

## MANITOBA ENVIROTHON OUTCOME A2, A3

### *The Water Cycle*

The hydrogen and oxygen atoms in water are nutrients that organisms need. Clearly there is no problem obtaining these nutrients in aquatic ecosystems. However, they are sometimes in short supply in terrestrial ecosystems. The overall cycling of water in nature involves both aquatic and terrestrial ecosystems and the air above them. Let's see how this occurs.

Water vapour enters the atmosphere through transpiration from vegetation. (Transpiration is the loss of water through pores in the leaves of plants.) It also enters the atmosphere by evaporation from bodies of water and the soil. In the cool upper atmosphere this vapour condenses, forming clouds. In time, enough water collects in the clouds to cause precipitation. When this occurs, some of the water falling on the ground runs along the surface of the ground to a stream, pond, or other body of water. This water is called surface runoff. Some of the water also soaks into the ground by a process called percolation. Some water percolates down to the bedrock. Then it becomes ground water and gradually runs back to lakes and other bodies of water.

Some of the water in the soil moves up to the roots of plants by capillarity. The roots absorb the water. This is how most plants get the hydrogen and oxygen they need. Animals can obtain water by eating plants or by eating other animals. Of course, they can also obtain water by drinking it directly from a body of water. When plants and animals die, they decompose. During this process, the water present in their tissues is released into the environment.

#### **Evaporation:**

As water is heated by the sun, its surface molecules become sufficiently energized to break free of the attractive force binding them together, and then *evaporate* and rise as invisible vapour in the atmosphere.

The following **Hydrological Cycle Illustration and text** is from: [www.ec.gc.ca/water/en/nature/prop/e\\_prop.htm](http://www.ec.gc.ca/water/en/nature/prop/e_prop.htm)

#### **Transpiration:**

Water vapour is also emitted from plant leaves by a process called transpiration. Every day an actively growing plant *transpires* 5 to 10 times as much water as it can hold at once.

#### **Condensation:**

As water vapour rises, it cools and eventually *condenses*, usually on tiny particles of dust in the air. When it condenses it becomes a liquid again or turns directly into a solid (ice, hail or snow). These water particles then collect and form clouds.

#### **Precipitation:**

Precipitation in the form of rain, snow and hail comes from clouds. Clouds move around the world, propelled by air currents. For instance, when they rise over mountain ranges, they cool, becoming so saturated with water that water begins to fall as rain, snow or hail, depending on the temperature of the surrounding air.

#### **Runoff:**

Excessive rain or snowmelt can produce overland flow to creeks and ditches. Runoff is visible flow of water in

rivers, creeks and lakes as the water stored in the basin drains out.

#### **Percolation:**

Some of the precipitation and snow melt moves downwards, *percolates* or *infiltrates* through cracks, joints and pores in soil and rocks until it reaches the water table where it becomes groundwater.

#### **Groundwater:**

Subterranean water is held in cracks and pore spaces. Depending on the geology, the groundwater can flow to support streams. It can also be tapped by wells. Some groundwater is very old and may have been there for thousands of years.

#### **Water table:**

The water table is the level at which water stands in a shallow well.

### **The sun-powered cycle**

The endless circulation of water from the atmosphere to the earth and its return to the atmosphere through condensation, precipitation, evaporation and transpiration is called the hydrologic cycle.

Heating of the ocean water by the sun is the key process that keeps the hydrologic cycle in motion. Water evaporates, then falls as precipitation in the form of rain, hail, snow, sleet, drizzle or fog. On its way to earth some precipitation may evaporate or, when it falls over land, be intercepted by vegetation before reaching the ground.

The cycle continues in three different ways:

- **Evaporation/transpiration** – On average, as much as 40% of precipitation in Canada is evaporated or transpired.
- **Percolation into the ground** – Water moves downward through cracks and pores in soil and rocks to the water table. Water can move back up by capillary action or it can move vertically or horizontally under the earth's surface until it re-enters a surface water system.
- **Surface runoff** – Water runs overland into nearby streams and lakes; the steeper the land and the less porous the soil, the greater the runoff. Overland flow is particularly visible in urban areas. Rivers join each other and eventually form one major river that carries all of the sub-basins' runoff into the ocean.

Although the hydrologic cycle balances what goes up with what comes down, one phase of the cycle is "frozen" in the colder regions during the winter season. During the Canadian winter, for example, most of the precipitation is simply stored as snow or ice on the ground. Later, during the spring melt, huge quantities of water are released quickly, which results in heavy spring runoff and flooding.

### ***The Carbon Cycle***

Carbon is another nutrient that all organisms need. In fact, it is the basic building block of all living things. Like water, carbon moves through an ecosystem in a cycle. Here is how the cycle works.

Carbon is present in the atmosphere as carbon dioxide. Producers (plants and algae) use it to make food. Now the carbon is in the producers. Herbivores eat the plants, and carnivores eat the herbivores. Now the carbon is in the animals. Both plants and animals respire. Their respiration returns carbon dioxide to the atmosphere. Decomposers break down dead plants and animals as well as animal waste. This too returns carbon dioxide to the atmosphere.

Some organic matter does not decompose easily. Instead, it builds up in the earth's crust. Oil and coal were formed from a build-up of plant matter millions of years ago.

At one time, the carbon cycle was almost a perfect cycle. That is, carbon was returned to the atmosphere as quickly as it was removed. Lately however, the increased burning of fossil fuels has added carbon to the atmosphere faster than producers can remove it.

The cycle just described occurs on, in and above the land. A similar cycle also occurs in aquatic ecosystems such as lakes and oceans. In fact, water (mainly in the oceans) hold over 50 times as much carbon dioxide as the air.

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### CHAPTER 9: Introduction to the Biosphere

#### (r). The Carbon Cycle

All life is based on the element **carbon**. Carbon is the major chemical constituent of most organic matter, from **fossil fuels** to the complex molecules (**DNA** and **RNA**) that control genetic reproduction in organisms. Yet by weight, carbon is not one of the most abundant elements within the Earth's crust. In fact, the lithosphere is only 0.032 % carbon by weight. In comparison, oxygen and silicon respectively make up 45.2 % and 29.4 % of the Earth's surface rocks.

Carbon is stored on our planet in the following major **sinks** (Figure 9r-1 and Table 9r-1): (1) as **organic molecules** in living and dead organisms found in the **biosphere**; (2) as the gas **carbon dioxide** in the **atmosphere**; (3) as **organic matter** in **soils**; (4) in the **lithosphere** as **fossil fuels** and **sedimentary rock** deposits such as **limestone**, **dolomite** and **chalk**; and (5) in the oceans as dissolved atmospheric **carbon dioxide** and as **calcium carbonate** shells in marine organisms.

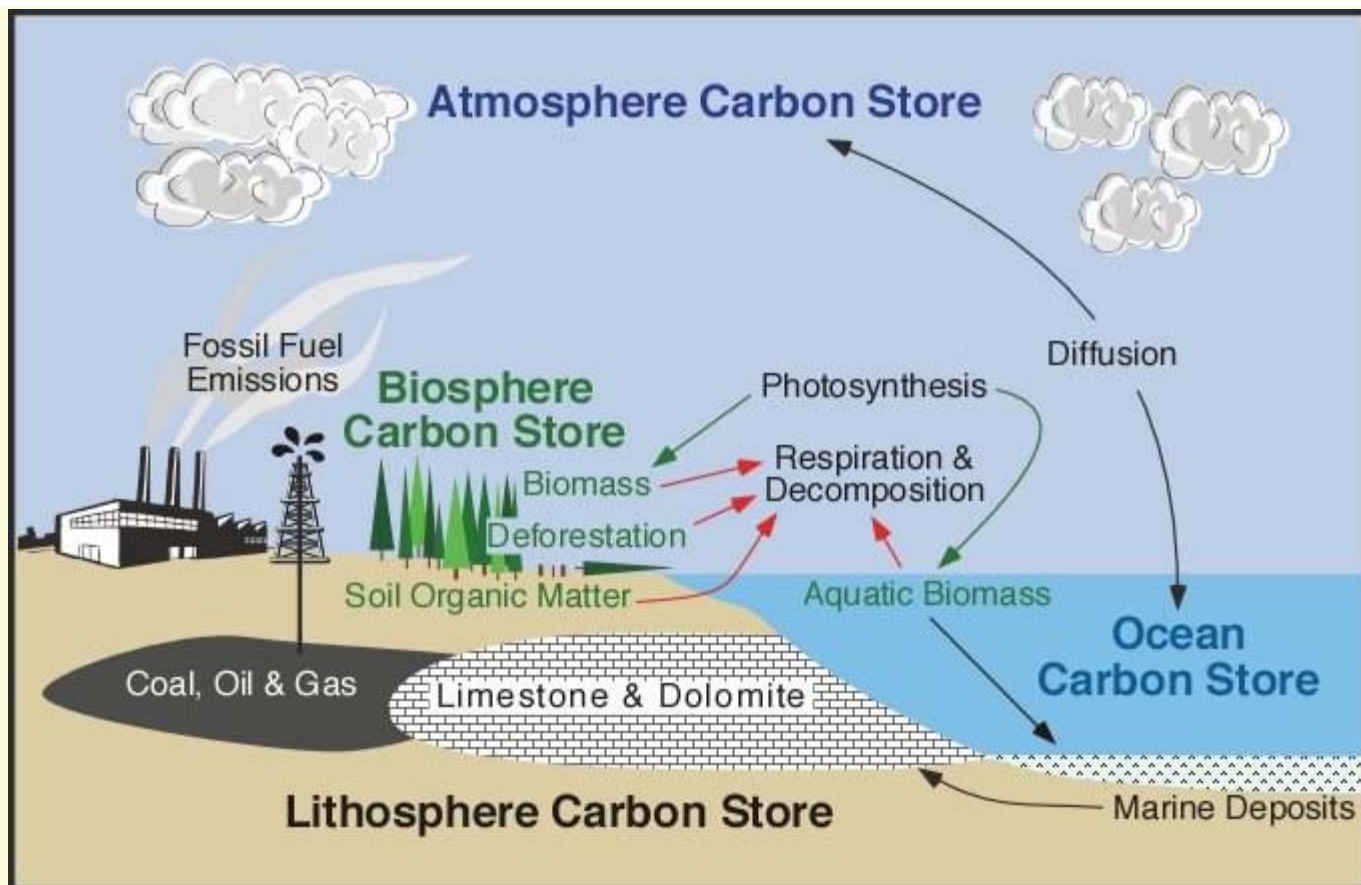


Figure 9r-1: Carbon cycle.

Table 9r-1: Estimated major stores of carbon on the Earth.

Sink	Amount in Billions of Metric Tons
Atmosphere	578 (as of 1700) - 766 (as of 1999)
Soil Organic Matter	1500 to 1600
Ocean	38,000 to 40,000
Marine Sediments and Sedimentary Rocks	66,000,000 to 100,000,000
Terrestrial Plants	540 to 610
Fossil Fuel Deposits	4000

Ecosystems gain most of their carbon dioxide from the atmosphere. A number of autotrophic organisms have specialized mechanisms that allow for absorption of this gas into their cells. With the addition of water and energy from solar radiation, these organisms use photosynthesis to chemically convert the carbon dioxide to carbon-based sugar molecules. These molecules

can then be chemically modified by these organisms through the metabolic addition of other elements to produce more complex compounds like **proteins**, **cellulose**, and **amino acids**. Some of the **organic matter** produced in plants is passed down to **heterotrophic** animals through consumption.

Carbon dioxide enters the waters of the ocean by simple **diffusion**. Once dissolved in seawater, the carbon dioxide can remain as is or can be converted into carbonate ( $\text{CO}_3^{-2}$ ) or bicarbonate ( $\text{HCO}_3^-$ ). Certain forms of sea life biologically fix bicarbonate with calcium ( $\text{Ca}^{+2}$ ) to produce **calcium carbonate** ( $\text{CaCO}_3$ ). This substance is used to produce shells and other body parts by organisms such as coral, clams, oysters, some protozoa, and some algae. When these organisms die, their shells and body parts sink to the ocean floor where they accumulate as carbonate-rich deposits. After long periods of time, these deposits are physically and chemically altered into **sedimentary rocks**. Ocean deposits are by far the biggest sink of carbon on the planet (Table 9r-1).

Carbon is released from ecosystems as **carbon dioxide** gas by the process of **respiration**. Respiration takes place in both plants and animals and involves the breakdown of carbon-based organic molecules into carbon dioxide gas and some other compound by products. The **detritus food chain** contains a number of organisms whose primary ecological role is the **decomposition** of organic matter into its abiotic components.

Over the several billion years of geologic history, the quantity of carbon dioxide found in the atmosphere has been steadily decreasing. Researchers theorized that this change is in response to an increase in the sun's output over the same time period. Higher levels of carbon dioxide helped regulate the Earth's temperature to levels slightly higher than what is perceived today. These moderate temperatures allowed for the flourishing of plant life despite the lower output of **solar radiation**. An enhanced **greenhouse effect**, due to the greater concentration of carbon dioxide gas in the atmosphere, supplemented the production of **heat energy** through higher levels of longwave counter-radiation. As the sun grew more intense, several biological mechanisms gradually locked some of the atmospheric carbon dioxide into **fossil fuels** and **sedimentary rock**. In summary, this regulating process has kept the Earth's global average temperature essentially constant over time. Some scientists suggest that this phenomena is proof for the **Gaia hypothesis**.

Carbon is stored in the lithosphere in both **inorganic** and **organic** forms. Inorganic deposits of carbon in the **lithosphere** include **fossil fuels** like

coal, oil, and natural gas, oil shale, and carbonate based sedimentary deposits like limestone. Organic forms of carbon in the lithosphere include litter, organic matter, and humic substances found in soils. Some carbon dioxide is released from the interior of the lithosphere by volcanoes. Carbon dioxide released by volcanoes enters the lower lithosphere when carbon-rich sediments and sedimentary rocks are subducted and partially melted beneath tectonic boundary zones.

Since the Industrial Revolution, humans have greatly increased the quantity of carbon dioxide found in the Earth's atmosphere and oceans. Atmospheric levels have increased by over 30 %, from about 275 parts per million (ppm) in the early 1700s to just over 365 PPM today. Scientists estimate that future atmospheric levels of carbon dioxide could reach an amount between 450 to 600 PPM by the year 2100. The major sources of this gas due to human activities include fossil fuel combustion and the modification of natural plant cover found in grassland, woodland, and forested ecosystems. Emissions from fossil fuel combustion account for about 65 % of the additional carbon dioxide currently found in the Earth's atmosphere. The other 35 % is derived from deforestation and the conversion of natural ecosystems into agricultural systems. Researchers have shown that natural ecosystems can store between 20 to 100 times more carbon dioxide than agricultural land-use types.

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## CHAPTER 9: Introduction to the Biosphere

### (s). The Nitrogen Cycle

The **nitrogen cycle** represents one of the most important nutrient cycles found in terrestrial ecosystems (**Figure 9s-1**). Nitrogen is used by living organisms to produce a number of complex **organic** molecules like **amino acids**, **proteins**, and **nucleic acids**. The store of nitrogen found in the atmosphere, where it exists as a gas (mainly  $N_2$ ), plays an important role for life. This store is about one million times larger than the total nitrogen contained in living organisms. Other major stores of nitrogen include organic matter in soil and the oceans. Despite its abundance in the atmosphere, nitrogen is often the most limiting nutrient for plant growth. This problem occurs because most plants can only take up nitrogen in two solid forms: **ammonium** ion ( $NH_4^+$ ) and the ion **nitrate** ( $NO_3^-$ ). Most plants obtain the nitrogen they need as **inorganic** nitrate from the **soil solution**. Ammonium is used less by plants for uptake because in large concentrations it is extremely toxic. Animals receive the required nitrogen they need for **metabolism**, growth, and reproduction by the consumption of living or dead organic matter containing molecules composed partially of nitrogen.

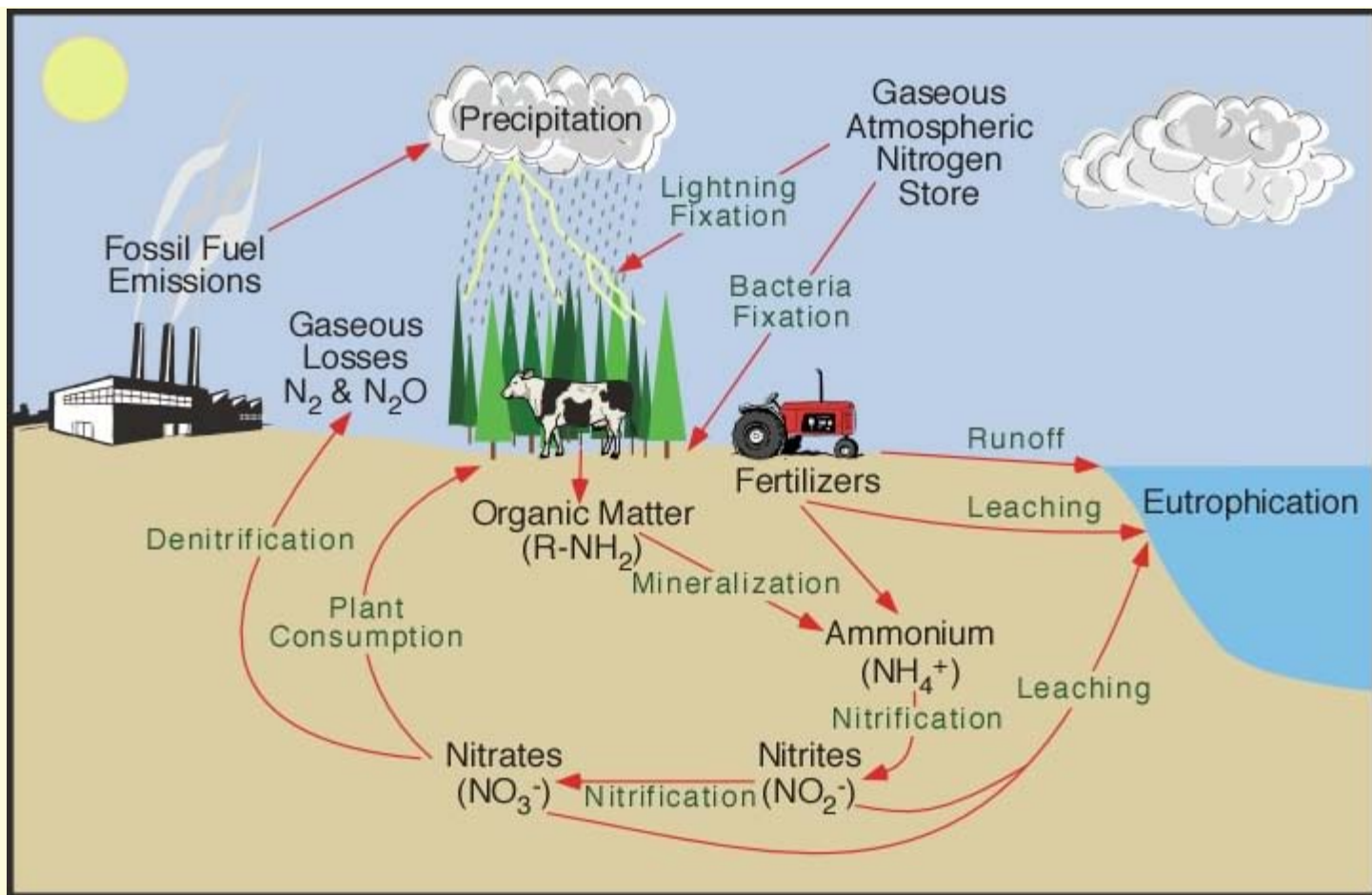


Figure 9s-1: Nitrogen cycle.

In most ecosystems nitrogen is primarily stored in living and dead **organic matter**. This organic nitrogen is converted into inorganic forms when it re-enters the **biogeochemical cycle** via **decomposition**. **Decomposers**, found in the upper soil layer, chemically modify the nitrogen found in **organic matter** from **ammonia** ( $NH_3$ ) to **ammonium** salts ( $NH_4^+$ ). This process is known as **mineralization** and it is carried out by a variety of **bacteria**, **actinomycetes**, and **fungi**.

Nitrogen in the form of **ammonium** can be absorbed onto the surfaces of clay particles in the soil. The ion of ammonium has a positive molecular charge is normally held by **soil colloids**. This process is sometimes called **micelle fixation** (see **Figure 9s-1**). Ammonium is released from the colloids by way of **cation exchange**. When released, most of the ammonium is often chemically altered by a specific type of **autotrophic bacteria** (bacteria that belong to the genus **Nitrosomonas**) into **nitrite** ( $NO_2^-$ ). Further modification by another type of

bacteria (belonging to the genus **Nitrobacter**) converts the **nitrite** to **nitrate** ( $\text{NO}_3^-$ ). Both of these processes involve chemical **oxidation** and are known as **nitrification**. However, nitrate is very soluble and it is easily lost from the soil system by **leaching**. Some of this leached nitrate flows through the **hydrologic system** until it reaches the oceans where it can be returned to the atmosphere by **denitrification**. Denitrification is also common in **anaerobic** soils and is carried out by **heterotrophic bacteria**. The process of denitrification involves the metabolic **reduction** of nitrate ( $\text{NO}_3^-$ ) into nitrogen ( $\text{N}_2$ ) or nitrous oxide ( $\text{N}_2\text{O}$ ) gas. Both of these gases then **diffuse** into the atmosphere.

Almost all of the nitrogen found in any terrestrial ecosystem originally came from the atmosphere. Significant amounts enter the soil in rainfall or through the effects of lightning. The majority, however, is biochemically **fixed** within the soil by specialized micro-organisms like **bacteria**, **actinomycetes**, and **cyanobacteria**. Members of the bean family (legumes) and some other kinds of plants form mutualistic symbiotic relationships with nitrogen fixing bacteria. In exchange for some nitrogen, the bacteria receive from the plants carbohydrates and special structures (nodules) in roots where they can exist in a moist environment. Scientists estimate that biological fixation globally adds approximately 140 million metric tons of nitrogen to ecosystems every year.

The activities of humans have severely altered the nitrogen cycle. Some of the major processes involved in this alteration include:

- The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into **groundwater**. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can lead to **eutrophication**.
- Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion.
- Livestock ranching. Livestock release a large amounts of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and **runoff**.
- Sewage waste and septic tank **leaching**.

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## CYCLING PHOSPHORUS

Phosphorus (P) is another one of the essential elements that cycle through the ecosystem. It is an element that is found in the ground and then taken up by plants and animals. Phosphorus starts its existence as phosphate ions ( $\text{PO}_4$ ) in the rocks of the world. When it rains, the phosphates and other minerals are removed from the rocks and distributed in soils and the water all over the planet.

## PLANTS NEED IT

Plants on land take in the inorganic (compounds without carbon) phosphorus compounds from the soil. The phosphorus atoms are then incorporated into many organic compounds that are used in cells. Animals can get their phosphorus by eating plants or drinking water. Algae and water plants are able to absorb the ions from the water. Unlike carbon and nitrogen, the phosphorus cycle is not a true cycle. There is a great deal of phosphorus lost.

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## LOSING THE ELEMENT

Phosphorus has a tendency to wind up at the bottom of the ocean. Once at the bottom, the phosphate ions are lost to the world. Sometimes the phosphates are found in runoff water and go to the bottom and sometimes human poop contains phosphate and those phosphates are returned to the ocean. The problem is that all usable phosphorus sources are on the surface. The atoms are useless once they reach the bottom of the ocean. Slowly but surely the surface of the Earth is running out of easy places to find phosphorus.

## ELEMENTAL CONCERN

Why is there a sudden concern? Phosphorus only gets into the soil by the weathering process on rocks. When plants die in the natural world, the phosphates return to the soil. In farming, the crops are taken away and then over many years the soil runs out of phosphorus compounds. We have created a situation where we must artificially replenish the nutrients in the land. Phosphorus is heavily used in the farming industry and fertilizers filled with phosphates are used all over the world to help plants grow.

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