**Lecture 6 – Mass Balance questions and answers**

(1) Only one of the following is the essential approximation made when assuming steady state:

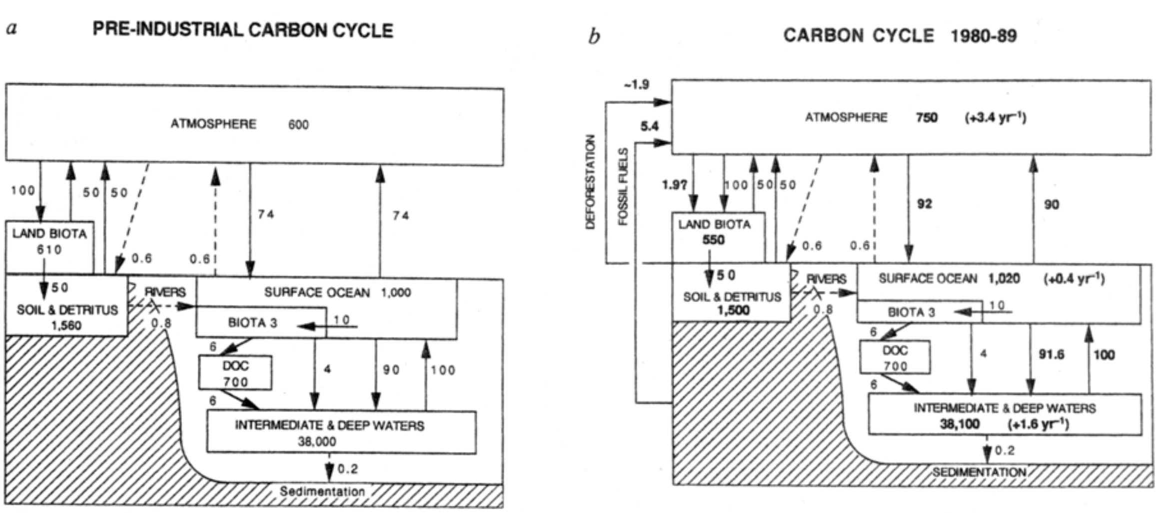
a. ocean inputs from rivers equals the particle flux out of the euphotic zone
b. the concentration does not change with time
c. the removal flux must be proportional to how much is there.
d. the river input must equal the atmospheric input.

(2) Element A has a residence time of 1Ma and element B has a residence time of 10 Ma. The only input source for both elements to the ocean is river input. Due to a major change in the climate the river flux to the ocean has doubled:

(a) It would take element A 10 times longer than element B to reach its new steady state in the ocean
(b) Since both element input doubled at the same time they would reach their new steady state at the same time.
(c) The elements concentration in the ocean would not change with time.
(d) Element B with the long residence time will reach the new steady state slower.
(e) Both elements will arrive to the new steady state after 1 residence time, for element A after 1Ma and for element B after 10Ma

(3) Siegenthaler and Sarmiento (1993) have presented box models of the global carbon cycle for pre-industrial (PI) times and the present (1980-89). These are shown below. Answer the following questions and show all your work and calculations.

a) Was atmospheric $CO_2$ in steady state in pre-industrial times? Yes
b) Is atmospheric $CO_2$ in steady state at present (1980-1989)? No
c) What is the residence time of atmospheric $CO_2$ for PI conditions? 3.4 years
d) What was the residence time of carbon in biota in the surface ocean in PI time? 0.3year



(4) What does residence time mean for an element? Calculate the oceanic residence time with respect to river input for $Ca^{+2}$ and $Mg^{+2}$.

ocean volume: $1.37 \times 10^{21}$ liters

world average river runoff rate: $3.6 \times 10^{16}$ liters/year

$Ca^{2+}$ in rivers $3.6 \times 10^{-4}$ moles/kg in the ocean $10.3 \times 10^{-3}$ moles/kg

$Mg^{+2}$ in rivers $1.6 \times 10^{-4}$ moles/kg in the ocean $5.3 \times 10^{-2}$ moles/kg

What assumptions are presumed in the definition of residence time?

(a) Residence time represents the average time an element spends in a reservoir before it is being removed (this is equivalent to the time it would take to fill the reservoir to the observed level if it were empty).

(b) The ratio of the content (M) of a reservoir divided by the sum of its sources ($\Sigma Q$) or sinks ($\Sigma S$). Thus $\tau = M/\Sigma Q$ or $\tau = M/\Sigma S$

For Ca: $(1.37 \times 10^{21} \times 10.3 \times 10^{-3})/ (3.6 \times 10^{16} \times 3.6 \times 10^{-4}) = 1.08$ Ma

For Mg: $(1.37 \times 10^{21} \times 5.3 \times 10^{-2})/ (3.6 \times 10^{16} \times 1.6 \times 10^{-4}) = 12.6$ Ma

Steady state is assumed.

(5) During the last ice age, some scientists (e.g. Froelich et al., 1992) believe that the river input increased by a factor of two. On the other hand, based on evidence that the climate was drier other researchers suggest that the river input was reduced by up to a factor of two. How would these two scenarios affect the residence time calculation for elements in the ocean. Assume that only the runoff rate changed, and that the elemental concentration of river water was constant from glacial to the present.

Residence time is the total amount in the reservoir divided by the total flux in or out. As input increases residence time decreases and when input decreases residence time increases.

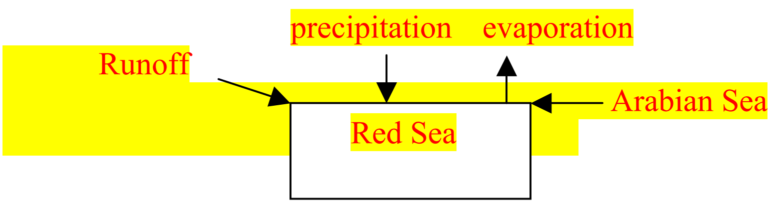
(6) Due to the cold, wet weather in the Bay Area during the winter, many residents fly to the warm, arid beaches of Cancun, Mexico. Custom officials report that 5,000 of us fly there each week in the wintertime. Mexicans from the big city enjoy the beaches too, and local papers indicate that 5,000 Mexico City residents also go to the beaches of Cancun every week. However, there are four times as many Californians on the beach compared to those from Mexico City. How can you account for this difference using a fundamental oceanographic principle? Be quantitative, assume that this is a steady state situation, and that both populations are on the beach if they are in Cancun.

$\tau = M/\Sigma Q$ M = X mexicans; M = 4X californians; Q = 5000/week

$\tau$ = # of people/ flux; This suggests that the residence time for the Bay Area people is 4 times that of the locals, they stay longer in Cancun.

(7) What is the effect of river water diversion on the water balance of marginal seas and other seas with limited connection to the oceans? Lets look at the Red Sea as an example to test a hypothetical situation (but some of these numbers are made up). The surrounding nations of Egypt, Sudan, Eritrea and Saudia Arabia are intent on exploiting all sources of water for irrigation. Current runoff to the Red Sea (rivers + groundwater) is $2.5 \times 10^{11}$ $m^3/y$. Direct precipitation to the surface is $1.25 \times 10^{11}$ $m^3/y$ and evaporation is $1 \times 10^{12}$ $m^3/yr$; both remain unchanged. Some amount of seawater enters from the Arabian Sea through the strait of *Bab el Mandeb*, but the total volume of the Red Sea is at steady state. The surface area is $0.5 \times 10^{12}$ $m^2$ and the total volume of water is $0.25 \times 10^{15}$ $m^3$.

a. Draw a sketch box model of the present situation. Label all the fluxes.
b. Write the mass balance equation for water at steady state.
c. Calculate the total residence time of water in the Red Sea and the residence time with respect to Arabian Sea input.
d. The total effect of the river diversion project is to reduce total runoff to 10% of its current value. Calculate the new flux of water from the Arabian Sea and the new residence time of the Red Sea with respect to Arabian Sea inflow.




Runoff + precipitation + Arabian Sea = evaporation

$0.25 \times 10^{15} / 1 \times 10^{12} = 250$ years; $0.25 \times 10^{15} / 6.25 \times 10^{11} = 400$ years

Runoff after diversion is $0.9 \times 2.5 \times 10^{11} = 2.25 \times 10^{11}$; To maintain steady state the Arabian Sea input must be now $6.5 \times 10^{11}$. Thus the new residence time is 385 years.

(8). Element "X" is at steady state in the contemporary ocean with a concentration of $1.0 \times 10^{-3}$ mol $L^{-1}$ (M). The main input is from rivers and the main removal is by the stripping of X from seawater during hydrothermal circulation (concentration of X in the return flow from the vents to the ocean is zero). The following information is available:

| | |
|---|---|
| Volume of ocean | $1.4 \times 10^{21}$ L |
| River Flow: | $3.2 \times 10^{16}$ L $year^{-1}$ |
| Concentration of X in rivers | $1.0 \times 10^{-4}$ M |
| Concentration of X in seawater | $1.0 \times 10^{-3}$ M |

**a.** Calculate the residence time of X with respect to total (e.g. river) inputs.
**b.** Set up the mass balance equation (sources = sinks) for X. Calculate the rate of water flow through the hydrothermal circulation that would have to exist for this to be a steady state system.

A change in climate patterns results in a new significant source of X to the ocean in the form of atmospheric deposition. Some phytoplankton in the surface ocean biota respond to the enhanced input by building their shells out of X, resulting in a new sedimentation flux as a sink of X from the ocean. The rate of water flow in the hydrothermal system is unchanged.

| | |
|---|---|
| Rate of atmospheric deposition of X | $2.0 \times 10^{12}$ mol year$^{-1}$ |
| Rate of burial of X in sediments | $0.5 \times 10^{12}$ mol year$^{-1}$ |

**c.** Set up the new mass balance equation for X. Calculate the concentration of X in seawater once the ocean reached its new steady state.
**d.** Calculate the new residence time of X with respect to total inputs.

(a) $(1.4 \times 10^{21} \times 1.0 \times 10^{-3}) / (3.2 \times 10^{16} \times 1.0 \times 10^{-4}) = 437{,}500$ years

(b) $(3.2 \times 10^{16} \times 1.0 \times 10^{-4}) = (1.0 \times 10^{-3} \times F_{hydrothhermal})$; $F = 3.2 \times 10^{15}$

(c) $(3.2 \times 10^{16} \times 1.0 \times 10^{-4}) + (2.0 \times 10^{12}) = (X \times 3.2 \times 10^{15}) + (0.5 \times 10^{12})$;
$X = 1.47 \times 10^{-3}$ M

(d) $(1.4 \times 10^{21} \times 1.47 \times 10^{-3}) / (3.2 \times 10^{16} \times 1.0 \times 10^{-4}) + (2.0 \times 10^{12}) = 395{,}769$ years

(9) Dissolved silica ($SiO_2$) is supplied to the oceans by the weathering of silicate minerals. If the average river water concentration is 10.4 mg/kg, and the average seawater concentration is 6.2 mg/kg, what is the residence time of silica in the ocean? (The mass of the ocean is approximately $1.4 \times 10^{21}$ kg, and the river flux is about $4.6 \times 10^{16}$ kg/yr).

Dissolved silica is used by organisms living in surface waters to make skeletons and protective chambers. Thus its concentration in surface waters its typically low compared with deep waters. If surface concentrations are 0.52 mg/kg, and deep water concentrations are 16.6 mg/kg, what fraction of the silica entering the surface waters leaves as particulate material, and what fraction of the silica in the particulate matter survives dissolution in the deep sea and is buried as opaline sediment? What is the mass of silica deposited each year?

Residence time = inventory/ input flux

$(6.2 \times 1.4 \times 10^{21})/ (10.4 \times 4.6 \times 10^{16}) = 18{,}143$ years

Need to calculate g and f

Determine $C_s/C_r = 0.05$; and $C_d/C_r = 1.596$

$g = 0.969$

$f = 0.02$

The mass of silica deposited each year must be equal to the river flux = $4.784 \times 10^{14}$ grams/year