Systems and Modeling Introduction

What is a system?

System: A collection of interconnected parts that function as a complex whole, through which matter cycles and energy flows.

System Characteristics

- Systems are made up of systems
- The whole is greater than the sum of its parts
- A system will change if one or more parts are removed.
- A system has qualities that could not be achieved simply by adding up its individual parts.
- Systems can be closed or open
- Systems have feedbacks

Examples	Non-examples
Human Body	Desk
Computer	Cooking pot
Water Cycle	Rocks
Baseball Team	Bowl of fruit
Car	Bottle of water
Earth	Book

Systems Vocabulary

- **Open System:** a system that continuously interacts with its environment
  - Transfer of information, matter, or energy across the system boundary
  - Implies there are inexhaustible amounts of energy available to the system
- **Closed System:** a system that is self-contained in regard to transfer of matter
  - No matter crosses the system boundary, but energy does
  - We have to use this definition because there is only one truly closed system the Universe (to our knowledge)
- **Feedback:** A response to some action within the system. The linkage between two or more system parts that forms a round-trip flow of information is thus called a feedback loop. (One event causes another, and the second event comes back around to influence the first.)
- **Negative Feedback (balancing feedback):** When an action in one direction eventually causes a balancing reaction in the opposite direction. Examples to remember include the heating system in your house or maintenance of your internal body temperature. (It has nothing to do with good or bad.)
- **Positive Feedback (reinforcing feedback):** A response that keeps the system moving in the same direction, amplifying the effect. This type of feedback is commonly associated with exponential growth, such as in a population.
- **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.
- **Flux** (also **flow**): The movement of **material** from one pool to another, per unit time. (Fluxes are often a process, such as photosynthesis or evaporation.)
- **Input:** flow of material entering a pool
- **Output:** flow of material leaving a pool

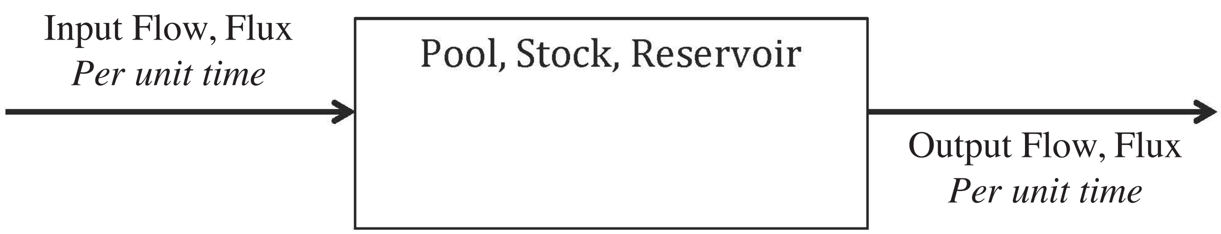
- **Steady state** (also **dynamic equilibrium**): A condition in which the amount of material within the pool at any time remains the same. In other words, the rate of input equals the rate of output, causing the total pool size to remain unchanging in time.

- **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

Systems Diagrams

It is often easiest to understand a system through visual representation. Here is a 1-box stock and flow diagram to show the basic system components. Once a basic system has been represented **modelers** add feedbacks, and define relationships using equations so the system can be observed over time and under varying conditions.



What are models?

When asked this same question, a group of GLOBE Carbon Cycle teachers defined models in their own words:

> "A model is a tool used to refine our understanding of the world, ask new questions, and make informed predictions."
>
> "A model is a small or large-scale representation of a process that occurs on earth that might be hard for us to study on its natural smaller or larger scale."
>
> "A model is a replica of an object or concept that helps increase our understanding."
>
> "A model is a representation of reality that can take many forms, physical, conceptual and/or mathematical. It has some characteristics of reality, but has other characteristics that won't match reality. Models are often used for testing purposes to evaluate different scenarios."

For the GLOBE Carbon Cycle Program we define models as: *tools that help us understand, and explain* *<u>systems</u>* *that are too complex or difficult to observe or comprehend on our own.*

We often think that models must include complicated mathematical functions, but we can learn a great deal about systems, especially environmental systems, using simple models that require only the basic math functions such as addition, subtraction, multiplication and division.

How are models developed?

The development of models is a cyclical process. Scientists begin with a question. They then collect field data or run experiments to understand relationships within a system that will help them answer the question. The information is then used to build simple computer models. Scientists continue to ask and answer questions by making model runs and examining the outcomes. Often model outcomes lead to new questions that require more complicated models. In order to answer these questions scientists must have more knowledge about the underlying processes of the system, which can only be understood through more data collection (fieldwork/experiments). As more and more detailed relationships and system processes are added to the model, the uncertainty we have in the model results decreases.

For example, the carbon storage in aboveground tree parts (leaves, branches, stems) has been successfully modeled based on millions of measurements. Measurements allowed scientists to build a model that reproduces what the environment actually does in one place at one particular time. This model can now be used to make best guesses about how carbon storage in these tree parts might change if there were changes in light, temperature or precipitation. On the other hand, while these models were being developed and used it became clear that there wasn't enough detailed information available about the belowground parts (coarse and fine roots) for scientists to fully understand how carbon storage below the ground changes over time. In this case scientists have to go back to the field and make more measurements, looking for clearer relationships between belowground parts and the aboveground parts and processes they already understand.

Why use models?

Models are particularly useful in the study of environmental systems. Scientists use models to examine the fundamental behavior of a system, such as how carbon is stored in a forest. By knowing more about the system through modeling and understanding where knowledge is incomplete, scientists can generate hypotheses to guide future research.

Models are also useful to predict future conditions. Although such predictions are not necessarily what will happen, they can provide a range of possibilities that help scientists refine their research and help policy makers create action plans to prevent any undesirable outcomes. As an example we might use a model in asking this question, how might carbon uptake and storage in forest ecosystems change if there is an increase in temperature over the next twenty years?

Among the good scientific reasons to use models, teachers have also found a lot of value to using models in the classroom. Just a few of their ideas are noted here:

- Shows complexity of systems and the interconnectedness of a system.
- Students have an impact on [model] outcomes.
- Students understand that designers have an impact on how the model works.
- Integrates science and technology.
- Illustrates how to control variables.
- Interdisciplinary (science, math, writing).
- Provides an opportunity for formative assessment.
- Allows students to have contact with the model 'code' - equations that run the model.

Modeling Systems - Examples

Consider a high school that has 800 students (pool) and these students are evenly divided among the 4 grade levels (Freshman, Sophomore, Junior, Senior). If we assume that all seniors graduate every spring, 200 students are leaving the school (output flux). Let us also assume 200 new freshman enter each fall (input flux). (Thus our system is in equilibrium.)

If **turnover rate** is the fraction of students that leave the school each year (output flux/ pool size), then our equation is:

$$(200 \text{ students/year}) \,/\, 800 \text{ students} = 0.25 \text{ per year}$$

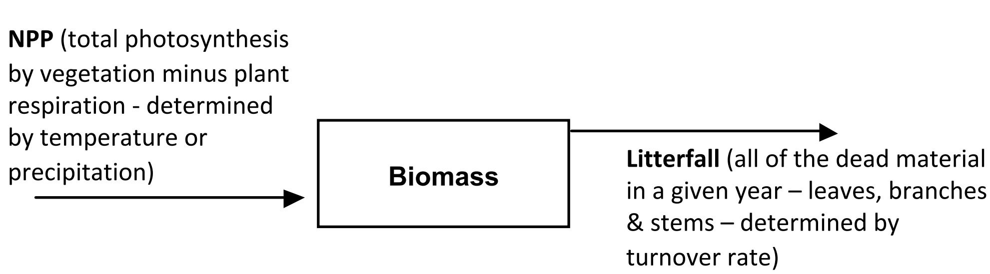
This means that 25% of the student body is graduating and leaving the school each year.

If **residence time** is the number of years that a student spends at the school before they graduate (pool size/output flux), then our equation is:

$$800 \text{ students} \,/\, (200 \text{ students/year}) = 4 \text{ years}$$

This means that every student spends 4 years in the school before they graduate.

The method we used to calculate turnover rate or residence time in the above example is the typical method, which can be used for systems that are either in **steady state OR non-steady state**. In some cases however the outputs of a system are hard to calculate at a particular scale, so we must assume the system is at steady state. In this case we can then use the known inputs because they are theoretically equal to the outputs. This will provide us with at least an estimate of turnover rate and residence time for the system. While this method is less desirable because inputs do NOT actually determine the turnover rate or residence time, in some cases it is necessary. One example of this situation is the GLOBE Carbon Cycle *Biomass Accumulation Model*.



Because litterfall is difficult to quantify at the biome-level spatial scale, this model uses a turnover rate that is determined by dividing NPP of the biome (vegetation) by the total biome biomass (vegetation), thus inputs were divided by pool size instead of the outputs. To do this we had to assume that the system was in steady state. To get a more accurate turnover rate for a particular location within the biome, we would have to make measurements of the total litterfall during a one-year period. This might include putting out baskets to catch leaves, twigs, and fruit, laying out tarps to collect falling branches, and setting up several transect lines to measure trees fallen across them.

To help students experience how modeling (diagramming, equations) can be used to understand systems, have them participate in the GLOBE Carbon Cycle: Paper Clip Simulation activity and Computer Model.

References/Resources

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