EARTH SYSTEM SCIENCE ANALYSIS

Earth System Science

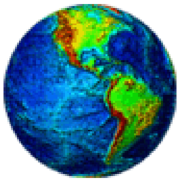
Earth is a system of individual parts that work together as a complex whole. We call the four major parts of the Earth system *spheres*. These parts include the lithosphere, hydrosphere, biosphere and atmosphere.

Changes continually occur within Earth's four major spheres. We call such changes *events*. An event can cause changes to occur in one or more of the Earth's four spheres. An event can also be the effect of changes in one or more of the Earth's four spheres. An *interaction* is the two-way, cause and effect relationship between an event and a sphere. Earth system science studies the interactions between and among events and the Earth's spheres.

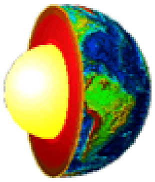
Earth's Spheres

Everything in Earth's system is in one of four major subsystems: land, water, living things or air. These spheres are the lithosphere (land), hydrosphere (water), biosphere (living things) and atmosphere (air). We can further subdivide each of these four spheres into sub-spheres. To keep things simple in this activity, there will be no distinction among the sub-spheres of any of the four major spheres.

Lithosphere



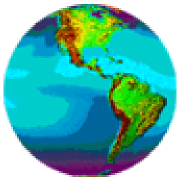
The lithosphere contains all of the cold, hard solid land of the planet's crust (surface), the semi-solid land underneath the crust, and the liquid land near the center of the planet.* The surface of the lithosphere is very uneven (see image on right). There are high mountain ranges like the Rockies and Andes (shown in red), huge plains or flat areas like those in Texas, Iowa, and Brazil (shown in green), and deep valleys along the ocean floor (shown in blue).



The solid, semi-solid and liquid land of the lithosphere forms layers that are physically and chemically different. If someone were to cut through Earth to its center, you could see these layers like the layers of an onion (see image on left). The outermost layer of the lithosphere consists of loose soil rich in nutrients, oxygen and silicon. Beneath that layer lies a very thin, solid crust of oxygen and silicon. Next is a thick, semi-solid mantle of oxygen, silicon, iron and magnesium. Below that is a liquid outer core of nickel and iron. At the center of Earth is a solid inner core of nickel and iron.

*Note: The word *lithosphere* can take on different meanings depending on the speaker and the audience. For example, many geologists - scientists who study the geologic formations of Earth - reserve the word *lithosphere* to mean only the hard surface of Earth, not the entire inside of the planet. For the purpose of this activity, however, there will be no distinction among the various layers of land. Lithosphere will refer to all land in Earth's system.

Hydrosphere



The hydrosphere contains all the solid, liquid and gaseous water of the planet.* It ranges from 10 to 20 kilometers in thickness. The hydrosphere extends from Earth's surface downward several kilometers into the lithosphere and upward about 12 kilometers into the atmosphere.

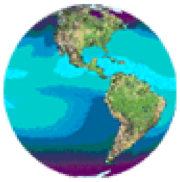
A small portion of the water in the hydrosphere is fresh (non-salty). This water flows as precipitation from the atmosphere down to Earth's surface, as rivers and streams along Earth's surface and as groundwater beneath Earth's surface. Most of Earth's fresh water, however, is frozen.

Ninety-seven percent of Earth's water is salty. The salty water collects in deep valleys along Earth's surface. These large collections of salty water are oceans. The image above depicts the different temperatures one would find on oceans' surfaces. Water near the poles is very cold (shown in dark purple), while water near the equator is very warm (shown in light blue). The differences in temperature cause water to change physical states. Extremely low temperatures like those found at the poles cause water to freeze into a solid such as a polar icecap, a glacier or an iceberg. Extremely high temperatures like those found at the equator cause water to evaporate into a gas.

*Note: Some scientists place frozen water - glaciers, icecaps and icebergs - in its own sphere called the *cryosphere*. For the purpose of this activity, however, frozen water will be part of the hydrosphere. Hydrosphere will refer to all water in Earth's system.

Biosphere

The biosphere contains all the planet's living things. This sphere includes all of the microorganisms, plants and animals of Earth.* Within the biosphere, living things form ecological communities based on the physical surroundings



of an area. We call these communities *biomes*. Deserts, grasslands and tropical rainforests are three of the many types of biomes that exist within the biosphere.

It is impossible to detect from space each individual organism within the biosphere. However, we can see biomes from space. For example, the image on the left distinguishes between lands covered with plants (shown in shades of green) and those that are not (shown in brown).

*Note: Some scientists place humans in their own sphere called the anthrosphere. For the purpose of this activity, however, humans will be included as part of the biosphere. Biosphere will refer to all living things in Earth's system.

Atmosphere

The atmosphere contains all the air in Earth's system.* It extends from less than 1 meter below the planet's surface to more than 10,000 kilometers above the planet's surface. The upper portion of the atmosphere protects the organisms of the biosphere from the sun's ultraviolet radiation. It also traps heat. Weather occurs when air temperature in the lower portion of this sphere changes. As air in the lower atmosphere is heated or cooled, it moves around the planet. The result can be as simple as a breeze or as complex as a tornado.

*Note: The atmosphere has many layers that differ in chemical composition and temperature. For the purpose of this activity, however, we will not differentiate among the layers of the atmosphere. Atmosphere will refer to all of the layers.

An Introduction to ESS Analysis

Earth system science examines each event to sphere, sphere to event and sphere to sphere interaction. This is Earth system science analysis, or ESS analysis.

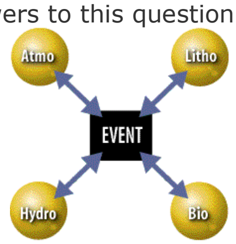
An ESS analysis has three steps, which include looking at

- how the event affects each of the spheres,
- how each sphere affects the event, and
- how the spheres affect each other.

The forest fires that occurred in Yellowstone National Park, Wyoming, in 1988 are the event for this activity. When writing your analysis ideas, abbreviate the event with the letter E and abbreviate each sphere using the first letter of its name (atmosphere = A; biosphere = B; etc). Use a single-headed arrow (>) to indicate the direction of effects. For example, the effects of the event on the hydrosphere should be written as E >H.

Step 1: Event > Sphere Interactions

How could an event affect each sphere? The answers to this question are the event > sphere impacts.



E > A

The fires created tremendous heat, developed fast rising columns of heated air, which in turn brought in more air at the base of the fires, dropped the humidity in the area of the active fire to near zero and made dense smoke, which actually traveled hundreds of miles. There were certainly other impacts on the atmosphere besides this one.

E > H

Ash from the fires fell into the ponds, lakes and streams. What impacts might you expect the event to cause in the hydrosphere? Is the effect of burning embers from the falling debris landing in the streams worth considering?

Don't worry about getting all the interactions … you probably won't be able to. Just focus on identifying a few impacts. And remember, the impacts on some spheres will be more numerous than on others. That's not a problem.

E > B

The fires burned and killed the plants and trees, as well as the animals that could not escape, in the area. How else did the fires affect the biosphere at Yellowstone National Park? There are the obvious destructive effects on plant and animal life as well as on the habitat. You might also consider the beneficial effects of burning off accumulated debris on the forest floor and similar occurrences that might be advantages of the burning.

E > L

The forest fires burned the parts of the soil where the plants put down their roots. What effects might these fires have had on the lithosphere? Here, you might consider the effects on soils or perhaps even on the water levels of the geysers and hot pools the Yellowstone National Park is so famous for.

Step 2: Sphere > Event Interactions

How could each sphere affect the event? The answers to this question are the sphere > event impacts.

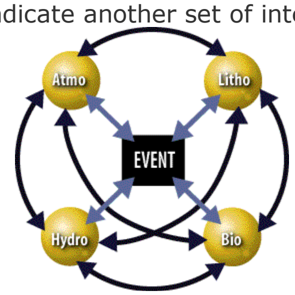
Take another look at the Earth System Diagram above. Notice that the arrows go not only from the event to each sphere but also from the spheres back to the event. Consider: if something happened to the biosphere because of the fires, might that have an effect on the fires themselves? For example, if the fires cause the forest floor debris (biosphere) to burn off, how might that change in the biosphere affect the fires? Clearly, the fires would be using up fuel necessary to keep them burning. So, a statement such as, "The leaf litter was burned by the fires thus diminishing the amount of fuel available to keep the fires burning in that area" might be a valid B > E interaction.

Look at each set of possible changes the fires might make on each sphere. If they occurred, how might these changes in turn affect the fires? Consider whether these changes have short-term or long-term effects.

Step 3: Sphere > Sphere Interactions

How can each sphere affect the other spheres? The answers to this question are the sphere > sphere impacts.

Now that you have an idea of how an event and the spheres can affect one another, it is time to introduce one more level of interaction. Take a look at the Earth System Diagram below. Notice the additional arrows going to and from each of the spheres. These additional arrows indicate another set of interrelationships influenced by an event.



If an event creates certain changes in one sphere, how might those changes lead to changes in the other spheres? For example, the Yellowstone fires burned the soil (lithosphere) to a depth of several inches or more in certain hot spots. What effect do you think that had when it finally started raining and there was runoff to the streams (hydrosphere)? If there were burning embers in the atmosphere that eventually fell back into the streams (hydrosphere), how might that blackened debris have affected the aquatic invertebrates and fish (biosphere) that survived the event?

Try to see what interactions you can find among the different spheres. Think about what changes might have occurred in each sphere as a result of the Yellowstone fires. Add these effects to your ESS analysis.

If you find yourself thinking, "If the hydrosphere is damaged by the falling charred debris and that does major damage to the fish, then how does that affect the biosphere?" that's a good sign because it means you're beginning to look at the way the world works. It seems to be one great collection of interacting spheres and then along comes a new event and the process of balancing starts over again.

At this point, you will not have all the possible interactions by any means. Furthermore, it is very unlikely that each group will have the same set of interactions. That's not a problem. The list of interactions each one of you contributes will simply reflect your own individual backgrounds and experiences. There isn't any right or complete answer for ESS analyses. You just need to be able to explain and support why you think something may have an impact.

Keep in mind as you list the interactions that it is important for you to offer scientific reasoning or explanations for why or how the interactions occur. Such reasoning and explanations display your understanding of the science behind the interactions. These explanations are valuable for you and others because they make your *why* and *how* thinking visible and they often help you to think about additional ESS interactions.

An ESS Analysis of the 1988 Yellowstone National Park Forest Fires

Event (E): the forest fires that occurred in Yellowstone National Park, Wyoming, in 1988

Spheres: Lithosphere (L)
Hydrosphere (H)
Biosphere (B)
Atmosphere (A)

Step 1: Event > Sphere Interactions

Step 2: Sphere > Event Interactions

Step 3: Sphere > Sphere Interactions

An Example of ESS Analysis

The examples below represent a few of the many interactions recorded during ESS analyses of the Yellowstone forest fires event. How do your interactions compare to those below? Are some of yours the same? Are they different? If the examples below include more detail and explanation think about how you could now revise your ESS analysis so that your explanations go deeper into the science behind the interactions.

Event ⟷ Sphere Interactions

The examples below address sphere to event and event to sphere interactions. When doing ESS analyses in the future, you can include your event to sphere and sphere to event interactions under one heading called Event ⟷ Sphere Interactions.

Event and Atmosphere

E > A
The forest fires could cause acid rain. As with industrial pollution, CO_2 from the fire would combine with the moisture in the atmosphere to form carbonic acid, or H_2CO_3.

E > A
Intense fires create their own upward air movement. Forest fires make updrafts of air like the warmth you can feel if you hold your hand about 12 inches above a candle flame.

A > E
I heard that lightning is a common cause of forest fires. This makes sense to me because the high temperature of a lightning bolt combined with the dry biomass often found in Yellowstone is a recipe for a forest fire.

Event and Hydrosphere

E > H
Burning pine needles, wood and other plant material can produce an ash that may come down in nearby streams and change (either up or down) the pH of water.

H > E
Precipitation can naturally extinguish wild land fires. On September 11, 1988, two inches of wet snow covered a large portion of Yellowstone National Park. The snow put out some of the flames and prevented the fire from spreading.

Event and Biosphere

E > B
Removal of leaf litter and other debris, as well as plant competitors such as non-natives, makes it easier for native plants and pioneer plants (fireweed, lodgepole pine, etc.) to germinate.

E > B
Forest fires are sometimes important in the life cycle of some living things. For example, some pinecones, like the lodgepole pinecones, need the heat of a fire to open them and release their seeds.

E > B
Animals that couldn't flee the flames died. Even those who could flee had trouble surviving after the fire because of the severe alteration of their habitat.

B > E
Future fires will be less likely to occur after all the fuel (biomass) in an area is gone. For instance, when the plant litter on the ground burns off, there is no more fuel for a new fire. And we know that a fire needs fuel. This makes sense to me because I read that leaf litter and other combustibles, which had collected on the Yellowstone forest floor since the previous fire 75 years ago, provided the fuel for the 1988 fire.

Event and Lithosphere

E > L
Intense heat from the fires may have caused some rocks to break apart as I have seen happen in campfires.

E > L
Heat from the fires can affect the topsoil. As an illustration, the fires baked out a lot of the living, nutrient-rich organic

matter, called humus.

In the future, as you list event > sphere, sphere > event, and sphere > sphere interactions, it is important that you be able to explain why or how the interactions occur. For example, the E > A interaction above doesn't merely state, "The forest fires could cause acid rain." It gives the reason, "As with industrial pollution, CO_2 from the fire would combine with the moisture in the atmosphere to form carbonic acid, or H_2CO_3." Such explanations display your understanding of the science behind the interactions. These explanations are valuable for you and others because they make your *why* and *how* thinking visible, and they often lead you to think of additional ESS interactions.

Sphere Interactions

Below are some of the sphere > sphere interactions recorded during ESS analyses of the Yellowstone forest fires event. Pay attention to the explanations for the interactions.

<u>Lithosphere and Biosphere</u>

L > B
Burned plant debris that did not blow away becomes the new soil that can provide some nutrients for pioneer plants. By comparison, gardeners prepare their soil with ashes from a fireplace.

L > B
Because soil moisture is extremely low due to the fires, surviving seeds of all types, plus windblown seeds and spores, cannot germinate until new rains fall in the area.

B > L
A decrease in vegetation may have resulted in increased erodibility of soil because there were fewer roots to hold the soil in place. In the area where I live, the roots from good plant cover appear to help keep the topsoil from washing away during heavy rains.

<u>Lithosphere and Hydrosphere</u>

L > H
Erosion increases from runoff following the fire and changes the turbidity, temperature and pH of the streams and rivers. A similar circumstance occurs in the strip mining areas near where I live. Following hard rains, the nearby streams become very muddy. An article in the local paper said such "erosion and drainage creates acidic conditions in the streams."

<u>Lithosphere and Atmosphere</u>

L > A
Blackened areas can absorb heat faster, increasing the rate of convection in cells. An increase in convection may move air masses through a burned area quicker and/or cause moist air to move vertically faster, increasing rain further downwind.

A > L
The wind could have carried ash particles in the air and dropped them on the ground miles away from the forest fires. The ash particles - which have a high pH - could have changed the pH of the soil.

<u>Atmosphere and Hydrosphere</u>

A > H
The wind may carry ash many miles from the fire and then drop it into streams. A similar thing happens when the wind carries ash from an erupting volcano to other regions.

A > H
There may have been more precipitation in neighboring areas because ash particles in the air could have become condensation centers upon which raindrops could form.

<u>Atmosphere and Biosphere</u>

A > B
Smoke and noxious fumes could have coated the lungs of animals and people, affecting their ability to breathe.

Biosphere and Hydrosphere

B > H
Destruction of waterside habitat (and cover) can raise water temperatures because it exposes ponds and streams to more radiant energy from the sun.

Remember

The above are NOT all the possible event > sphere, sphere > event and sphere > sphere interactions that could have occurred as a result of the Yellowstone forest fires event. These are merely a few examples of what seem to be some reasonable causes and effects. There are many other possibilities.

Some of the interactions also establish feedback loops. For example, the E > H interaction leads to the continuation of the fire. As the fires burn, they dry vegetation around them, thus creating more fuel for the fire. This positive feedback loop reinforces the burning of the forest fires. A negative feedback loop that lessens the intensity of the fires is established when ash from the fires is carried into the atmosphere and forms condensation particles for water vapor. These condensation particles eventually form clouds that release precipitation. The precipitation can put out the forest fires.

One More Step: Causal Chains

The interactions that occur within Earth's system actually occur as a series of chain reactions, which ripple through Earth's spheres like waves that spread out from a pebble tossed in a still pond. This means that an event often leads to a change in one sphere, which leads to a change in another sphere, which leads to a change in yet another sphere. For example:

1. A forest fire destroys all the plants in an area (E > B).
2. The absence of plants leads to an increase in the erosion of the soil (B > L).
3. Increased amounts of soil enter streams leading to increased turbidity, or muddiness, of the water (L > H).
4. Increased turbidity of the water has a negative impact on the plants and animals living in the stream (H > B).

You can write the four interactions above as a causal chain that synthesizes the results of the ESS analysis and describes how the event can lead to a ripple of effects throughout the Earth system. Causal chains show the interdependence of Earth's spheres. I've summarized the causal chain outlined above in a narrative form below.

E > B > L > H > B
The fire consumed the vegetation. A decrease in vegetation resulted in increased soil erosion because there were fewer roots to hold the soil in place. Increased erosion of loose soil led to increased soil particles, or sediments, in streams. This would make stream water muddier. Sediments in the water clogged the gills of fish and other aquatic organisms and choked them.

The following are some simple causal chains.

A > B > E
I read that more than eight weeks of warm to hot, low humidity air masses drew moisture out of grasses and trees in Yellowstone National Park prior to the 1988 fires.

E > A > E
The intense fires created their own upward air movement, increasing the wind velocity and drawing in oxygen at the base of the flames to continue to feed the fire.

Notice in the case above the causal chain is from the event to a sphere and then back to the event. Causal chains don't always have to go just from an event to one sphere then another sphere. They can also lead back to the event.

Finally, the following is a more complex illustration of an ESS causal chain.

E > L > B > L > B > L > H > B
Heat from the fires can affect the topsoil. As an illustration, the fires baked out a lot of the nutrient-rich organic matter, humus. This may make it more difficult for many of the plants to start growing again. However, burned plant debris that did not blow away becomes part of the new soil and can provide some nutrients for pioneer plants, much as gardeners prepare soil with ashes from a fireplace. However, because soil moisture is extremely low due to the fires, surviving seeds of all types, plus windblown seeds and spores, cannot germinate until new rain falls in the area.