Chapter One

Systems and Feedback Loops

Let's start our journey together from a quote from John Muir in 1869:

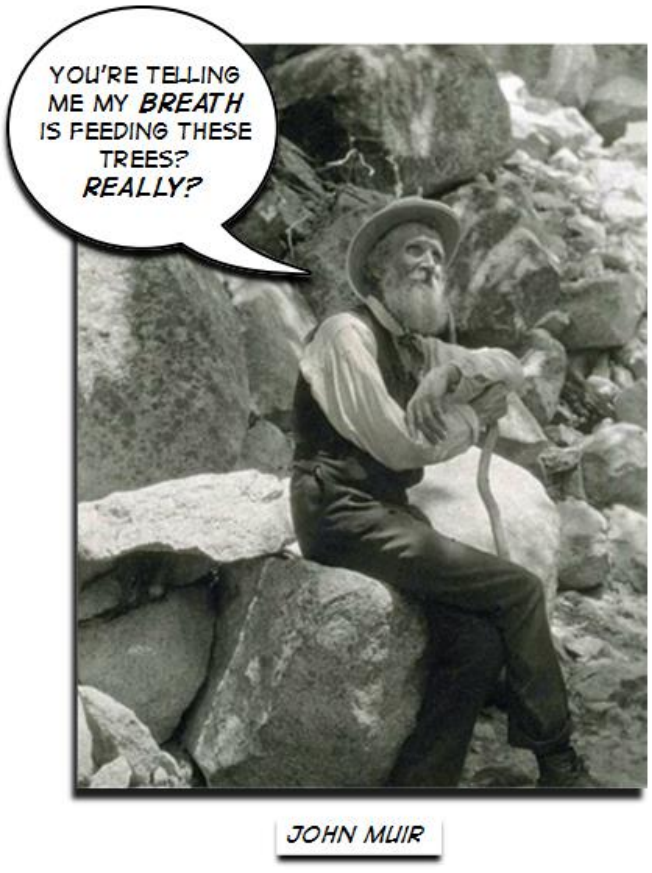
> *"When we try to pick out anything by itself we find that it is bound fast by a thousand invisible cords that cannot be broken, to everything in the universe."*

This statement should sound somewhat familiar if you have spent any time within this series of textbooks. If you have, you should easily remember the following phrase that has been repeated over and over again:

Everything in the universe is connected together

This phrase has never been more important than it will be throughout your studies into **ecology** – the study of the relationships between living organisms and their environment. Perhaps a little story will help get you going:

Look out your window right now and spend a few moments observing the largest tree you can find. Notice its woody trunk and how it is anchored into the ground and its branches which may be covered in leaves or pine needles. Now, let me ask you a question: Where did that tree receive all of the atoms needed to grow to such a height?



If you said the ground you would be incorrect!

Trees use the element carbon to grow to magnificent heights. However, this element comes from the <u>air</u>, not the ground. **Carbon dioxide (CO_2)**, the waste gas that animals exhale into the air, is the source of all the carbon within a tree.

But how does the tree use the carbon from the two oxygen atoms in CO_2 for the purposes of growth? It can't do this on its own so it relies on the power of the sun.

Energy from the sun splits water within the leaves of a plant and binds these products with carbon dioxide through a chemical reaction known as **photosynthesis**. The main products of this reaction are **oxygen gas (O_2)** and a more usable chemical energy source (glucose) that is used by the plant for growth, repair, and development.

So where does a tree receive all of its water?

If you believe that a tree's roots are responsible for absorbing the water needed for the tree to grow you would be correct. And where did most of that water come from? The same place where the tree found all of its carbon - the air!

Roots anchor the tree firmly into the ground. This is needed for structural support as well as for the transport of water and nutrients from the earth.

And what happens when we burn the wood from this tree? Where does all of the energy needed to produce both heat and light come from?

It comes from the energy of the sun that was originally used to split the water during the process of photosynthesis.

In summary, life depends upon a complex relationship between air, water, and the earth itself.

We are all connected together.

This will be your main focus throughout your study of earth science.

Let's begin our journey by looking at a few general descriptions that define our dynamic planet. You will soon become very familiar with a very powerful word in your study of earth science – **system**. Generally, a system is a set of components linked together which function as a whole. Therefore, from the example described above, the tree would be considered a system composed of various components (air, water, living organisms, and the earth) all working together to produce a single tree. But why should we stop there?

Your body can be a considered a system of organs, your computer is a system of hardware and software, and the earth itself is a system of large compartments (also known as **reservoirs**) which are constantly receiving and transferring both matter and energy to and from other reservoirs.

By identifying the earth as a system, you will recognize a few reoccurring themes throughout this textbook. Keep your eye open for the following overlapping concepts:

- How systems are connected to each other within our environment
- How **flux** (amount and rate of matter and energy transfer) flows between these systems
- How a system changes, or can change, over time (which can extend over millions of years)
- How feedback affects a system(we will be exploring this concept shortly)

A system can be one of two types:

Open systems or Closed systems

Open systems allow for the transfer of both matter and energy among reservoirs while **closed systems** only allow energy to pass through. The earth is considered to be a closed system as it receives energy from the sun and emits some of its energy back into space (in a process we will discuss in future chapters); however, virtually no matter is allowed to leave or enter the earth system.

**If you want to be technical, the earth does receive a tiny amount of matter from meteorites which reach the surface. The total amount of these alien invaders is so minimal when compared to the size of the earth that researchers do not consider them relevant in the classification of earth as a closed system.*

Classifying the earth as a closed system has two important consequences to consider:

The total amount of matter on the earth is static (does not alter) and is therefore limited.

Any alterations to a reservoir will eventually affect all of the reservoirs in a closed system.

This second statement helps us to understand that even though the earth system is relatively closed, its reservoirs are mostly open systems.

Both matter and energy never stop flowing among the reservoirs within the earth system. When the amount and rate in which matter and energy flows out of a reservoir equals that which is flowing in, the reservoir is said to be at a **steady state** – but this does not always take place.

Sometimes, the amount and/or rate of energy and matter flowing into a reservoir are greater than what is flowing out. When this occurs, the reservoir is known as a **sink**. Oppositely, when more matter/energy is flowing out of a reservoir than is coming in, it is known as a **source**.

Scientists focus their attention a great deal on the on the amount of time a substance, especially water, remains within a system. The study of this **residence time** allows scientists to track the amount time it takes for a pollutant to reach a particular area in the environment and how long it may take for the flow of water to remove it into a neighboring reservoir.

As you previously read, any alteration to a reservoir eventually affects all other reservoirs around the earth. These effects may cause positive or negative impacts on the reservoir, depending of course on the actions taking place. Scientists have a general description of these actions known as:

Positive and Negative Feedback loops

Don't let these names fool you! The latter is not always a bad thing and the former is not always beneficial either. I believe it's time for another example:

When the sun comes up each morning, many flowers open their leaves and petals. This action allows more light to reach their surface which, in turn, causes the plants to open up even more. This is an example of a **positive feedback loop** that ends in a positive result.

An example of a positive feedback loop with negative consequences can be found during a flood. A rush of moving water carries soil away from a particular area along with its vegetation. Unfortunately, it is the plant roots which hold onto the soil and keep it in place. Without the plants, the soil is easily removed, causing the flood waters to persist.

Generally speaking, positive feedback loops take place when a stimulus causes an action that result in the continuation of the stimulus. For those of you who are more math-orientated:

A produces more of B which in turn produces more A

A **negative feedback loop** takes place when the stimulus produces an action which acts to slow down the stimulus. For example, when a gland in the human body releases a particular hormone (X) into the body, other cells within the body detect this hormone and begin to produce their own hormone (Y). When the gland detects hormone Y it stops producing hormone X. At the risk of confusing you, here comes another math analogy:

A produces B which produces C which, in turn, causes A to stop producing B

Throughout your journey through this text, you will be exposed to many examples of feedback loops within earth's reservoirs. Be mindful to look for unmentioned loops that exist in each chapter. Making a few notes about these examples may help you to make connections between concepts as you progress through this text.

For now, let's take a look at our last concept for this week.

As you read previously, the total amount of matter on the earth is limited and does not change because matter cannot escape or enter the earth. Therefore, matter must be recycled constantly throughout all of the reservoirs over long periods of time. This fact is summarized beautifully in the **Law of Conservation of Matter.** This fundamental law states that:

Matter cannot be created or destroyed, only changed into different forms.

The same is true for energy as well – as you will soon learn in Chapter Three.

Feedback loops and the conservation of matter/energy require a much deeper understanding of the physical world than has been previously undertaken. The traditional way to study earth science was to view each of its collective parts/reservoirs apart from each other. Researchers would dedicate their professional lives towards one particular branch of earth science.

In many respects, this is still happening today!

Researchers spend many years learning about individual factors within their specific fields. Although this focus is highly needed and respectable, more is required for a student of earth science.

This book has attempted to break this tradition by focusing on the interactions between each of earth's reservoirs. Naturally, any resource that successfully connects every single aspect and feedback loop existing among reservoirs would fill several libraries. Your exploration through this text will give you a small taste of many different connections between our physical resources.

Sinks, sources, feedback loops, and the conservation of both matter and energy will all be reoccurring concepts throughout this text. They are a vital link towards the understanding of our planet.

Simply put, the interconnectedness of earth's reservoirs cannot be understated. What happens within our oceans affects the air we breathe, the food we eat, and the land we use for our survival. Never forget the following statement as it should be the keystone for your study of earth science:

Next week you will explore what these "reservoirs" actually are and how both energy and matter flow within and among each other. Sit back and enjoy - this is going to be a fun ride!

Match the following vocabulary terms with their correct definition:

carbon dioxide (CO_2)	**negative feedback loop**	**residence time**
closed systems	**open systems**	**sink**
ecology	**oxygen gas (O_2)**	**source**
flux	**photosynthesis**	**static**
Law of Conservation of Matter	**positive feedback loop**	**steady state**
	reservoirs	**system**

1)	_____	fundamental law which states that matter cannot be created or destroyed, only changed into different forms
2)	_____	a situation when the stimulus produces an action which acts to lower the stimulus itself; A produces B which produces C which in turn causes A to stop producing B
3)	_____	the study of the relationships between living organisms and their environment
4)	_____	a process in which plants use the energy of the sun to synthesize food through the combination of carbon and water
5)	_____	a set of components linked together which function as a whole
6)	_____	only allow energy to pass through reservoirs
7)	_____	gas required for most life on earth; can be created from the splitting of water during photosynthesis
8)	_____	allow for the transfer of both matter and energy among reservoirs
9)	_____	the status of a reservoir when the volume of flux flowing into a reservoir is less than what is flowing out
10)	_____	the status of a reservoir when the volume of flux

		flowing into a reservoir is greater than what is flowing out
11)	_____	when the volume of flux flowing out of a reservoir matches that which is flowing in
12)	_____	amount of time a substance remains within a system
13)	_____	a situation when a stimulus causes an action that result in the continuation of the stimulus; A produces more of B which in turn produces more A
14)	_____	Earth's spheres; a system of large compartments which are constantly receiving and transferring both matter and energy to and from other spheres
15)	_____	amount and rate of matter and energy transfer
16)	_____	does not alter
17)	_____	the waste gas that animals exhale into the air; the source of nearly all the carbon within plants

Choose the correct answer from the following questions:

1) Which of these situations is (are) an example of an open system?

I. A car's cooling system
II. A boiling teakettle
III. A loaf of bread in a sealed plastic bag
IV. Your digestive system

a) I only
b) II and IV
c) I and III
d) I, II, III, and IV

2) Plants conduct photosynthesis which results in the construction of food for the plant. To do this plants require _____.

a) water from the soil
b) water from the humid atmosphere and carbon dioxide from the soil
c) water from the soil and carbon dioxide from the soil
d) carbon dioxide from the atmosphere
e) water from the soil and carbon dioxide from the atmosphere

3) Which of the following are correct according to the law of conservation of matter?

I. Matter can be created
II. Matter cannot be destroyed
III. Atoms can be rearranged into different types of matter

a) I only
b) II only
c) III only
d) I and II
e) II and III

4) Any network of relationships among a group of components which interact with and influence one another's behavior through exchange of matter and/or energy is referred to as _____.

a) an interchange
b) a system
c) an ecosystem
d) an environmental collaboration
e) hierarchy

5) Define the following physical systems as either positive or negative feedback loops (Hint: each answer is based upon the previous scenario):

As carbon dioxide levels in the atmosphere rise:

a) _____ the temperature of the earth rises
b) _____ the rate of photosynthesis in plants increases
c) _____ more carbon dioxide is therefore removed from the atmosphere by plants, reducing the greenhouse effect and reducing global temperatures

6) Differentiate between an open and a closed system. Provide a specific and detailed example of each. Do both exist in nature? Why or why not?