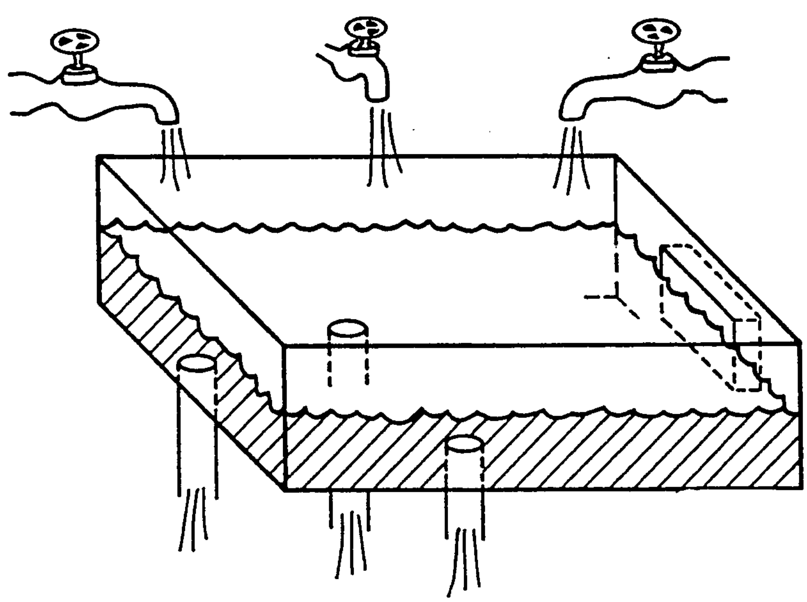
Teacher Background Information: The Global Carbon Budget

Part I: The Budget Concept:

Most people are familiar with the concept of a financial budget and balance sheet. In such a system, estimates or actual values of income and expense for a selected period are recorded. If income exceeds expense, the monetary reserves increase; if expense exceeds income, then the money reserves decrease. An approach similar to financial budgeting is used to design budgets in Earth system science. An important difference between the two, however, is that in an Earth system budget, all the input or output processes may not have been identified, and even if they have been, their magnitudes may be uncertain.

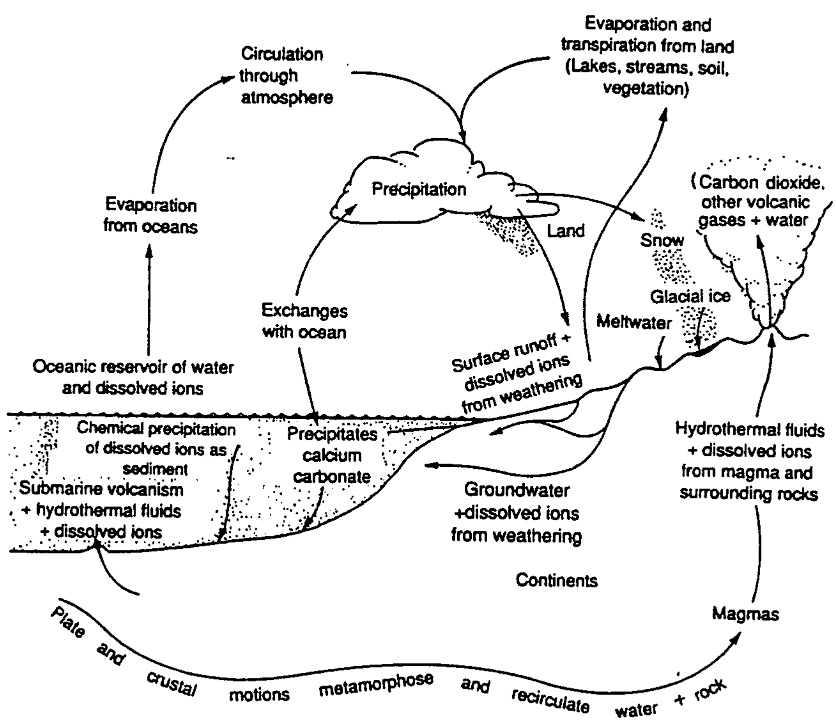
This situation can be appreciated with the aid of a diagram of a tub receiving water from several faucets and having a number of drains of various sizes. When the water is supplied at a constant rate, and is removed at an equal rate by all the drains, the level of water in the tank remains constant. Suppose, however, that the input from one or all of the sources is increased. Will the water level keep increasing? The answer depends on whether one or all of the drains can accommodate the additional supply; if this is not possible, then the water level will surely increase. Conversely, if the flow into a drain is enhanced for some reason, such as the removal of an obstruction, or the drain hole in enlarged, then the water level will decrease in the absence of a corresponding increase in water supply. Such a process will continue until the flows through the drains adjust themselves, or unless the new factor results in other drains changing their functioning. The system is basically nonlinear, as is often the Earth system, a characteristic which severely limits and complicates analysis.



A simple conceptual system for budget calculations

All of the circumstances mentioned above occur in budgets devised for the Earth system as well, and all budgets involve the same concepts. The first is that of the *reservoir or pool* - an entity defined by physical, chemical or biological properties that are uniformly distributed (Ex. the atmosphere as a whole, a section of the atmosphere, or the water vapor or oxygen pools in the atmosphere). The second is the *flux* - the amount and rate of a specific material entering or leaving a reservoir. Third, there are *sources (rates of creation) and sinks (rates of destruction)* of a specific material within a reservoir per unit time. A system of connected reservoirs that transfer and conserve a specific material is a *biogeochemical cycle.* Most Earth system cycles are closed; they lose no material.

An example is the planetary water cycle, the reservoirs being the oceans, lakes groundwater, soils, glaciers, ice sheets, the biosphere, clouds and atmospheric water vapor. Budgets for the Earth system have the same basic components as those for the tank: determination of the present level, a measurement or estimations of the sources, and a measurement or estimate of sinks. A perfect determination of any two of these three components determines the third.

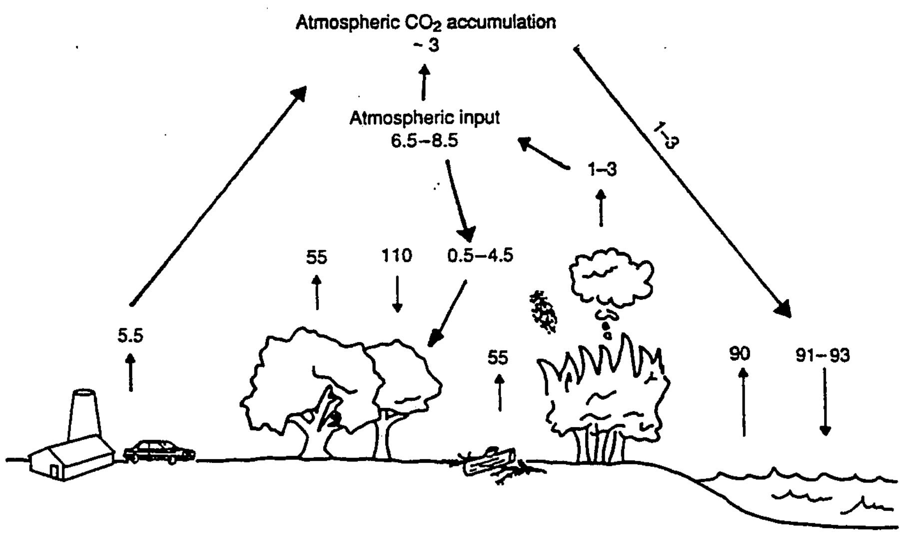


Features of the overall hydrologic cycle of Earth

Part II: The Global Carbon Budget

The biogeochemical cycle considered to be of greatest importance to climatology is the *carbon cycle* and the most intensively studied global budget in Earth science is the *carbon budget.* Although many carbon - bearing constituents can be found, by far the most abundant and dominant species in the atmospheric budget is *carbon dioxide.* Carbon exists in trace amounts as CO_2 and as other compounds in larger amounts in the oceans and other bodies of water. A simplified annual average carbon dioxide budget identifies 5 different fluxes, three of which are wholly or predominately natural: photosynthesis, detritus decomposition and ocean cycling. Two are wholly or predominately anthropogenic (man-made): deforestation and fossil fuel combustion.

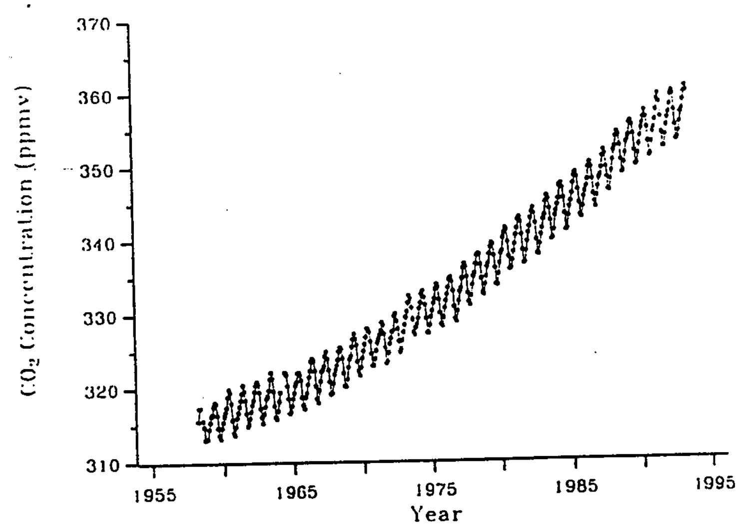
Constructing a budget for carbon requires that accurate figures be available on each flux. For fossil fuel combustion, commercial records are sufficient to estimate CO_2 fluxes. Also required are numbers for the rate of deforestation, a process that releases CO_2 into the atmosphere because the standing biomass in the forests is greater than that of the new growth vegetation. These numbers are harder to come by because of insufficient or incorrect record keeping in developing countries where most of the deforestation occurs. This problem has been alleviated to some degree in recent years by analyses of scientific data from satellites.



A simplified annual average atmospheric carbon dioxide budget for the 1980s; fluxes are given in units of petagrams C per year.

Perhaps the most difficult aspect to assess in the budget operation are the natural components of the carbon cycle. These processes occur over large, poorly accessible geographical areas and have uncertain variations as a result of temperature, local environment, plant species and other factors. For example, some studies seriously imply that the natural fluxes of carbon through the vegetative cycle dominate the atmospheric cycling of carbon. Plants employ carbon to form carbohydrates that build their tissues by using sunlight to combine CO_2 and water in the *photosynthesis* process. The CO_2 "captured" by photosynthesis is no longer free to function as a greenhouse gas - or any gas - while it is packed away as cellulose or plant fiber. In general, the carbon held by plants during photosynthesis is in balance with that released during decomposition.

CO_2 uptake increases in the spring and summer when increasing sunlight and warmer temperatures help planets to take up CO_2 from the air at a faster rate. In the fall and winter, when temperatures drop and less solar energy is available, photosynthesis rates slow and the other part of the carbon cycle - *respiration and decomposition* - take over at a rate faster that photosynthesis. This seasonal cycle is clearly evident at temperate and subtropical latitudes where CO_2 amounts in the atmosphere have been closely monitored since the late 1950's.



Monthly atmospheric CO2 concentrations at Mauna Loa, Hawaii

Because the exchange between the atmosphere, the land and the oceans is so large there are large uncertainties in the fluxes. Scientists at the National Oceanic and Atmospheric Administration (NOAA) in Boulder, CO, study the budget of CO_2 isotopes using computer models and suggest that the role of the oceans as a sink for atmospheric CO_2 may have been overestimated. They suggest that some sink of carbon to soil organic matter or to vegetation not affected by deforestation may be occurring. In other words, the flux, that all along had been assumed to balance the CO_2 added to vegetation by photosynthesis, may be out of balance. One possible explanation for this may be may be that plants are reacting to higher levels of CO_2 in the atmosphere by "fixing" more in plant matter, a process called *CO_2 fertilization.* Also, plant growth and carbon storage may also be stimulated by increased amounts of CO_2 and NO in the atmosphere as a result of combustion and the use of fertilizers containing nitrogen and phosphorus. While studies of this aspect of the global carbon budget are ongoing, they are still generally unresolved and hampering reliable predictions of future atmospheric CO_2 concentrations.