Turnover Rate & Residence Time (Mini-Activity)

Purpose

- To understand turnover rate and residence time, in the context of the global carbon cycle.

Overview

Students discuss as a class the concepts of turnover rate and residence time using a simplified example. Students use the *Global Carbon Cycle Diagram* to calculate turnover rate and residence time for each pool.

Time

30 minutes

What To Do and How To Do It

1. Define the terms:

- **Pool** (also **stock** or **reservoir)**: A pool is the storehouse of material in a portion of the environment. Examples of 'pools' scientists might consider include: carbon in leaves, trees or entire ecosystems; water in a river, lake or all of the world's oceans; calcium in rocks, seashells or your own body. Scientists use the concept of a pool as a way of simplifying what would otherwise be very difficult to study.
- **Turnover rate**: The fraction of material that leaves a pool in a specified time interval. Turnover rate is the mathematical inverse of residence time.
- **Residence time**: The average length of time that material spends in a given pool. Residence time depends on the rate of outflow and on the size of the pool. Residence time is the mathematical inverse of turnover rate.

2. As an example, consider a very small lake:

The lake is the **pool**. It contains 1000 liters of water. Water is what we are interested in.
The total **flow** of water into the lake is 40 liters per year. This is the **input**.
The total **flow** of water out of the lake is 40 liters per year. This is the **output**.

<u>Calculate the turnover rate and residence time of the lake:</u>

Turnover rate is the fraction of water that leaves the lake each year.

(40L/year)/1000L = 0.04 per year

This calculation tells us that 4% of the water leaves the lake each year, which means that the turnover rate of water in the lake is 4% per year.

Residence time is the average length of time water spends in the lake. Residence time is the ratio of the pool size, to the rate of outflow.

1000L/(40L/year) = 25 years

Residence time is also the inverse of turnover rate:

1/(0.04/year) = 25 years

- **Remember if there are multiple outputs you will need to sum them to get the total amount of material leaving the pool over a 1-year time span.**

3. Go over the first pool (atmosphere) as a class.

References

Global Carbon Project. (2010). Available: http://www.globalcarbonproject.org/ File: Carbon Budget 2009 Presentation [2010, November 15].

Houghton, R.A. (2007). Balancing the global carbon budget. Annual Review of Earth and Planetary Science, 35, 515-523.

Le Quéré, C., Raupach, M.R., Canadell, J.G., Marland, G. et al. (2009) Trends in the sources and sinks of carbon dioxide. Nature Geoscience, 2, 831-836.

Schlesinger, William H. (1997). Biogeochemistry. San Diego: Academic Press.

Teacher Answers

Using the *Global Carbon Cycle Diagram*, calculate turnover and residence time for all carbon pools in the global carbon cycle.

Notes – Use outputs to calculate turnover rate and residence time. If a pool has multiple outputs, sum them before making calculations.

Pool	Turnover Rate	Residence Time
Atmosphere 750Pg C	Photosynthesis: 120 + Ocean Uptake: 92 = 212Pg C/year 212/750 = 0.28 = 28%/year	750/212 = 3.5 years
Earth's Crust 100,000,000Pg C	Volcanos: 0.1Pg C/year 0.1/100000000 = 1^{-9} = 0.0000001%/year	100000000/0.1 = 1,000,000,000 (1 billion) years
Oceans 38,000Pg C	Ocean Loss: 90 + Burial to Sediment: 0.1 = 90.1Pg C/year 90.1/38000 = 0.002 = 2%/year	38000/90.1 = 422 years
Plants 560Pg C	Respiration: 59 + Litterfall: 59 + Land Use Change 2.0= 120Pg C/year 120/560 = 0.21 = 21%/year	560/120 = 4.7 years
Soils 1,500Pg C	Soil Respiration: 58Pg C/year 58/1500 =0.039 = 3.9%/year	1500/58 = 26 years
Fossil Fuels 7,500Pg C	Burning Fossil Fuels: 6.3Pg C/year 6.3/7500 = 0.00084 = 0.084%/year	7500/6.3 = 1190 years

Answer these questions: (You are looking for evidence of students' critical and creative thinking.)

Do you think the residence time of carbon in the fossil fuel pool is realistic? Why or why not?

While for this particular time period the residence time may be realistic this scenario assumes that both the rate of fossil fuel burning and the size of the fossil fuel pool are not changing over time. Already, since 1995, as cited by Schlesinger (1997), the rate of fossil fuel burning has increased from 6PgC/year to 7.7PgC/year (Global Carbon Project, 2010) and is continuing to rise. In addition to an increase in fossil fuel burning flux, it is also important to realize that the fossil fuel pool is a finite resource (because there are no new inflows). Although new fossil fuels can form, the rate is significantly slower than the rate at which they are being used. For this *reason, fossil fuels are considered to be a limited resource. (In contrast, the plant pool is constantly dying and re-growing at a similar rate.) If you were to try and calculate a new residence time of carbon in the fossil fuel pool, you would need to predict the rate of burning and know the new fossil fuel pool size.*

Why do you think it is important to understand turnover rate and residence time in the context of the global carbon cycle?

An understanding of turnover rates and residence times is essential for understanding how the materials in different parts of our environment are changing. With respect to carbon, this is very important because of the effect carbon in the atmosphere has on the Earth's climate. Because the components of a system are all interconnected, a change in any carbon pool can lead to a change in how much carbon is in the atmosphere. In light of the relationship between the carbon cycle and climate change, scientists may ask questions such as: Is there a way to increase residence time in the soil or terrestrial vegetation? Will there be a feedback between global temperatures and the ability of the ocean to store carbon? Will warmer temperatures increase decomposition, thus accelerating the rate at which carbon is transferred from soils to the atmosphere (i.e. reducing the residence time of the soil carbon pool)? Industry specialists may want to calculate: How long will the Earth's fossil fuel reserves last? Will there be enough to continue business as usual?

GLOBE Carbon Cycle

Student Directions

Using the *Global Carbon Cycle Diagram*, calculate turnover and residence time for all carbon pools in the global carbon cycle.

Notes – Use outputs to calculate turnover rate and residence time. If a pool has multiple outputs, sum them before making calculations.

Pool	Turnover Rate	Residence Time

Use critical thinking to answer these questions. There is more than one correct answer.

Do you think the residence time of carbon in the fossil fuel pool is realistic? Why or why not?

Why do you think it is important to understand turnover rate and residence time in the context of the global carbon cycle?