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NON-POINT SOURCE POLLUTION MITIGATION - IT BEGINS AT HOME!

STUDY RESOURCES

PART A

ENVIROTHON

MISSISSIPPI 2026

2026 NCF-Envirothon Mississippi

Current Issue Study Resources Part A

Non-Point Source Pollution:
It Begins at Home

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The Role of the Individual/Community in NPS Issues and Solutions	Change begins at home and spreads through community action. Focuses on civic engagement, community science, and grassroots solutions. Promotes empowerment and collaboration.
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Legislation, Regulations, and Voluntary Measures	What are the rules– and who makes them? Explores policy, governance, and incentives behind NPS management. Emphasizes civic literacy and institutional collaboration.
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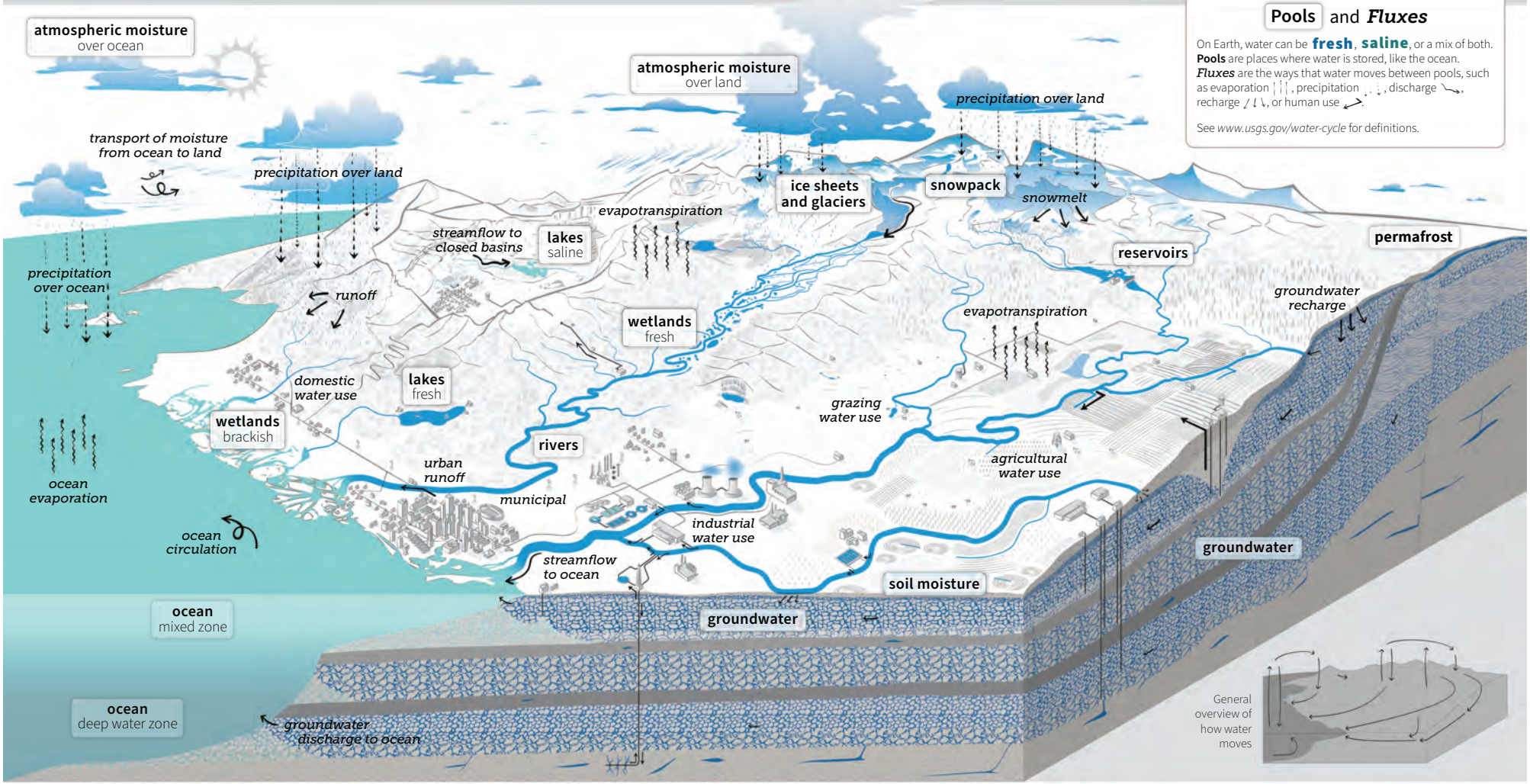
Please Note: Any hyperlinks within the study resources, except for those specifically mentioned as a resource on the Key Topics pages and with a dedicated page in the resources (*i.e., YouTube videos*), are supplemental material ONLY. They may be used for additional information but are not required study resources.

Key Topic #1: Non-Point Source Pollution Status

Learning Objectives

1. **Define** non-point source (NPS) pollution and **differentiate** it from point source pollution using real-world examples from urban and rural settings.
2. **Explain** changes in watershed ecology that influence NPS pollution (Water cycle, nutrient cycles, carbon cycles, river continuum concept).
3. **Identify** major types, sources and pathways of NPS pollution in surface water systems, including stormwater runoff, agricultural fields, and impervious surfaces.
4. **Describe** the impacts of NPS pollution on water quality and designated water uses (e.g., recreation, fisheries, drinking water).

Resource Title	Source	Located on
The Water Cycle	*U.S. Geological Survey,2022*	Page 4
Biogeochemical Cycles: C, N, & P	*Melissa Ha and Rachel Schleiger,Yuba College & Butte, Libre Texts (2020, August 6)*	Page 5-14
Nutrient Dynamics	*Water on the Web*	Page 15-17
What is a Watershed?	*U.S. EPA factsheet*	Page 18-20
Understand Your Watershed: Hydrology and Geomorphology, *excerpts*	*Minnesota Pollution Control Agency, 2006*	Page 21-38
Designated Uses and Why They are Important, *excerpts from Section 2.1.1*	*Water Quality Standards Handbook- U.S. EPA, 2024*	Page 39-40
Basic information about Nonpoint Source	*U.S. EPA factsheet*	Page 41-42
Introduction to Clean Water Act (CWA) Section 303(d) Impaired Waters	*U.S. EPA factsheet (July 17, 2009)*	Page 43-44
Overview of Identifying and Restoring Impaired Waters under Section 303(d) of the CWA	*U.S. EPA factsheet*	Page 45



The Water Cycle

The water cycle describes where water is found on Earth and how it moves. Water can be stored in the atmosphere, on Earth's surface, or below the ground. It can be in a liquid, solid, or gaseous state. Water moves between the places it is stored at large scales and at very small scales. Water moves naturally and because of human interaction, both of which affect where water is stored, how it moves, and how clean it is.

Liquid water can be fresh, saline (salty), or a mix (brackish). Ninety-six percent of all water is saline and stored in **oceans**. Places like the ocean, where water is stored, are called **pools**. On land, saline water is stored in **saline lakes**, whereas fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, **wetlands**, and in soil as **soil moisture**. Deeper underground, liquid water is stored as **groundwater** in aquifers, within the cracks and pores of rock. The solid, frozen form of water is stored in **ice sheets**, **glaciers**, and **snowpack** at high elevations or near the Earth's poles. Frozen water is also found in the soil as **permafrost**. Water vapor, the gaseous form of water, is stored as **atmospheric moisture** over the ocean and land.

As it moves, water can transform into a liquid, a solid, or a gas. The different ways in which water moves between pools are known as **fluxes**. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the Earth's surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the land surface through **snowmelt**, **runoff**, and **streamflow**. Through infiltration and **groundwater recharge**, water moves into the ground. When underground, groundwater flows within aquifers and can return to the surface through **springs** or from natural **groundwater discharge** into rivers and oceans.

Humans alter the water cycle. We redirect rivers, build dams to store water, and drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water (1) to supply our **homes** and **communities**; (2) for **agricultural** irrigation and **grazing** livestock; and (3) in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of available water depends on how much water is in each pool (water quantity). Water availability also depends on when and how fast water moves (water timing), how much water is used (water use), and how clean the water is (water quality).

Human activities affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these types of sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is also affecting the water cycle. It affects water quality, quantity, timing, and use. Climate change is also causing ocean acidification, sea level rise, and extreme weather. Understanding these impacts can allow progress toward sustainable water use.

U.S. Department of the Interior
U.S. Geological Survey

7.3: Biogeochemical Cycles

Biogeochemical cycles, also known as nutrient cycles, describe the movement of chemical elements through different media, such as the atmosphere, soil, rocks, bodies of water, and organisms. Biogeochemical cycles keep essential elements available to plants and other organisms.

Energy flows directionally through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during energy transformation between trophic levels. Rather than flowing through an ecosystem, the matter that makes up organisms is conserved and recycled. The **law of conservation of mass** states that matter is neither created nor destroyed. For example, after a chemical reaction, the mass of the products (ending molecules) will be the same as the mass of the reactants (starting molecules). The same is true in an ecosystem. Matter moves through different media, and atoms may react to form new molecules, but the amount of matter remains constant.

The biogeochemical cycles of four elements—carbon, nitrogen, phosphorus, and sulfur—are discussed below. The cycling of these elements is interconnected with the water cycle. For example, the movement of water is critical for the leaching of sulfur and phosphorus into rivers, lakes, and oceans. Today, **anthropogenic** (human) activities are altering all major ecosystems and the biogeochemical cycles they drive.

The Carbon Cycle

Carbon is the basic building block of all organic materials, and therefore, of living organisms. The carbon cycle is actually comprised of several interconnected cycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes (figure $7.3.a$). The overall effect is that carbon is constantly recycled in the dynamic processes taking place in the atmosphere, at the surface and in the crust of the earth. The vast majority of carbon resides as inorganic minerals in crustal rocks. Other **reservoirs** of carbon, places where carbon accumulates, include the oceans and atmosphere. Some of the carbon atoms in your body today may long ago have resided in a dinosaur's body, or perhaps were once buried deep in the Earth's crust as carbonate rock minerals.

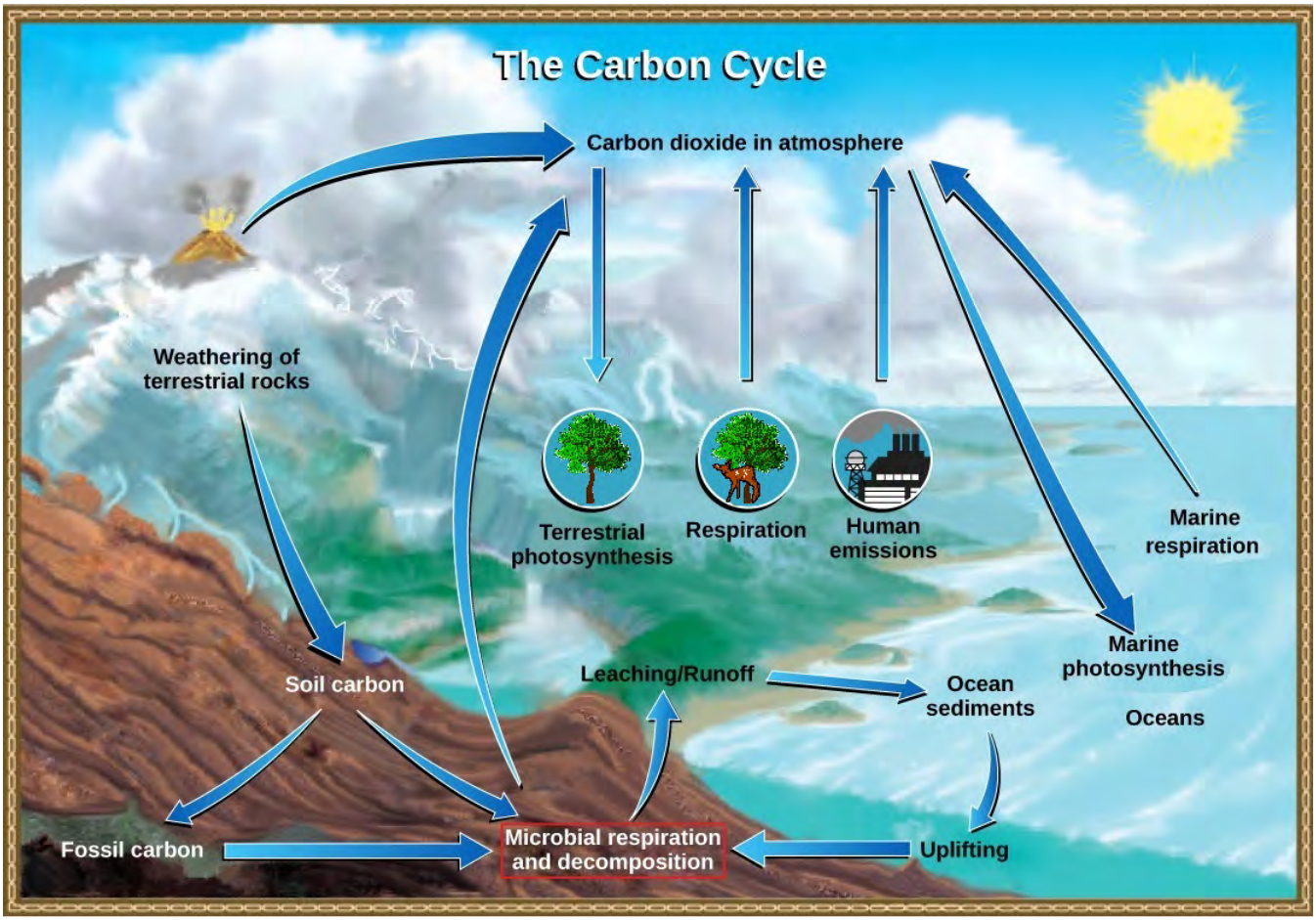


Figure 7.3.*a*: Carbon dioxide in the atmosphere is converted to organic carbon through photosynthesis by terrestrial organisms (like trees) and marine organisms (like algae). Respiration by terrestrial organisms (like trees and deer) and marine organisms (like algae and fish) release carbon dioxide back into the atmosphere. Additionally, microbes that decompose dead organisms release carbon dioxide through respiration. Weathering of terrestrial rocks also brings carbon into the soil. Carbon in the soil enters the water through leaching and runoff. It can accumulate into ocean sediments and reenter land through uplifting. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground and becomes fossilized. Volcanic activity and, more recently, human emissions stored carbon back into the carbon cycle. Modified from John M. Evans and Howard Perlman, USGS using tree and deer (both public domain).

Carbon Cycles Slowly between Land and the Ocean

On land, carbon is stored in soil as organic carbon in the form of decomposing organisms or terrestrial rocks. Decomposed plants and algae are sometimes buried and compressed between layers of sediments. After millions of years fossil fuels such as coal, oil, and natural gas are formed. The **weathering** of terrestrial rock and minerals release carbon into the soil.

Carbon-containing compounds in the soil can be washed into bodies of water through **leaching.** This water eventually enters the ocean. Atmospheric carbon dioxide also dissolves in the ocean, reacting with water molecules to form carbonate ions (CO_3^{2-}). Some of these ions combine with calcium ions in the seawater to form calcium carbonate ($CaCO_3$), a major component of the shells of marine organisms. These organisms eventually die and their shells form sediments on the ocean floor. Over geologic time, the calcium carbonate forms limestone, which comprises the largest carbon reservoir on Earth.

Carbonate also precipitates in sediments, forming carbonate rocks, such as limestone. Carbon sediments from the ocean floor are taken deep within Earth by the process of **subduction**: the movement of one tectonic plate beneath another. The ocean sediments are subducted by the actions of **plate tectonics**, melted and then returned to the surface during volcanic activity. Plate tectonics can also cause **uplifting**, returning ocean sediments to land.

Carbon Cycles Quickly between Organisms and the Atmosphere

Carbon dioxide is converted into glucose, an energy-rich organic molecule through **photosynthesis** by plants, algae, and some bacteria (figure 7.3.*b*). They can then produce other organic molecules like complex carbohydrates (such as starch), proteins and

lipids, which animals can eat. Most terrestrial autotrophs obtain their carbon dioxide directly from the atmosphere, while marine autotrophs acquire it in the dissolved form (bicarbonate, HCO_3^-).

Figure 7.3.*b*: (a) Plants, (b) algae, and (c) certain bacteria, called cyanobacteria, are can carry out photosynthesis. Algae can grow over enormous areas in water, at times completely covering the surface. (credit a: Steve Hillebrand, U.S. Fish and Wildlife Service; credit b: "eutrophication&hypoxia"/Flickr; credit c: NASA; scale-bar data from Matt Russell)

Plants, animals, and other organisms break down these organic molecules during the process of **aerobic cellular respiration**, which consumes oxygen and releases energy, water and carbon dioxide. Carbon dioxide is returned to the atmosphere during gaseous exchange. Another process by which organic material is recycled is the decomposition of dead organisms. During this process, bacteria and fungi break down the complex organic compounds. Decomposers may do respiration, releasing carbon dioxide, or other processes that release methane (CH_4).

Photosynthesis and respiration are actually reciprocal to one another with regard to the cycling of carbon: photosynthesis removes carbon dioxide from the atmosphere and respiration returns it (figure 7.3.*c*). A significant disruption of one process can therefore affect the amount of carbon dioxide in the atmosphere.

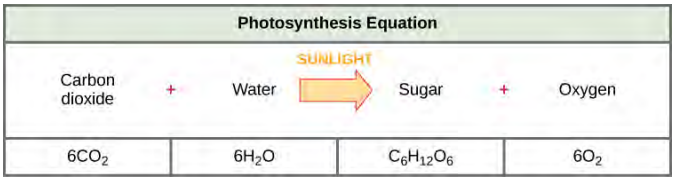


Figure 7.3.*c*: This equation means that six molecules of carbon dioxide (CO_2) combine with six molecules of water (H_2O) in the presence of sunlight. This produces one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O_2).

Cellular respiration is only one process that releases carbon dioxide. Physical processes, such as the eruption of volcanoes and release from **hydrothermal vents** (openings in the ocean floor) add carbon dioxide to the atmosphere. Additionally, the **combustion** of wood and fossil fuels releases carbon dioxide. The level of carbon dioxide in the atmosphere is greatly influenced by the reservoir of carbon in the oceans. The exchange of carbon between the atmosphere and water reservoirs influences how much carbon is found in each.

Importance of the Carbon Cycle

The carbon cycle is crucially important to the biosphere. If not for the recycling processes, carbon might long ago have become completely sequestered in crustal rocks and sediments, and life would no longer exist (figure 7.3.*e*). Photosynthesis not only makes energy and carbon available to higher trophic levels, but it also releases gaseous oxygen (O_2). Gaseous oxygen is necessary for cellular respiration to occur. Photosynthetic bacteria were likely the first organisms to perform photosynthesis, dating back 2-3 billion years ago. Thanks to their activity, and a diversity of present-day photosynthesizing organisms, Earth's atmosphere is currently about 21% O_2. Also, this O_2 is vital for the creation of the ozone layer, which protects life from harmful ultraviolet radiation emitted by the sun. Ozone (O_3) is created from the breakdown and reassembly of O_2.

Figure 7.3.*e*: Decomposers will break down the organic compounds in this fallen tree at Cliffs of the Neuse State Park in Wayne County, North Carolina, releasing carbon dioxide into the atmosphere. Decomposition ensures that carbon dioxide will be available in the atmosphere for photosynthetic organisms, which then provide carbon for consumers. Image by Gerry Dincher (CC-BY-SA).

The global carbon cycle contributes substantially to the provisioning ecosystem services upon which humans depend. We harvest approximately 25% of the total plant biomass that is produced each year on the land surface to supply food, fuel wood and fiber from croplands, pastures and forests. In addition, the global carbon cycle plays a key role in regulating ecosystem services because it significantly influences climate via its effects on atmospheric CO_2 concentrations.

Human Alteration of the Carbon Cycle

Atmospheric CO_2 concentration increased from 280 parts per million (ppm) to 413 ppm between the start of industrial revolution in the late eighteenth century and 2020. This reflected a new flux in the global carbon cycle—anthropogenic CO_2 emissions—where humans release CO_2 into the atmosphere by burning fossil fuels and changing land use. Fossil fuel burning takes carbon from coal, gas, and oil reserves, where it would be otherwise stored on very long time scales, and introduces it into the active carbon cycle. Land use change releases carbon from soil and plant biomass pools into the atmosphere, particularly through the process of deforestation for wood extraction or conversion of land to agriculture. In 2018, the additional flux of carbon into the atmosphere from anthropogenic sources was estimated to be 36.6 gigatons of carbon (GtC = 1 billion tons of carbon)—a significant disturbance to the natural carbon cycle that had been in balance for several thousand years previously. High levels of carbon dioxide in the atmosphere cause warming that results in climate change. (See Threats to Biodiversity and Climate Change for more details.)

The Nitrogen Cycle

All organisms require nitrogen because it is an important component of nucleic acids, proteins, and other organic molecules. Getting nitrogen into living organisms is difficult. Plants and algae are not equipped to incorporate nitrogen from the atmosphere (where it exists as tightly bonded, triple covalent N_2) although this molecule comprises approximately 78 percent of the atmosphere. Because most of the nitrogen is stored in the atmosphere, the atmosphere is considered a reservoir of nitrogen.

The nitrogen molecule (N_2) is quite inert. To break it apart so that its atoms can combine with other atoms requires the input of substantial amounts of energy. **Nitrogen fixation** is the process of converting nitrogen gas into ammonia (NH_3), which spontaneously becomes ammonium (NH_4^+). Ammonium is found in bodies of water and in the soil (figure 7.3.*f*).

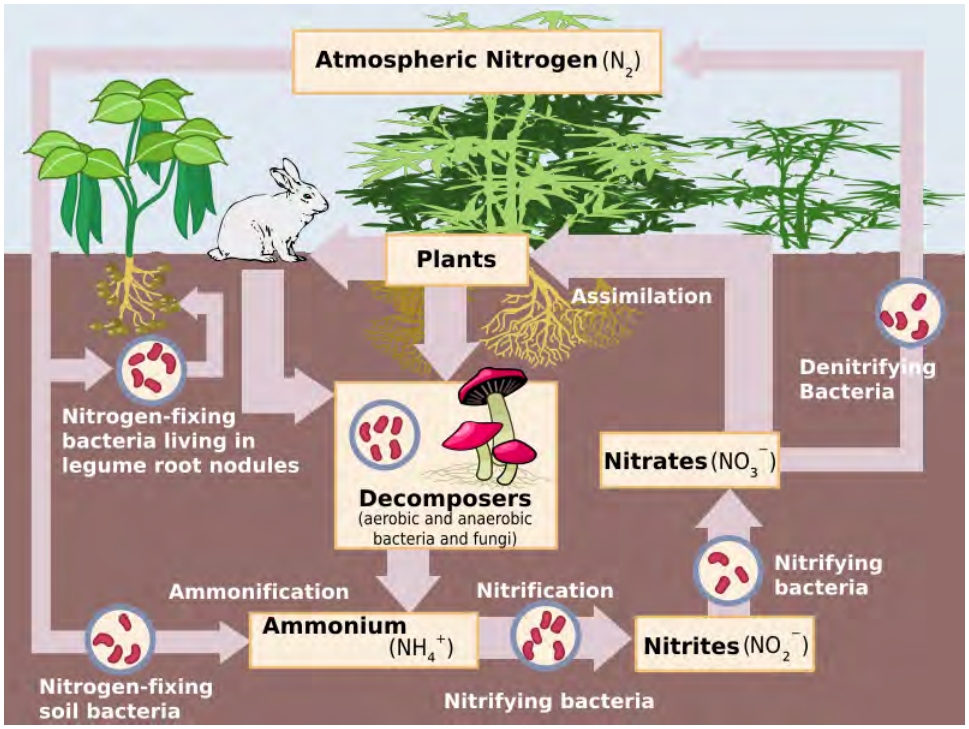


Figure 7.3.f: In the nitrogen cycle, nitrogen-fixing bacteria in the soil or legume root nodules convert nitrogen gas (N_2) from the atmosphere to ammonium (NH_4^+). Nitrification occurs when bacteria convert ammonium to nitrites (NO_2^-) and then to nitrates (NO_3^-). Nitrates re-enter the atmosphere as nitrogen gas through denitrification by bacteria. Plants assimilate ammonium and nitrates, producing organic nitrogen, which is available to consumers. Decomposers, including aerobic and anaerobic bacteria and fungi, break down organic nitrogen and release ammonium through ammonification. (credit: "Nitrogen cycle" by Johann Dréo & Raeky is licensed under CC BY-SA 3.0)

Three processes are responsible for most of the nitrogen fixation in the biosphere. The first is **atmospheric fixation** by lightning. The enormous energy of lightning breaks nitrogen molecules and enables their atoms to combine with oxygen in the air forming nitrogen oxides. These dissolve in rain, forming nitrates, that are carried to the earth. Atmospheric nitrogen fixation probably contributes some 5-8% of the total nitrogen fixed. The second process is **industrial fixation.** Under great pressure, at a temperature of 600°C (1112°F), and with the use of a **catalyst** (which facilitates chemical reactions), atmospheric nitrogen and hydrogen can be combined to form ammonia (NH_3). Ammonia can be used directly as fertilizer, but most of it is further processed to urea and ammonium nitrate (NH_4NO_3).

The third process is **biological fixation** by certain free-living or symbiotic bacteria. Some form a symbiotic relationship with plants in the legume family, which includes beans, peas, soybeans, alfalfa, and clovers (figure 7.3.g). Some nitrogen-fixing bacteria even establish symbiotic relationships with animals, e.g., termites and "shipworms" (wood-eating bivalves). Nitrogen-fixing cyanobacteria are essential to maintaining the fertility of semi-aquatic environments like rice paddies. Although the first stable product of the process is ammonia, this is quickly incorporated into protein and other organic nitrogen compounds.

Figure 7.3.*g*: Nitrogen-fixing bacteria live in the spherical nodules of this soybean root. Image by United Soybean Board (CC-BY).

Ammonium is converted by bacteria and archaea into nitrites (NO_2^-) and then nitrates (NO_3^-) through the process of **nitrification**. Like ammonium, nitrites and nitrates are found in water and the soil. Some nitrates are converted back into nitrogen gas, which is released into the atmosphere. The process, called **denitrification**, is conducted by bacteria.

Plants and other producers directly use ammonium and nitrates to make organic molecules through the process of **assimilation**. This nitrogen is now available to consumers. Organic nitrogen is especially important to the study of ecosystem dynamics because many processes, such as primary production, are limited by the available supply of nitrogen.

Consumers excrete organic nitrogen compounds that return to the environment. Additionally dead organisms at each trophic level contain organic nitrogen. Microorganisms, such as bacteria and fungi, decompose these wastes and dead tissues, ultimately producing ammonium through the process of **ammonification.**

In marine ecosystems, nitrogen compounds created by bacteria, or through decomposition, collects in ocean floor sediments. It can then be moved to land in geologic time by uplift of Earth's crust and thereby incorporated into terrestrial rock. Although the movement of nitrogen from rock directly into living systems has been traditionally seen as insignificant compared with nitrogen fixed from the atmosphere, a recent study showed that this process may indeed be significant and should be included in any study of the global nitrogen cycle.

Human activity can alter the nitrogen cycle by two primary means: the combustion of fossil fuels, which releases different **nitrogen oxides** into the atmosphere, and by the use of artificial fertilizers in agriculture. Atmospheric nitrogen (other than N_2) is associated with several effects on Earth's ecosystems. Nitrogen oxides (HNO_3) can react in the atmosphere to form nitric acid, a form of **acid deposition**, also known as acid rain. Acid deposition damages healthy trees, destroys aquatic systems and erodes building materials such as marble and limestone. Like carbon dioxide, nitrous oxide (N_2O) causes warming resulting in climate change.

Humans are primarily dependent on the nitrogen cycle as a supporting ecosystem service for crop and forest productivity. Nitrogen fertilizers are added to enhance the growth of many crops and plantations (figure 7.3.*h*). The enhanced use of fertilizers in agriculture was a key feature of the green revolution that boosted global crop yields in the 1970s. The industrial production of nitrogen-rich fertilizers has increased substantially over time and now matches more than half of the input to the land from biological nitrogen fixation (90 megatons = 1 million tons of nitrogen each year). If the nitrogen fixation from legume crops is included, then the anthropogenic flux of nitrogen from the atmosphere to the land exceeds natural fluxes to the land. Fertilizers are washed into lakes, streams, and rivers by surface runoff, resulting in saltwater and freshwater **eutrophication**, a process whereby nutrient runoff causes the overgrowth of algae, the depletion of oxygen, and death of aquatic fauna.

Figure 7.3.*h*: Fertilizer containing nitrogen is conventionally applied at large scales in agriculture. Image by Bob Nichols, USDA Natural Resources Conservation Service (public domain).

The Phosphorus Cycle

Several forms of nitrogen (nitrogen gas, ammnoium, nitrates, etc.) were involved in the nitrogen cycle, but phosphorus remains primarily in the form of the phosphate ion (PO_4^{3-}). Also in contrast to the nitrogen cycle, there is no form of phosphorus in the atmosphere. Phosphorus is used to make nucleic acids and the phospholipids that comprise biological membranes.

Rocks are a reservoir for phosphorus, and these rocks have their origins in the ocean. Phosphate-containing ocean sediments form primarily from the bodies of ocean organisms and from their excretions. However, volcanic ash, aerosols, and mineral dust may also be significant phosphate sources. This sediment then is moved to land over geologic time by the uplifting of Earth's surface (figure 7.3.*i*). The movement of phosphate from the ocean to the land and through the soil is extremely slow, with the average phosphate ion having an oceanic residence time between 20,000 and 100,000 years.

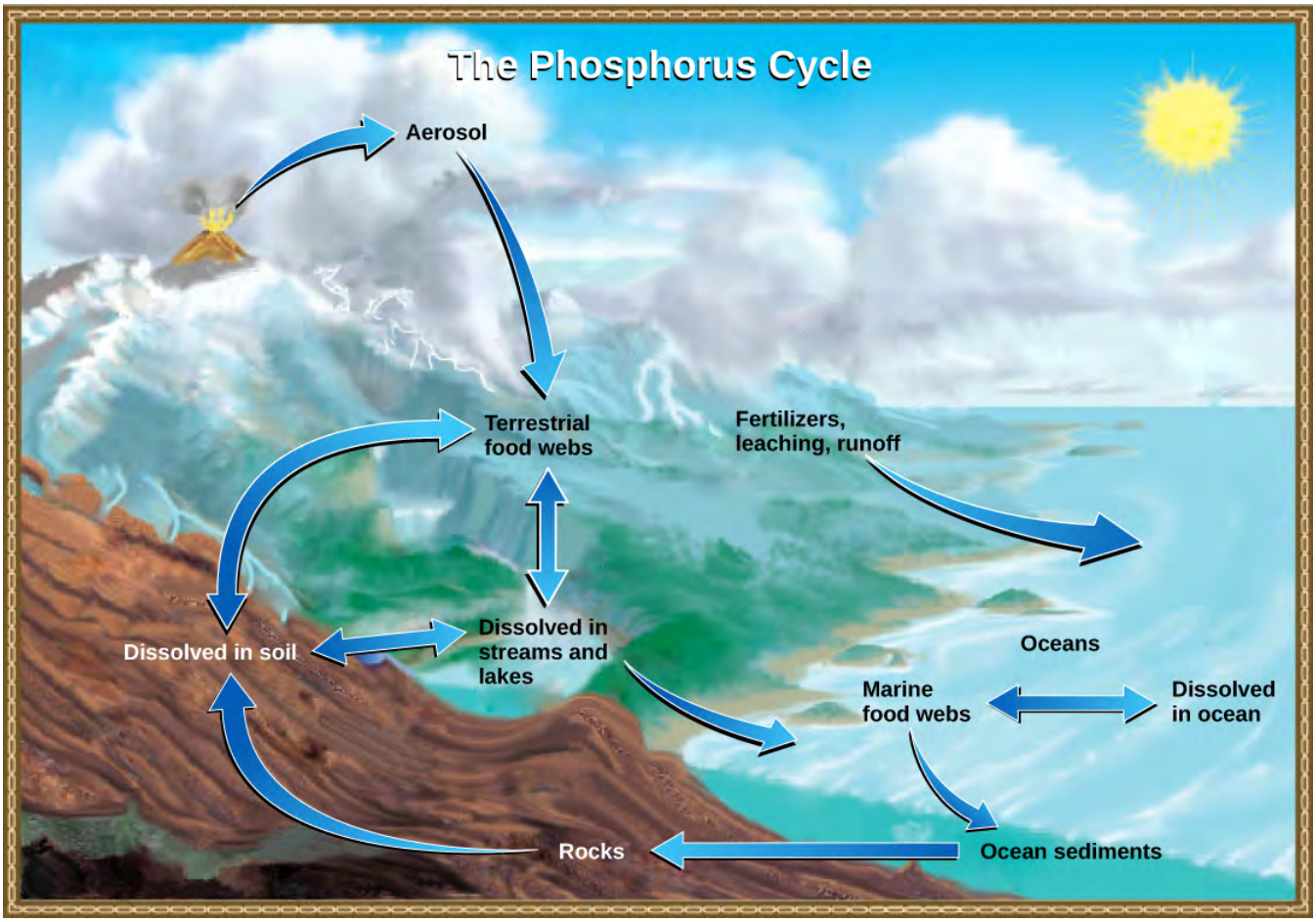


Figure 7.3.*i*: In nature, phosphorus exists as the phosphate ion (PO_4^{3-}). Phosphate enters the atmosphere from volcanic aerosols, which precipitate to Earth. Weathering of rocks also releases phosphate into the soil and water, where it becomes available to terrestrial food webs. Some of the phosphate from terrestrial food webs dissolves in streams and lakes, and the remainder enters the soil. Phosphate enters the ocean via surface runoff, groundwater flow, and river flow, where it becomes dissolved in ocean water or enters marine food webs. Some phosphate falls to the ocean floor where it becomes sediment. If uplifting occurs, this sediment can return to land. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

Marine birds play a unique role in the phosphorous cycle. These birds take up phosphorous from ocean fish. Their droppings on land (**guano**) contain high levels of phosphorous and are sometimes mined for commercial use. A 2020 study estimated that the **ecosystem services** (natural processes and products that benefit humans) provided by guano are worth $470 million per year.

Weathering of rocks releases phosphates into the soil and bodies of water. Plants can assimilate phosphates in the soil and incorporate it into organic molecules, making phosphorus available to consumers in terrestrial food webs. Waste and dead organisms are decomposed by fungi and bacteria, releasing phosphates back into the soil. Some phosphate is leached from the soil, entering into rivers, lakes, and the ocean. Primary producers in aquatic food webs, such as algae and photosynthetic bacteria, assimilate phosphate, and organic phosphate is thus available to consumers in aquatic food webs. Similar to terrestrial food webs, phosphorus is reciprocally exchanged between phosphate dissolved in the ocean and organic phosphorus in marine organisms.

The movement of phosphorus from rock to living organisms is normally a very slow process, but some human activities speed up the process. Phosphate-bearing rock is often mined for use in the manufacture of fertilizers and detergents. This commercial production greatly accelerates the phosphorous cycle. In addition, runoff from agricultural land and the release of sewage into water systems can cause a local overload of phosphate. The increased availability of phosphate can cause overgrowth of algae. This reduces the oxygen level, causing eutrophication and the destruction of other aquatic species.

Eutrophication and Dead Zones

Eutrophication occurs when excess phosphorus and nitrogen from fertilizer runoff or sewage causes excessive growth of algae. Algal blooms that block light and therefore kill aquatic plants in rivers, lakes, and seas. The subsequent death and decay of these organisms depletes dissolved oxygen, which leads to the death of aquatic organisms such as shellfish and fish. This process is

responsible for **dead zones**, large areas in lakes and oceans near the mouths of rivers that are periodically depleted of their normal flora and fauna, and for massive fish kills, which often occur during the summer months (figure 7.3.*j*). There are more than 500 dead zones worldwide. One of the worst dead zones is off the coast of the United States in the Gulf of Mexico. Fertilizer runoff from the Mississippi River basin created a dead zone, which reached its peak size of 8,776 square miles in 2017. Phosphate and nitrate runoff from fertilizers also negatively affect several lake and bay ecosystems including the Chesapeake Bay in the eastern United States.

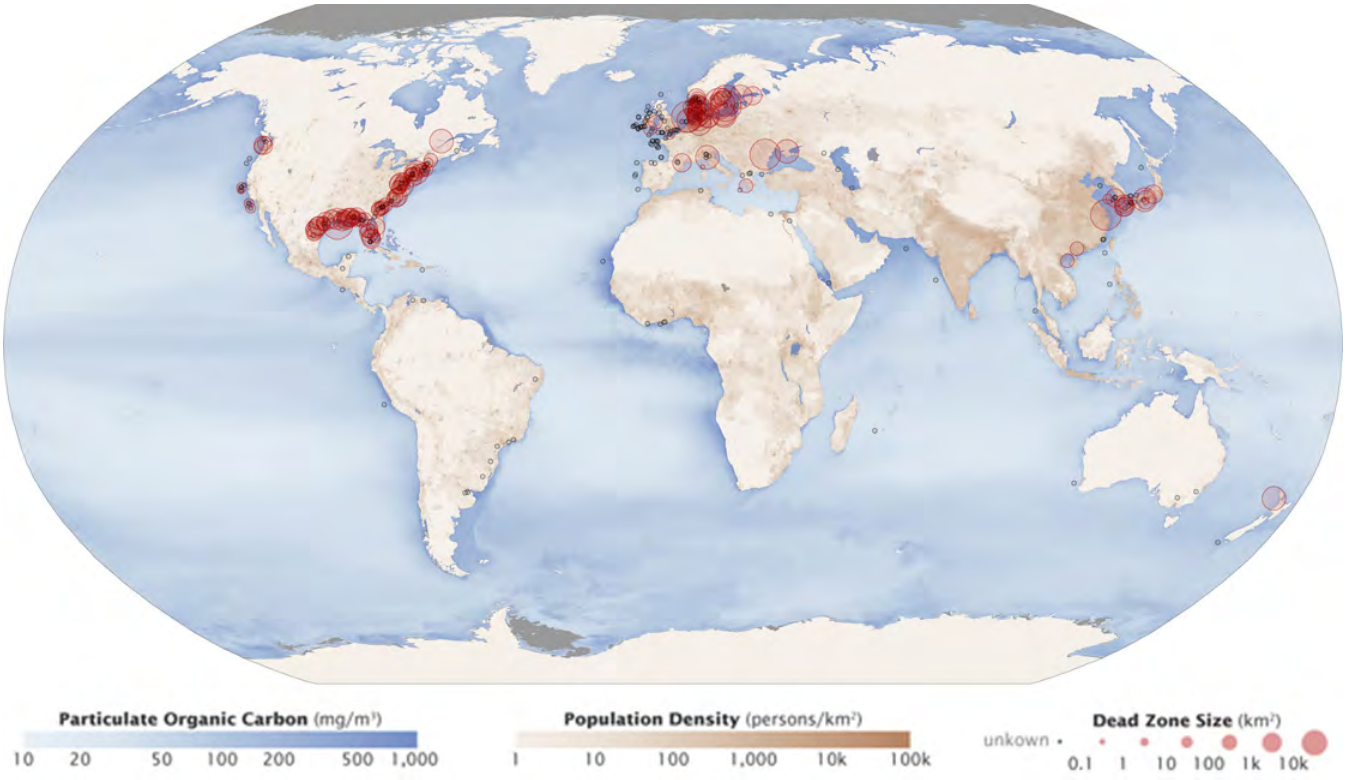
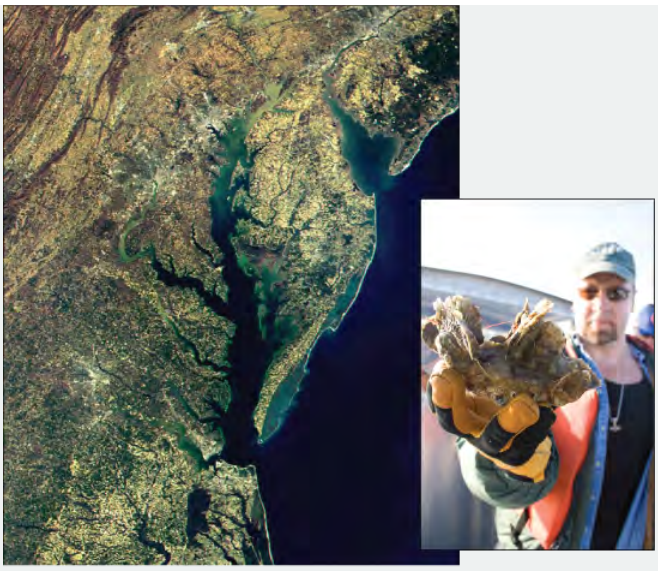


Figure 7.3.*j*: Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. This map shows dead zones around the world in 2008. Worldwide, large dead zones are found in coastal areas of high population density. (credit: NASA Earth Observatory)

Everyday Connection: Chesapeake Bay

The Chesapeake Bay has long been valued as one of the most scenic areas on Earth; it is now in distress and is recognized as a declining ecosystem. In the 1970s, the Chesapeake Bay was one of the first ecosystems to have identified dead zones, which continue to kill many fish and bottom-dwelling species, such as clams, oysters, and worms (figure 7.3.*k*). Several species have declined in the Chesapeake Bay due to surface water runoff containing excess nutrients from artificial fertilizer used on land. The source of the fertilizers (with high nitrogen and phosphate content) is not limited to agricultural practices. There are many nearby urban areas and more than 150 rivers and streams empty into the bay that are carrying fertilizer runoff from lawns and gardens. Thus, the decline of the Chesapeake Bay is a complex issue and requires the cooperation of industry, agriculture, and everyday homeowners.



(a) (b)

Figure 7.3.*k*: This (a) satellite image shows the Chesapeake Bay, an ecosystem affected by phosphate and nitrate runoff. A (b) member of the Army Corps of Engineers holds a clump of oysters being used as a part of the oyster restoration effort in the bay. (credit a: modification of work by NASA/MODIS; credit b: modification of work by U.S. Army)

Of particular interest to conservationists is the oyster population; it is estimated that more than 200,000 acres of oyster reefs existed in the bay in the 1700s, but that number has now declined to only 36,000 acres. Oyster harvesting was once a major industry for Chesapeake Bay, but it declined 88 percent between 1982 and 2007. This decline was due not only to fertilizer runoff and dead zones but also to overexploitation. Oysters require a certain minimum population density because they must be in close proximity to reproduce. Human activity has altered the oyster population and locations, greatly disrupting the ecosystem.

The restoration of the oyster population in the Chesapeake Bay has been ongoing for several years with mixed success. Not only do many people find oysters good to eat, but they also clean up the bay. Oysters are filter feeders, and as they eat, they clean the water around them. In the 1700s, it was estimated that it took only a few days for the oyster population to filter the entire volume of the bay. Today, with changed water conditions, it is estimated that the present population would take nearly a year to do the same job.

Restoration efforts have been ongoing for several years by non-profit organizations, such as the Chesapeake Bay Foundation. The restoration goal is to find a way to increase population density so the oysters can reproduce more efficiently. Many disease-resistant varieties (developed at the Virginia Institute of Marine Science for the College of William and Mary) are now available and have been used in the construction of experimental oyster reefs. Efforts to clean and restore the bay by Virginia and Delaware have been hampered because much of the pollution entering the bay comes from other states, which stresses the need for inter-state cooperation to gain successful restoration.

The new, hearty oyster strains have also spawned a new and economically viable industry—oyster aquaculture—which not only supplies oysters for food and profit, but also has the added benefit of cleaning the bay.

The Sulfur Cycle

Sulfur is an essential element for the molecules of living things. As part of the amino acid cysteine, it is critical to the three-dimensional shape of proteins. As shown in Figure 7.3.*l*, sulfur cycles among the oceans, land, and atmosphere. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), which enters the atmosphere in three ways: first, from the decomposition of organic molecules; second, from volcanic activity and geothermal vents; and, third, from the burning of fossil fuels by humans.

Nutrient Dynamics

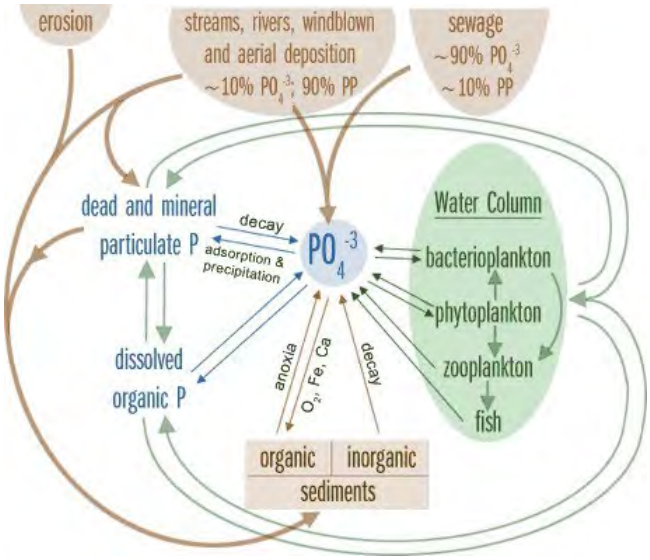
Solutes in rivers and streams are influenced by interactions with the streambed, streambanks, and the land as they travel downstream. This ongoing process interests stream ecologists because some of those solutes are essential to the lives of organisms, most notably phosphorus and nitrogen. Their uptake, transformation, and release play an important role in determining the amount of life an ecosystem can support. As nutrient atoms are used in a stream they are displaced further and further downstream, leading to the term "nutrient spiraling" being used to describe the interdependent processes of nutrient cycling and downstream transport. These interdependencies can be looked at in two ways: (1) how nutrient supply affects biological productivity; and (2) how the stream ecosystem influences the supply of nutrients being transported downstream.

Basic Nutrient Cycles

It is a basic rule of ecology that chemical constituents of organisms are continually recycled between the biota and the environment. Carbon, nitrogen, phosphorus, and silicon are the elements most utilized by organisms as nutrients. Carbon, being readily available as dissolved carbon dioxide, is usually left out of consideration as one of nutrients considered to be most ecologically important. As a group nitrogen, phosphorus, and silicon are referred to as macronutrients.

Phosphorus

Phosphorus is often the nutrient in most limited supply and thus the nutrient most likely to limit the productivity of plants and other autotrophs in stream environments. Plants and microbes assimilate dissolved inorganic phosphorus (DIP) into cellular structures. This process transforms phosphorus into particulate organic phosphorus (POP). Dying cells may excrete or release particulate organic phosphorus as dissolved organic phosphorus (DOP). Dissolved organic phosphorus is then broken down to DIP by bacterial activity, making it available to autotrophs once again.



Major Forms of Phosphorus

- Dissolved Inorganic Phosphorus (DIP)

(also known as orthophosphate or PO_4^{-3})

- Dissolved Organic Phosphorus (DOP)
- Particulate Organic Phosphorus (POP)
- Particulate Inorganic Phosphorus (PIP)

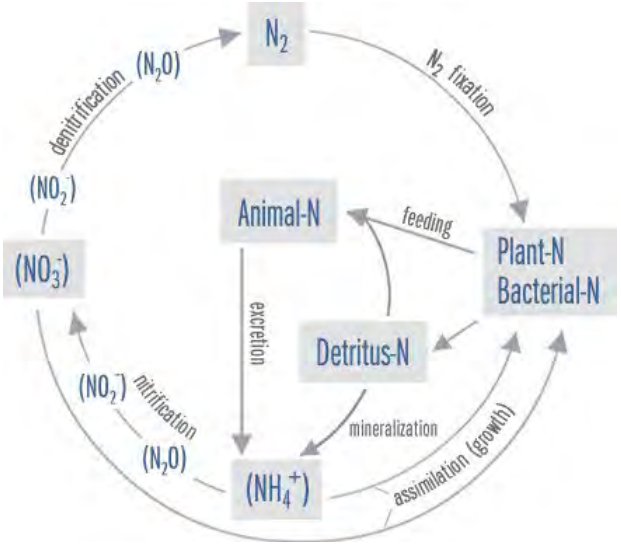
General availability of phosphorus is not only shaped by its abundance in local rocks and soils, but also by physical-chemical transformations. Sorption of phosphate ions onto charged clay or organic particles occurs when dissolved inorganic phosphorus (DIP) concentrations are relatively high, while release or desorption is favored at low DIP concentrations. Additionally, DIP and DOP may complex with metal oxides and hydroxides to form insoluble precipitates which can be released under anaerobic conditions.

Silicon

Diatoms are the only lotic organism to which silicon is limiting. The silicon cycle begins with silicic acid being dissolved from the weathering of rocks and anthropogenic inputs (especially sewage). It is assimilated by diatoms and eventually released by chemical dissolution over time.

Nitrogen

The cycling of nitrogen within ecosystems is complex due to the many transformations in form it goes through as a result of microbial processing. The principal forms of dissolved organic nitrogen (DON) include urea, uric acid, and amino acids. Dissolved inorganic nitrogen (DIN) is present as ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-). Nitrogen is also present in gases as nitrogen gas (N2) and nitrous oxide (N_2O). The atmosphere, natural runoff, sewage, and agriculture all deliver various forms of nitrogen to receiving bodies of water such as streams and rivers.



Major Forms of Nitrogen

1. Dissolved Inorganic Nitrogen (DIN)
   - NO_3^- NO_2^- NH_4^+
2. Dissolve Organic Nitrogen (DON)
3. Particulate Organic Nitrogen (PON)

In order for nitrogen to enter and move through an ecosystem it must be transformed by microbes a number of times. Initially, dissolved inorganic nitrogen (DIN - N_2,NH_3, NO_3^-,NH_4^+) must be fixed or assimilated by organisms to make it available for inclusion in the synthesis of organic molecules. Autotrophs, bacteria, and fungi utilize NH_4^+ preferentially over nitrate and nitrite, while bacteria and cyanobacteria fix nitrogen gas (N_2) in to NH_4^+ for its inclusion in structural organic molecules. Following excretion and decomposition Ammonium (NH_4^+) is converted to nitrite and then nitrate by nitrifying bacteria in aerobic conditions. If conditions are anaerobic, nitrate is converted to nitrite, and is eventually returned to the atmosphere as nitrogen gas by denitrifying bacteria. Denitrifying bacteria use ammonia as an energy source and nitrate as an oxidizing agent in the breakdown of organic matter under anaerobic conditions. In well-oxygenated streambeds, denitrification is of little consequence, but in deep sediments or in oxygen depleted streams, denitrification can be more important, occasionally leading to an accumulation of ammonia.

Nutrient Concentrations in Rivers and Streams

River chemistry is highly variable over time and space, making nutrient concentrations difficult to use as a predictor of biological activity and overall water quality. Where human influence is thought to be minimal, such as in small temperate streams or large tropical rivers, natural levels of nutrients can be estimated. Nutrient concentrations from these systems are very similar to levels found in rainfall, supporting the thought that they are unpolluted. Dissolved phosphorus levels are low, approximately 0.01 mg/L for orthophosphate and 0.025 mg/L for total dissolved phosphate. Levels of DIN are about 0.12 mg/L, nitrate (84%) the major contributor and ammonia (15%) and nitrite (1%) making lesser contributions. It is important to note that human activity can dramatically influence nutrient concentrations in rivers through industrial emissions, sewage and agricultural inputs, and other alterations to watersheds that facilitate the delivery of nutrients from the landscape. Non point nutrient pollution is currently a topic of major interest in addressing river water quality. For an introduction to this topic read "Nutrients in the Mississippi River" at **http://water.usgs.gov** and "Sediments and Nutrients in the Mississippi" at **www.americanrivers.org**.

It is normal to find higher nutrient concentrations at downstream sites along large rivers primarily due to increasing human influence. Nutrient concentrations also vary seasonally due to seasonal hydrologic regimes, the growing season, and seasonal variation in human inputs. If the input of a nutrient is relatively constant it is normal then to find that low flows will concentrate the nutrient and high flows will dilute it.
Uptake by organisms can also influence nutrient concentrations and can, for example, explain why summer nutrient concentrations can be extremely low.

Land use has been shown to clearly influence nutrient levels in streams. For example, as land loses forest cover, nitrogen and phosphorus levels increase, with nitrogen levels increasing to a greater degree.

Nitrogen:Phosphorus Ratios

The ration of nitrogen to phosphorus in water indicates which nutrient is likely to limit algal growth. In algal tissues carbon, nitrogen, and phosphorus are found in a very consistent ratio of atomic weights, approximating 106:16:1. This indicates that if nitrogen to phosphorus ratios fall below 16:1 algae will become limited by low nitrogen availability. Conversely, if N:P ratios exceed 16:1 algae will be limited by phosphorus availability. When ratios are between 10:1 and 20:1, evidence indicates that limitation by both nutrients is occurring.

It is more common to find N:P ratios exceeding 16:1, indicating that nitrogen is less commonly a limiting nutrient than phosphorus. This varies regionally, however, with eastern streams more commonly showing high nitrogen levels and phosphorus limitation (high N:P values), and western streams showing nitrogen limitation and relatively higher phosphorus levels (low N:P values).

Nutrient Spiraling

As a nutrient molecule travels downstream it changes form, from being available as a dissolved nutrient, assimilated into living tissue, possibly passing through several links in the stream´s food web, being released via excretion or decomposition, and re-entering the pool of available, dissolved nutrients. As this process occurs in running waters it is important to keep in mind that transport downstream is simultaneously occurring - thus conceptually making it spiral-like in nature (Webster and Patten, 1979).

Understanding nutrient spiraling requires quantifying the distance that nutrient molecules travel within a river or stream. This is usually estimated by measuring the uptake rate of nutrient molecules and the distance traveled. The spiraling length (S) is the average distance a nutrient molecule travels downstream during one cycle. The cycle begins with the availability of the nutrient in the water column in inorganic form, and includes the distance traveled in the water (S_w) until its uptake (U) and assimilation by an organism where the nutrient becomes part of an organic molecule. Additional distance traveled as part of the biota (S_b) completes the distance as the nutrient atom is re mineralized and released (Newbold, 1992).

$$S = S_w + S_b$$

Nutrient isotopes such as ^{32}P are commonly used to track dissolved nutrients along their spiraling path.

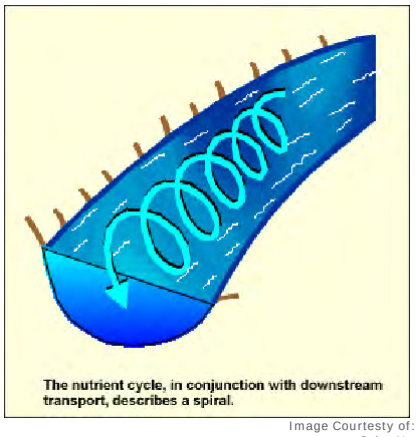


Image Courtesty of: Hebert, P.D.N, ed. Canada's Aquatic Environments [Internet]. CyberNatural Software, University of Guelph. Revised 2002.
www.aquatic.uoguelph.ca

The distance traveled in the biota (S_b) can be subdivided in various ways. A nutrient atom is likely to be incorporated initially into an autotroph associated with the streambed and then be consumed by a microbe or benthic invertebrate before eventually being released. As many as 12 compartments have been used to track the fate of nutrient molecules in the water column and the biota, including: the water column, coarse particulate organic matter, benthic and suspended fine particulate organic matter, Aufwuchs, and an array of consumer compartments, including benthic macro invertebrates (Newbold, et al., 1983a).

Newbold, et al. (1981) found that ^{32}P traveled a total distance of 193 m in a small Tennessee woodland stream, 167 m of the total distance in the water column and 26 m within the biota. Spiraling length can be influenced by many things, some of which are abiotic, including; physical-chemical transformations, hydrologic regimes, and sediment characteristics. Other influences are biotic in nature, including: abundance of periphyton, abundance of heterotrophic microbes, uptake rates, and the composition of the animal community. Hydrologic influences may be seasonal or annual. Low flow conditions, especially when combined with a high ratio of streambed area to channel volume, favor retention of nutrients within a stream segment. High flow conditions favor export from a stream segment, increasing spiraling distance. Retention of nutrients can be enhanced (downwelling) or reduced (upwelling) by factors that favor interaction between the water column and streambed.

Animal communities play a variety of roles in nutrient cycling. Direct consumption of periphyton, microbes, and other animals reduces standing stock of such organisms and may serve to stimulate or reduce their productivity depending upon the severity of the reduction in standing stock. Movements and migrations of animals can influence nutrient spiraling as well. Insect emergence can reallocate nutrients within the stream or, perhaps, remove nutrients from a stream if the emerging insects move a great enough distance. Spawning migrations by fish can move significant amounts of nutrients, enough to demonstrate assimilation of phosphorus and carbon from the fish into periphyton, macroinvertebrates, and fish following the death and decomposition of the migratory, spawning fish (Kline, et al, 1990).

NEXT PAGE
PREVIOUS PAGE

http://www.waterontheweb.org
date last updated:

What is a Watershed?

A watershed – the land area that drains to one stream, lake or river – affects the water quality in the water body that it surrounds. Like water bodies (e.g., lakes, rivers, and streams), individual watersheds share similarities but also differ in many ways. Every inch of the United States is part of a watershed – in other words, all land drains into a lake, river, stream or other water body and directly affects its quality. Because we all live on the land, we all live in a watershed — thus watershed condition is important to everyone.

Watersheds exist at different geographic scales, too. The Mississippi River has a huge watershed that covers all or parts of 33 states. You might live in that watershed, but at the same time you live in a watershed of a smaller, local stream or river that flows eventually into the Mississippi. EPA's healthy watersheds activities mainly focus on these smaller watersheds.

What is a Healthy Watershed?

A healthy watershed is one in which natural land cover supports:

- dynamic hydrologic and geomorphologic processes within their natural range of variation,
- habitat of sufficient size and connectivity to support native aquatic and riparian species, and
- physical and chemical water quality conditions able to support healthy biological communities.

Natural vegetative cover in the landscape, including the riparian zone, helps maintain the natural *flow regime** and fluctuations in water levels in lakes and wetlands. This, in turn, helps maintain natural geomorphic processes, such as sediment storage and deposition, that form the basis of aquatic habitats. Connectivity of aquatic and riparian habitats in the longitudinal, lateral, vertical, and temporal dimensions helps ensure the flow of chemical and physical materials and movement of biota among habitats.

A healthy watershed has the structure and function in place to support healthy aquatic ecosystems. Key components of a healthy watershed include:

- intact and functioning headwater streams, floodplains, riparian corridors, biotic refugia, instream habitat, and biotic communities;
- natural vegetation in the landscape; and
- hydrology, sediment transport, fluvial geomorphology, and disturbance regimes expected for its location.

*A stream's *flow regime* refers to its characteristic pattern of flow magnitude, timing, frequency, duration, and rate of change. The flow regime plays a central role in shaping aquatic ecosystems and the health of biological communities. Alteration of natural flow regimes (e.g., more frequent floods) can reduce the quantity and quality of aquatic habitat, degrade aquatic life, and result in the loss of ecosystem services.

Are Healthy Watersheds Very Common?

Unfortunately not. Healthy watersheds are uncommon, particularly in the eastern U.S. as well as in most other parts of the nation that are urbanized, farmed, or mined. Large tracts of protected wildlands, mostly in the western U.S., are where most healthy watersheds can be found. However, some healthy watersheds exist in many regions of the country where water pollution has been prevented or well controlled, and where communities maintain the benefits of their clean waterways.

How Might Healthy Watersheds Affect Me?

You may potentially benefit from healthy watersheds in numerous ways, generally unseen and unrecognized by the average citizen:

- Healthy watersheds are necessary for virtually any high quality outdoor recreation sites involving the use of lakes, rivers, or streams. Great fishing opportunities are usually due to healthy watersheds that surround the waters that people love to fish.
- Your drinking water, if it comes from a surface water source, might be substantially less expensive to treat, if a healthy watershed around the water source filters pollution for free.
- Your property values may be higher, if you are fortunate enough to reside near healthy rather than impaired waters.

You and your community's quality of life may be better in these and other ways due to healthy watersheds; now, imagine how unhealthy watersheds might affect you as well.

Why Do Watersheds Need to Be Protected?

Healthy watersheds not only affect water quality in a good way, but also provide greater benefits to the communities of people and wildlife that live there.

A watershed – the land area that drains to a stream, lake or river – affects the water quality in the water body that it surrounds. Healthy watersheds not only help protect water quality, but also provide greater benefits than degraded watersheds to the people and wildlife that live there. We all live in a watershed, and watershed condition is important to everyone and everything that uses and needs water.

Healthy watersheds provide critical services, such as clean drinking water, productive fisheries, and outdoor recreation, that support our economies, environment and quality of life. The health of clean waters is heavily influenced by the condition of their surrounding watersheds, mainly because pollutants can wash off from the land to the water and cause substantial harm.

Streams, lakes, rivers and other waters are interconnected with the landscape and all its activities through their watersheds. They are influenced by naturally varying lake levels, water movement to and from groundwater, and amount of stream flow. Other factors, such as forest fires, stormwater runoff patterns, and the location and amount of pollution sources, also influence the health of our waters.

These dynamics between the land and the water largely determine the health of our waterways and the types of aquatic life found in a particular area. Effective protection of aquatic ecosystems recognizes their connectivity with each other and with their surrounding watersheds. Unfortunately, human activities have greatly altered many waters and their watersheds. For example:

- Over the last 50 years, coastal and freshwater wetlands have declined; surface water and groundwater withdrawals have increased by 46%; and non-native fish have established themselves in many watersheds (Heinz Center, 2008).
- A national water quality survey of the nation's rivers and streams showed that 55% of the nation's flowing waters are in poor biological condition and 23% are in fair biological condition (U.S. EPA, 2013). Compared to a 2006 survey (U.S. EPA, 2006), which only assessed wadeable streams, 7% fewer stream miles were in good condition.
- Nearly 40% of fish in North American freshwater streams, rivers and lakes are found to be vulnerable, threatened or endangered; nearly twice as many as were included on the imperiled list from a similar survey conducted in 1989 (Jelks et al., 2008)
- Rainbow trout habitat loss from warmer water temperatures associated with climate change already has been observed in the southern Appalachians (Flebbe et al., 2006).

Why is EPA Concerned with Healthy Watersheds?

One of EPA's most important jobs is to work with states and others to achieve the Clean Water Act <https://epa.gov/laws-regulations/summary-clean-water-act>'s primary goal – restore and maintain the integrity of the nation's waters. Despite this law's many pollution control successes, tens of thousands of streams, rivers and lakes have been reported as still impaired. The great majority of these involve pollution sources in their watersheds – the land area that surrounds and drains into these waters. Knowing the conditions in watersheds is crucial for restoring areas with degraded water quality, as well as protecting healthy waters from emerging problems before expensive damages occur.

Achieving the Clean Water Act's main goal depends on having good information about watersheds – their environmental conditions, possible pollution sources, and factors that may influence restoration and protection of water quality. EPA is investing in developing scientifically sound and consistent data sources, and making this information public and easily accessible to the wide variety of our partners working toward clean and healthy waters.

What is Being Done to Protect Healthy Watersheds?

A very wide range of activities could be called healthy watersheds protection. These may include regulatory and non-regulatory approaches. EPA's healthy watersheds protection activities are nonregulatory. Approaches used at state and local level could be either. The private sector is also actively involved in many forms of protection.

After decades of focusing almost exclusively on restoring impaired waters, EPA created the Healthy Watersheds Program (HWP) to bring more emphasis to proactively protecting high quality waters, following the Clean Water Act (CWA)'s objective "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The HWP takes a non-regulatory, collaborative approach to maintaining clean waters by supporting EPA and its partners in their efforts to identify, assess and protect watershed health through Clean Water Act programs. This approach is essential for addressing future threats such as:

- emerging water quality problems,
- loss and fragmentation of aquatic habitat,
- altered water flow and availability,
- invasive species, and
- climate change.

How is a Healthy Watershed Identi ied?

There are literally hundreds of watershed characteristics (such as environmental traits, sources of degradation, and community factors) that may influence environmental health and quality of life, for better or worse. Identifying and comparing these characteristics is known as watershed assessment. This process is the main way to compare watershed condition across large areas such as states, and find the healthy watersheds among the rest.

Session 5: *Understand Your Watershed: Hydrology and Geomorphology*

In This Training Session

- Introduction
- What is a watershed?
- What is hydrology
  - Components of the hydrologic cycle
- Groundwater/surface water interactions
  - Groundwater recharge and discharge zones
  - Gaining and losing stream reaches
  - Groundwater and wetlands interactions
- Streamflow
  - Streamflow and hydrographs
  - Stream order
- Geomorphology – the shape of a river
  - Channel shape and function
  - Channel equilibrium
  - Shape depends on ten variables
  - Stream classification predicts shape
  - Why stream classification matters
- Connectivity
  - River Continuum Concept
  - Physical changes in the stream channel affect connectivity
  - Changes in land use affect connectivity
- Take a holistic approach to your TMDL study
- References

Acronyms

BMP - Best management practices
ET - Evapotranspiration
MDNR - Minnesota Department of Natural Resources
TMDL - Total Maximum Daily Load
USEPA - United States Environmental Protection Agency

Introduction

A watershed is an identified geographical area that drains to a common point such as a river, wetland, lake or estuary. Watersheds or subwatersheds are the common physical boundary used to study an impaired river or stream. Watersheds are useful physical boundaries within which to study an impaired waterbody since they integrate the complex physical, chemical and biological processes that ultimately influence waterbody health (Davenport, 2003).

The physical processes, which consist of the hydrologic and geomorphorphic forces within a watershed, are the focus of this chapter. These processes are often the primary factors that influence the health of a waterbody and are therefore must be carefully examined when conducting a TMDL study.

Understanding hydrology (the science of water) and geomorphology (the study of geologic forces that shape the landscape) and their application at various watershed scales is key to understanding water quality impairments. At the most basic level, this involves understanding the hydrologic cycle (also know as the water cycle) as the source of all water at a global, regional and local watershed scale. At a more complex level, it means understanding the unique interplay of the groundwater, surface water, topography, geologic forces and living things within a specific watershed. **Without this understanding, efforts to diagnose a waterbody impairment and to restore beneficial uses will likely prove ineffective.**

This chapter focuses on the basic principles of hydrology and geomorphology and how they interact to affect water quality at a watershed scale. Given the complexity of these two disciplines and the many linkages between them, presenting a general overview of important concepts and principles is challenging at best. Entire books have been written about specific principles within hydrology, for example. This chapter presents a simple overview of the basic principles and concepts within these two disciplines as they relate to watershed management.

This chapter provides only the most essential concepts, intended to stimulate more thorough discussions among you and your colleagues. For more in-depth, complete information on the physical processes within a watershed, we recommend the following resources:

***Hydrology and the Management of Watersheds*, 2003, Kenneth N. Brooks, et. al.**

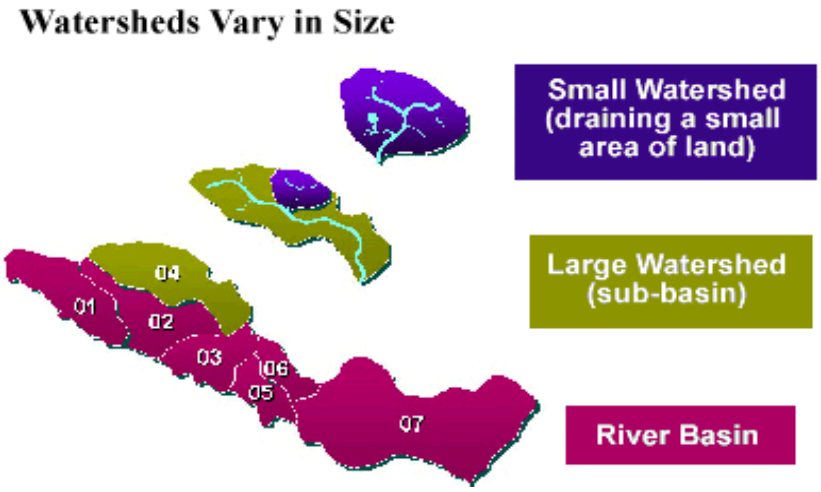
***Watershed Hydrology*, 1996, Peter Block.**

***Environmental Hydrology*, 2004, Andrew D. Ward and Stanley Trimble.**

***Eco-Hydrology*, 1999, Andrew Baird and Robert Wilby.**

What is a Watershed?

A watershed can be defined as all of the land area that drains to a common waterway, such as a stream, lake, estuary or wetland (EPA, 2005). A watershed can be very large (e.g. draining thousands of square miles to a major river or lake or the ocean), or very small, such as a 20-acre watershed that drains to a pond. A small watershed that nests inside of a larger watershed is sometimes referred to as a subwatershed (EPA, 2007).



Source: USEPA, 2007

There are maps and computer databases you can turn to that have watershed boundaries already delineated--particularly for larger basins and watersheds. EPA has a popular internet site called "Surf Your Watershed" found at: http://www.epa.gov/surf (EPA, 2007). Contact MPCA for more detailed information about your watershed.

Streamflow

Streamflow and hydrographs

Streamflow is water moving/flowing in a stream or river. Flow rates vary over time due to components of the hydrologic cycle and factors affecting those components. Flow can be depicted as a hydrograph where flow rate is plotted against time. Hydrographs show the length of time it takes for streamflow to peak after a precipitation event. The shorter the lag time between the on-set of a precipitation event and the peak discharge, the more "flashy" surface runoff is and the higher its erosive potential is.

The variability of watersheds and climatic factors means that the shape of hydrographs can vary tremendously. The main factors affecting the shape of a hydrograph are:

- climatic conditions (duration, magnitude of precipitation, etc);
- watershed drainage characteristics (topography);
- soil characteristics (porosity)
- land use (changes from permeable to impermeable cover)

Figure 8 (below) compares two different hydrographs. The dark line represents a hydrograph for a stream which experiences rapid responses from rainfall events. Note the sharp increases in streamflow after a precipitation event, as well as the rapid recession of the flow. This particular hydrograph is for a watershed that is characterized by row crop agriculture where during several months of the year, vegetative cover is minimal.

In contrast, the light line represents a hydrograph for a stream which responds to precipitation events with a slow, less dramatic increase in flow. In this instance, the watershed has stable vegetative cover which increases infiltration and decreases the amount of runoff that can become streamflow.

Hydrographs allow technical staff to see streamflow patterns within the watershed. For this reason, stormflow hydrographs, those that depict stream flow patterns, quantity of flow, flow rate changes, duration of flow levels, etc.) are of particular interest in almost all TMDL studies. The rate, duration and rapidity of change in streamflow are the keys to understanding stream and pollutant transport process within a watershed.

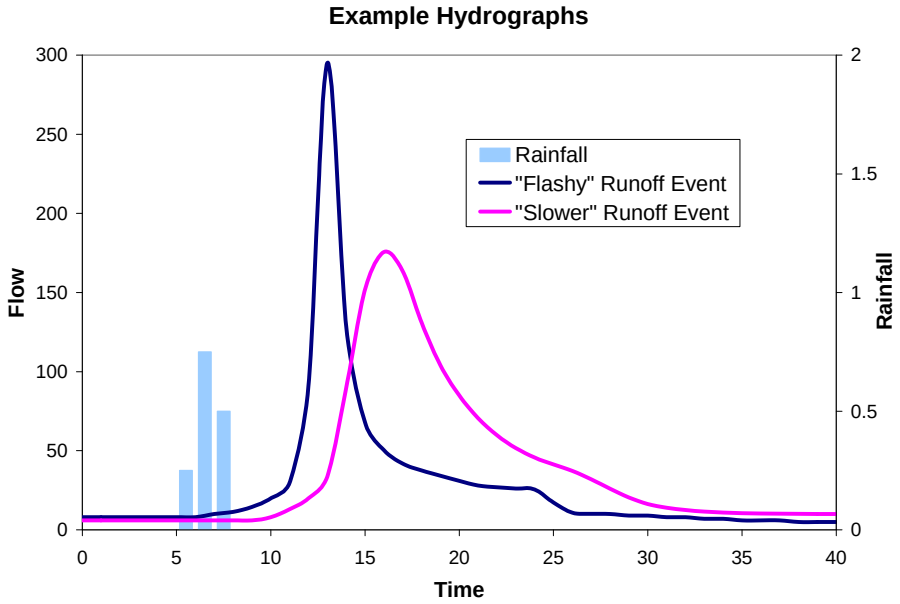


Figure 8: Sample Hydrograph

Influences on Streamflow

Variability in streamflow (across seasons) is natural and necessary to the healthy functioning of river systems. Aquatic life has successfully evolved and adapted over time to significant differences in flow, such as drought or flooding. However, human influences on the landscape (development, dams, farming, etc.) can disrupt the naturally cyclic nature of streamflow, upsetting the natural processes that have evolved over time (MDNR, 2005).

There are a number of important conditions that influence how much of the precipitation that falls within a watershed becomes streamflow. These are briefly discussed below.

1. Climatic conditions and the amount of precipitation within a geographic area are the most important factors affecting streamflow. Snowmelt and spring storms often produce one of the highest annual peak streamflows. During the summer, streamflow typically declines because of the consumption of soil water by vegetation. During these warm, dry months, streamflow is often maintained by groundwater and wetlands (base flow). During the fall, when ET drops off, water levels in lakes, wetlands and streams will rise. If new precipitation is added, peak flows can occur. During winter months, when surface water and soil water freeze, streams are typically fed by warmer groundwater discharge.

Streamflow can also vary significantly across years as a result of natural variations in the weather. Long-term weather patterns, such as drought and wet periods, cause changes in streamflow patterns from year to year. The natural variability between drought and flood years can be important to the healthy functioning of river ecosystems. Flooding can help to form floodplains; spread new, rich, alluvial soils; clear organic debris, prevent encroachment of streamside vegetation; and recharge riverine wetlands. On the other hand, drought, while devastating in the short term, can help to reinvigorate floodplain wetlands and to compact/consolidate alluvial sediments, among other benefits (MDNR, 2005).

2. The Topography (slope of land and the stream channel) within the watershed is a major influence on streamflow. Steep, hilly areas of a watershed drain quickly to the stream, while in flat terrain, water drains at a much slower and more even rate.

The amount of water stored in soils above the stream channel can also influence the amount of streamflow due to displacement. Displacement could be compared to what happens when a garden hose is turned on after it has been sitting in the sun. Initially, the water coming from the hose is warm. Eventually warm water is displaced by cold water from the well. Similarly, new water falling on the uplands surrounding a stream will eventually displace existing subsurface water near the stream. Interflow is that part of excess precipitation that infiltrates soils in the uplands but arrives at the stream over a relatively short period of time. Displacement of subsurface flow can account for a major source of streamflow in some types of watersheds, especially forested watersheds (Brooks, et. al, 2003)

3. Soil characteristics and conditions can affect streamflow. The physical properties of some soils will encourage infiltration and discourage surface runoff, while other soils will have diminished infiltration capacities that result in greater surface runoff that can increase streamflow.

The rate at which precipitation enters the soil surface depends upon several factors, including texture, structure, surface conditions, amount of organic matter, soil depth, presence of large pores (macropores), antecedent soil moisture, etc. The size and interconnection of pores within soils greatly affects how much infiltration will occur at any point in time. Fine-textured soils such as clay have smaller pores and do not infiltrate water as quickly as medium- or coarse-textured soils would. (Brooks, 2003).

Where there is less infiltration, greater surface runoff typically occurs, resulting in a greater and more rapid rise in streamflow in a watershed. When infiltration capacity is high, streamflow will rise more gradually and peak at lower levels.

4. Land cover/land uses can also have a major influence on the amount of precipitation that becomes streamflow. Human activities greatly affect streamflow by decreasing the amount of vegetation on the land. Below are examples of human activities that reduce vegetative cover in a watershed or subwatershed:

- Wetland drainage
- Agricultural drainage
- Home construction
- Road building
- Agriculture
- Clear-cutting of forests

Loss of perennial vegetation influences the following changes in a watershed:

- ET
- speed and intensity of runoff.
- the infiltration capabilities of soils
- the retention or detention storage in the watershed
- surface runoff and streamflow
- surface runoff and decreased movement of water to underground aquifers.

In contrast, abundant vegetation slows runoff, encourages infiltration, and consequently increases the amount of water stored in the watershed. For example, surface runoff moving over bedrock or barren soils moves more quickly to the stream than it would if moving over thick grasses or through a forest under-story.

When organic matter is removed from the land due to cultivation, clear-cutting of forests, wetland drainage, urban development, channelization of streams or other land uses, the amount and speed of surface runoff will increase. Consequently, the potential for increased loadings of nonpoint source to surface water increases.

The presence or absence of vegetation can have a significant effect on water quality in many Minnesota streams. This becomes evident when one looks closely at differences in streamflow over a cropping season.

During the spring and early summer, when crops have not yet been planted and soils are bare, precipitation events typically cause a rapid rise in streamflow due to rapid surface runoff. Hydrographs peak and recede quickly under these conditions.

As the summer progresses and crops become well-established, precipitation events cause only a modest increase in streamflow. Rainfall is largely intercepted and transpired by the crops and the hydrograph peaks at a much lower flow rate. The majority of precipitation that falls, instead of running off land surfaces to the stream, is instead infiltrated to groundwater aquifers, used by plants or returned back to the atmosphere through ET. Maintaining good vegetative cover is an important and effective tool for improving water quality.

B. Geomorphology – The Shape of a River

While physical watershed factors affect hydrology, hydrology also affects some of the physical characteristics of a waterbody and its watershed. Geomorphology is the study of the geologic forces that shape our landscape largely through the action and effects of moving water. Physics can explain why some rivers flow slowly, meandering through a prairie landscape, while others rush quickly through rocky channels and over waterfalls. Large-scale geologic forces such as volcanoes, earthquakes, glaciers, and deposition are all forces that can form a landscape over which water flows. Water flowing over different landscapes, typically responds differently (MDNR, 2005).

Smaller-scale, geologic forces also affect the landscape and the shape of the waterbodies in it. Stream channels form as a result of the interplay between hydraulic forces (erosion, deposition, and resuspension of sediment) and the materials forming the streambed. Stream channels and the water that flows through them (each defined by stream width, depth, velocity, cover and substrate) then determine habitat conditions for aquatic organisms (Annear, 2004).

Channel Shape

Nearly all channels are formed, maintained, and altered by the water and the sediment they carry. Minnesota stream channels that are not impacted by human development are gently rounded in shape and roughly parabolic, but channel forms can vary greatly. Figure 9 represents a cross section of a typical Midwestern stream channel.

A stream channel is comprised of an area that contains continuously or periodically flowing water that is confined by stream banks. The unvegetated sloped bank is called a **scarp**. The deepest part of the channel is called the **thalweg**. The dimensions of a channel cross section are determined over time and through the continuous interaction between water and the landscape.

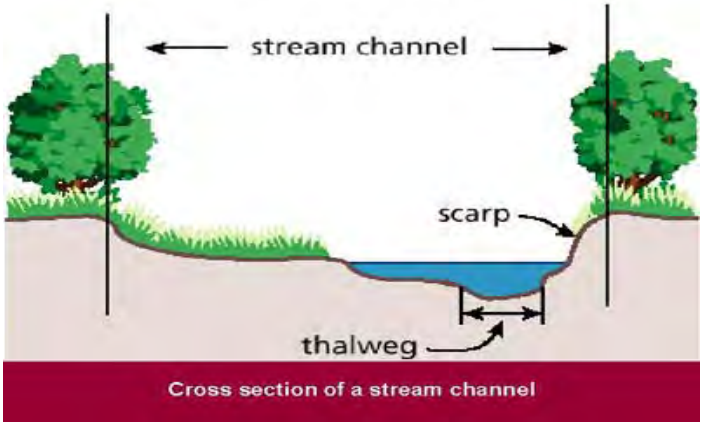


Figure 9: Cross section of a stream channel
(EPA, 2007)

Floods are not the most important flow situation affecting the shape and condition of a stream channel. Rather, bank-full flows typically define a river's shape. Bank-full refers to the water level stage just as it begins to spill out of the channel into the floodplain. It has been found that this flow typically occurs about once every 2.3 years (averaged over wet and dry years) (MDNR 2005) Bankfull flows are subject to minimal flow resistance and are therefore able to transport the greatest loads of sediment (MDNR, 2005)

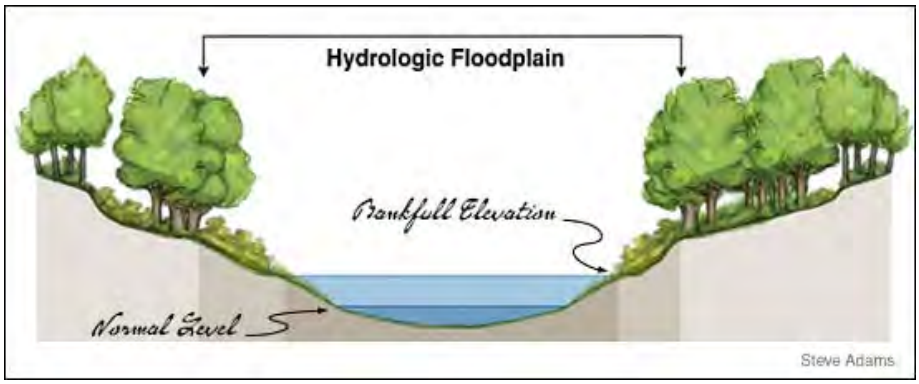


Figure 10: Stream Channel Shape
(MDNR, 2005)

Rivers are constantly changing, but the change can be stable or unstable. Stream morphology expert, Dr. David Rosgen, has identified 10 variables that affect a channel's shape. These variables are determined by the climate and the geology of the area and they interact in predictable and measurable ways.

This classification system helps to predict the form and shape of a stream when there have been changes in a watershed's hydrologic regime due to straightening, increased erosion from upland areas, etc. Rosgen's classification system brings many pieces of stream data together in a useable format. Rosgen's classification system allows watershed managers to predict a stream's behavior from measurements of its appearance. This can be useful when developing an impact assessment for a stream and when developing restoration strategies as well.

Rosgen's classification system considers:

The movement of flow through a stream channel:

- Channel width
- Channel depth
- Water velocity
- Channel slope
- Channel roughness
- Sediment load
- Sediment size
- Material shear stress
- Vegetation
- Channel discharge

(MDNR, 2005)

Changes in any of these variables will affect degradation (sediment removal) or aggradation (sediment deposition) and thereby the channel form.

Aggradation and degradation within a stream channel are important concepts to understand since these are the main mechanisms for sediment storage and release. When sediment supply exceeds stream energy, aggradation occurs (Brooks 2003). Aggradation typically results in the deposition of course material first, while finer particles move further downstream. The streambed begins to rise slowly over time, often resulting in water flowing over the banks (Brooks, 2003).

Degradation takes place slowly under normal conditions. When stream energy exceeds sediment supply, degradation occurs. If the stream channel is in disequilibrium, then degradation can occur more rapidly. Channel cross-sections of degrading stream system tend to be V-shaped due to the differences in flow resistance across the channel. More material is picked up and carried downstream by erosive, concentrated flows, causing a V-shaped channel (Brooks, et. al, 2003).

A healthy stream with good water quality need not be sediment-free. Some sediment deposits are normal and expected. Channels are always changing whether or not they are in equilibrium. The goal is for aggradation and degradation to be in dynamic equilibrium within the channel. Channel equilibrium involves the interplay of four basic factors:

1. Sediment discharge
2. Sediment particle size
3. Streamflow
4. Stream slope

Lane (1955) showed this relationship qualitatively in this way:

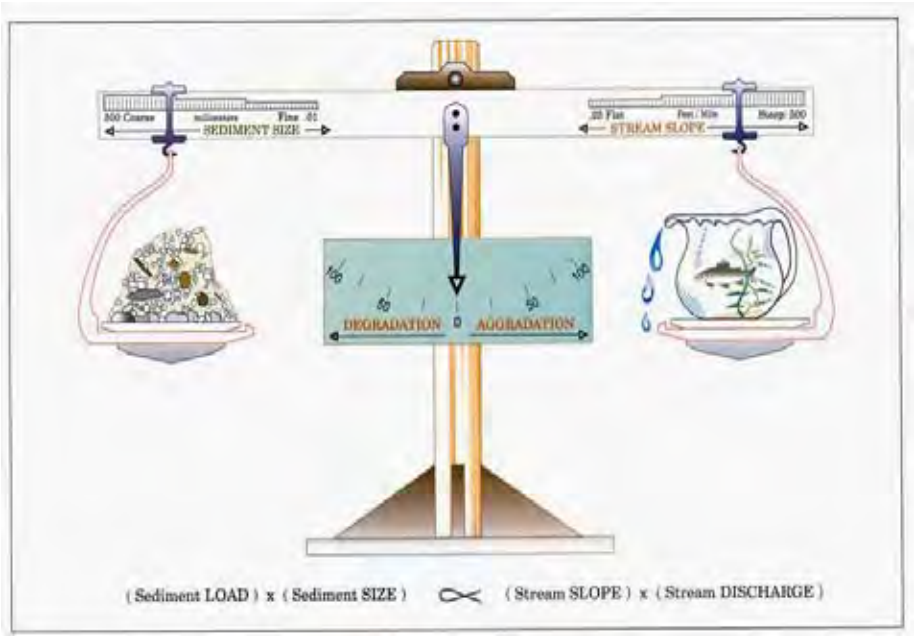


Figure 11: Relationships involved in maintaining a stable channel balance (from Lane 1955, based on Rosgen 1980)

The equation is shown here as a balance, with sediment load on one weighing pan and streamflow on the other. The hook holding the sediment pan can slide along the horizontal arm to adjust according to sediment size. The hook holding the streamflow side can adjust according to stream slope.

Channel equilibrium occurs when all four variables are in balance. If a change occurs, the balance will temporarily be tipped and equilibrium lost. If one variable changes, one or more of the other variables must increase or decrease proportionately, if equilibrium is to be maintained. For example, if channel slope is increased (e.g., by channel straightening) and streamflow remains the same, either the sediment load or the size of the particles must also increase. Likewise, if flow is increased and the slope stays the same, sediment load or sediment particle size has to increase to maintain channel equilibrium. Under the conditions outlined in these examples, a stream seeking a new equilibrium will tend to erode more of its banks and bed, transporting larger particle sizes and a greater sediment load (EPA, 2007).

The stream balance equation is useful for making qualitative predictions concerning channel impacts due to changes in surface runoff or sediment loads from within the watershed. Quantitative predictions, however, require the use of more complex equations (EPA, 2007).

Stream Classification

The types and amounts of sediment traveling throughout a stream system will vary, as will the aquatic life living in them. Within a watershed, depending on historic land use activities, geology, topography, soils, etc., many different channel shapes can exist. Stream systems are inherently complex and challenging to understand. By placing streams into a classification system, we can better comprehend the processes that influence the pattern and character of the stream.

The types and amounts of sediment traveling throughout a stream system will vary, as will the aquatic life living in them. Within a watershed, depending on historic land use activities, geology, topography, soils, etc., many different channel shapes can exist. Stream systems are inherently complex and challenging to understand. By placing streams into a classification system, we can better comprehend the processes that influence the pattern and character of the stream.

Stream classification can be helpful in determining:

- The character of the watershed when it was undisturbed
- Current channel conditions
- How the river is changing to accommodate changes in flow volumes, channel alteration, etc.
- Sensitivity to disturbance
- Sediment supply
- Potential for stream bank erosion
- Recovery potential

Such information is helpful when linking past and present land uses to channel changes. Ultimately, this information can also be helpful when planning restoration activities for the waterbody.

Using a stream classification system provides a systematic approach to characterizing the shape and condition of watersheds, yielding consistent results what allow comparisons with other streams (Brooks, et. al., 2003).

There are several stream classification systems available for use. The Rosgen stream classification system is commonly used in Minnesota. Figure 12 presents an overview diagram of Rosgen's stream classification system. Rosgen classifies streams by morphological characteristics. Generally speaking, the greater the downward slope of a stream, the straighter and deeper it tends to be. As downward slopes decrease, rivers tend to become more sinuous (meandering), wider and shallower.

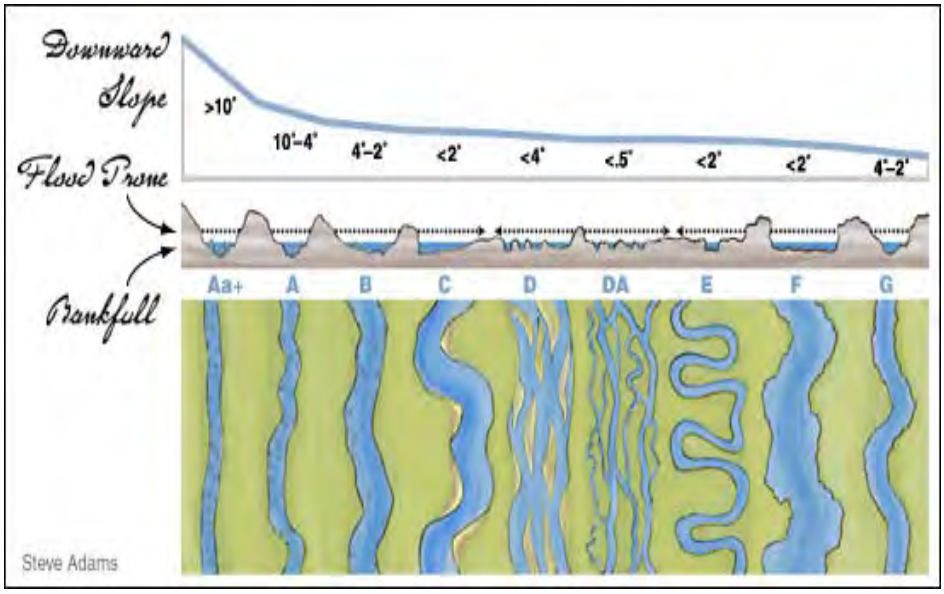


Figure 12: Rosgen Stream Classification (MDNR, 2005)

Photographs of several examples of the types of channel shapes commonly seen in Minnesota are shown below.

A prairie stream is a highly meandering, low-gradient waterbody. It is nearly as deep as it is wide.

Photo: Pat Baskfield, MPCA

A bedrock stream is a steep, fairly straight stream flowing over resistant bedrock. The stream will be much wider than it is deep.

Photo: ©Explore Minnesota Tourism

A ditch is narrow, straight and deep.

Photo: Joe Magner, MPCA

The types and amounts of sediment traveling through these streams will differ, as will the fish and invertebrates living within them. Within a watershed, depending on historic land use activities, geology, topography, soils, etc., many different channel shapes can exist.

Stream systems are inherently complex and challenging to understand. By placing streams into a classification system, we can better comprehend the processes that influence the pattern and character of the stream.

(Repeated from above) Stream classification can be helpful in determining:

- the character of the watershed when it was undisturbed
- current channel conditions
- how the river is changing to accommodate changes in flow volumes/duration, channel alteration etc.
- sensitivity to disturbance
- recovery potential
- sediment supply
- potential for stream bank erosion, etc.

Such information is helpful when linking past and present land uses to channel changes. Ultimately, this information can also be helpful when planning restoration activities for the waterbody.

Connectivity: Linking the Physical Watershed and Stream Channel to Biological Systems

Figure 13: Stream Connectivity (MDNR, 2005)

River Continuum Concept

The River Continuum Concept (Vannote et. al., 1980) describes the evolving patterns and interactions of energy inputs, the physical environment and biological communities as one moves from the source of a stream toward its mouth (longitudinal connectivity).

Developed by a group of stream ecologists, the Continuum Concept hypothesizes that streams exist in a continuous and fairly predictable pattern along their entire length. Generally, as one moves downstream, the physical environment and the biological communities that live there increase in complexity. Stream organisms change predictably along the length of the stream in response to changing food sources (MDNR, 2005).

As one moves from the headwaters of a stream to its mouth, one can find variety with respect to channel width and depths, substrates, and water velocities, all supporting a wide array of aquatic organisms. Therefore, it is critical to study as much of the stream system as possible, not just certain reaches.

Headwaters, midstream and lower reaches are the home to different species of fish and invertebrates, all taking advantage of different habitat niches within the same stream. Biological monitoring results collected as part of a TMDL study can be reviewed and better understood within the context of this predictable pattern of stream evolution.

Understanding connectivity within a stream system should be an important goal of any TMDL studies. Rather than merely focusing on a single impairment on a small reach of a subwatershed, we should instead seek to understand the complex, ever-changing system that it is part of.

Physical Changes in the Shape of Rivers Affects Connectivity

Radical changes in the shape of a river will ultimately destroy connectivity within the stream system. A good example of this is the process of channeling streams. Stream channelization has been a common practice within many watersheds across Minnesota.

Example: Stream Channelization	Consequences
	1) Erosion of streambed upstream 2) Downstream sedimentation 3) Increased peak flows 4) Downstream flooding 5) Reduced biodiversity

Changes in Land use Affect Connectivity

Large-scale development projects contribute to habitat loss and changes in species diversity. The following human development projects can all decrease connectivity within a stream:

- Dams – block movement and migration of fish, block the downstream movement of sediment, disrupt nutrient and energy spiraling, and modify thermal and flow regimes
- Construction activities within the watershed (highways, parking lots, other large impervious surfaces) can greatly increase surface runoff into nearby waterways, which can divert water from recharging groundwater aquifers.
- Water appropriations can reduce stream flows and change the stream's equilibrium.

In addition, the secondary effects of development projects in a watershed also affect connectivity:

- Persistent chemical or thermal pollution may create a barrier within the river that disrupts longitudinal connectivity.
- Invasive species can decimate native species, disrupting part of the river's continuum of biota.

Land use practices and other human influences can all impact connectivity within a stream system. Consider that changes in one natural process or system are likely to impact others. Therefore, it is important to keep linkages between land forms, hydraulic forces and biota in mind. Connectivity provides a holistic framework for understanding the complexity and interrelatedness of all stream systems.

2.1 BACKGROUND

Water Quality Standards Handbook, DRAFT CHAPTER 2: Designated Uses, U.S. EPA

211 Designated Uses and Why They are Important

40 CFR 131.3(f) defines designated uses as "those uses specified in water quality standards for each water body or segment whether or not they are being attained." Designated uses represent each state's or authorized Tribe's water quality goals and expectations for its surface waters. Each designated use is protected by an associated level of water quality. Such designated uses can reflect a variety of goals for the waterbody such as recreation in and on the water, protection of human health and aquatic life, irrigation, agriculture, public water supply, and cultural uses of the waterbody.

Section 101(a)(2) of the CWA provides that "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water be achieved..." Therefore, such uses must be protected unless shown to be unattainable. The U.S. Environmental Protection Agency's regulation at 40 CFR 131.10 provides a framework for how a state or authorized Tribe would demonstrate a use specified in CWA Section 101(a)(2) is not attainable. Please see section 2.3 for more discussion.

What are Designated Uses?

Designated uses are "those uses specified in water quality standards for each water body or segment whether or not they are being attained." Designated uses represent each state's or authorized Tribe's water quality goals and expectations for its surface waters. Each designated use is protected by an associated level of water quality. Such designated uses can reflect a variety of goals for the waterbody such as recreation in and on the water, protection of human health and aquatic life, irrigation, and agriculture.

Designated uses do not need to be currently attained to be designated, but rather can represent a state's or authorized Tribe's current or *future* management goals for a waterbody. For example, in anticipation of future population growth, a state or authorized Tribe may designate a waterbody for use as a public water supply. While the state or authorized Tribe does not currently use the waterbody as a source of drinking water, it anticipates the need to use the waterbody for such a use in the future based on projected population growth, and therefore, desires to protect water quality now for this future goal.

States and authorized Tribes have flexibility when establishing their designated uses as long as they meet the requirements of the CWA, 40 CFR Part 131, and other applicable legal requirements. The EPA has found that the clearer and more accurate the designated uses are in describing the water quality goals, the more effective those use designations can be in driving management actions necessary to restore, maintain, and protect water quality. Moreover, designated uses communicate to the public the state's or authorized Tribe's water quality goals for each of its waters. These designated uses are also essential to determine and implement actions necessary to restore and maintain water quality consistent with the objectives of the CWA.

Designated uses are also important because they inform the water quality criteria that states and authorized Tribes must adopt to protect their designated uses.[8] The CWA and 40 CFR Part 131 require establishing and reviewing designated uses and criteria protective of those designated uses through a public process, including a public hearing.[9] The criteria that a state or authorized Tribe adopts define the specific water quality conditions that will protect the designated use. These criteria are essential for determining whether the designated use provides for the protection required by CWA Section 101(a)(2). Clear and accurate designated uses and their associated criteria are foundational elements when implementing key CWA requirements, such as WQBELs for point source dischargers in NPDES permits under CWA Section 402 and TMDLs for waters not meeting applicable WQS under CWA Section 303(d).

Why are Designated Uses Important?

Designated uses communicate to the public the state's or authorized Tribe's water quality goals for each of its waters. These designated uses are essential to determine and implement actions necessary to restore and maintain water quality consistent with the objectives of the CWA.

Designated uses are also important because they inform the water quality criteria that states and authorized Tribes must adopt to protect their designated uses. These criteria are essential when implementing key CWA requirements, such as effluent limitations for point source dischargers in NPDES permits under CWA Section 402, and TMDLs for waters not meeting applicable WQS under CWA Section 303(d).

Determining the designated uses that appropriately reflect the potential for a waterbody involves balancing—within the boundaries established by the CWA and 40 CFR Part 131—environmental, scientific, technical, economic, and social considerations, as well as public input on the desired condition for the waterbody. The EPA can assist the state or authorized Tribe in evaluating these considerations when determining the appropriate designated uses for their waters.

[8] 40 CFR 131.2, 131.3(b), 131.5(a)(2), 131.6(c), and 131.11(a).
[9] CWA Section 303(c)(1) and 40 CFR 131.20(b).

Basic Information about Nonpoint Source

On this Page:

Overview

NPS pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. NPS pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.

Nonpoint source pollution can include:

- Excess fertilizers, herbicides and insecticides from agricultural lands <https://epa.gov/nps/nonpoint-source-agriculture> and residential areas <https://epa.gov/nps/nonpoint-source-urban-areas>
- Oil, grease and toxic chemicals from urban runoff <https://epa.gov/nps/nonpoint-source-urban-areas> and energy production
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks <https://epa.gov/nps/nonpoint-source-hydromodification-and-habitat-alteration>
- Salt from irrigation practices and acid drainage from abandoned mines <https://epa.gov/nps/abandoned-mine-drainage>
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems
- Atmospheric deposition and hydromodification <https://epa.gov/nps/nonpoint-source-hydromodification-and-habitat-alteration>

States report that nonpoint source pollution is the leading remaining cause of water quality problems. The effects of nonpoint source pollutants on specific waters vary and may not always be fully assessed. However, we know that these pollutants have harmful effects on drinking water supplies, recreation, fisheries and wildlife.

Nonpoint Sources vs. Point Sources

The term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act:

> The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

Illustrations of nonpoint and point source pollution along with elements of the hydrologic cycle.
Developed by the EPA, Office of Water, Nonpoint Source Program

Download the above diagram in a screen-reader compatible format: Sources of Pollution Diagram (pdf) <https://www.epa.gov/system/files/documents/2024-11/508_final-nps-diagram_11-18-24.pdf> (2.13 MB, November 2024)

What You Can Do to Prevent Nonpoint Source (NPS) Pollution

In Urban Environments

- Keep litter, pet wastes, leaves and debris out of street gutters and storm drains—these outlets drain directly to lake, streams, rivers and wetlands.
- Apply lawn and garden chemicals sparingly and according to directions.
- Dispose of used oil, antifreeze, paints and other household chemicals properly—not in storm sewers or drains. If your community does not already have a program for collecting household hazardous wastes, ask your local government to establish one.
- Clean up spilled brake fluid, oil, grease and antifreeze. Do not hose them into the street where they can eventually reach local streams and lakes.
- Control soil erosion on your property by planting ground cover and stabilizing erosion-prone areas.
- Encourage local government officials to develop construction erosion and sediment control ordinances in your community.
- Have your septic system inspected and pumped, at a minimum every three to five years, so that it operates properly. Purchase household detergents and cleaners that are low in phosphorous to reduce the amount of nutrients discharged into our lakes, streams and coastal waters.

Forestry

- Use proper logging and erosion control practices on your forest lands by ensuring proper construction, maintenance, and closure of logging roads and skid trails.
- Report questionable logging practices to state and federal forestry and state water quality agencies.

Agriculture

- Manage animal manures to minimize losses to surface water and ground water.
- Reduce soil erosion and nutrient loss by using appropriate conservation practice systems and other applicable best management practices.
- Use planned grazing systems on pasture and rangeland.

  Dispose of pesticides, containers, and tank rinsate in an approved manner.
- Work with conservation partners locally including Soil and Water Conservation Districts to understand local strategies.

Fact Sheet: Introduction to Clean Water Act (CWA) Section 303(d) Impaired Waters Lists

What is a 303(d) list of impaired waters?

The goal of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C §1251(a)). Under section 303(d) of the CWA, states, territories, and authorized tribes, collectively referred to in the Act and here as "states," are required to develop lists of impaired waters. The term "303(d) list" is short for the list of impaired and threatened waters (e.g., stream/river segments, lakes) that all states are required to submit for EPA approval during even-numbered years. The main program result of this process is EPA's national tracking system for impaired waters.

A state's 303(d) impaired waters list is comprised of all waters where the state has identified that required pollution controls are not sufficient to attain or maintain applicable water quality standards. The law requires that states establish a prioritized schedule for waters on the lists, and develop Total Maximum Daily Loads (TMDLs) for the identified waters based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors (40C.F.R. §130.7(b)(4)).

A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards, and an allocation of that load among the various sources of the pollutant. States provide to EPA a long-term plan for completing TMDLs within 8 to 13 years from the first listing of the waterbody. EPA policy allows states to remove waterbodies from their 303(d) list after they have developed a TMDL or made other changes to correct water quality problems.

How do states identify impaired waters?

Regulations say states must evaluate "all existing and readily available information" in developing their 303(d) lists (40 C.F.R. §130.7(b) (5)). Usually due to a lack of resources, most state water quality agencies are able to monitor only a limited percentage of their waters consistently enough to detect water quality problems. Many state agencies use data collected from outside organizations and the public to compile their lists. There are usually quality requirements for data collection and submission before state agencies will consider the data.

How do states submit lists?

In addition to the 303(d) impaired waters list, the CWA requires each state report every two years on the health of *all* its waters, not just those that are impaired. Information from this report, known as the 305(b) report or "biennial water quality report," has historically been used to develop the "threatened and impaired waters" (303(d)) list. Most states compile the data and findings from the 305(b) report and add information from other sources to produce the 303(d) list. EPA recommends that states combine the threatened and impaired waters list with the 305(b) report to create an "Integrated Report," due April 1 of even-numbered years.

Once states submit their 303(d) list to EPA, EPA then has 30 days to approve or disapprove the 303(d) lists. If EPA disapproves a state list, EPA has 30 days to develop a new list for the state; although historically, EPA has rarely established an entire list for a state. Sometimes EPA partially disapproves a list because of omission and adds waters to the state's list.

National Summary of Top 303(d) Listing Impairments

EPA's Assessment and TMDLs Tracking and Implementation System (ATTAINS) provides state-reported data on the condition of monitored surface waters. ATTAINS is the primary result of long-term state and EPA collaboration on tracking, characterizing, and mapping of 303(d)-listed waters. Below is an excerpt showing the top15 causes of impairment for 303(d) listed waters in ATTAINS. Note that one body of water may have single or multiple listed impairment causes.

Causes of Impairment for 303(d) Listed Waters

Description of this table

NOTE: Click on a cause of impairment (e.g. pathogens) to see the specific state-reported causes that are grouped to make up this category. Click on the "Number of Causes of Impairment Reported" to see a list of waters with that cause of impairment.

Cause of Impairment Group Name	Number of Causes of Impairment Reported
Pathogens	10,249
Mercury	7,966
Metals (other than Mercury)	7,164
Nutrients	6,900
Sediment	6,477
Organic Enrichment/Oxygen Depletion	5,989
pH/Acidity/Caustic Conditions	3,756
Polychlorinated Biphenyls (PCBs)	3,286
Cause Unknown - Impaired Biota	3,254
Turbidity	3,062
Temperature	3,025
Pesticides	1,558
Salinity/Total Dissolved Solids/Chlorides/Sulfates	1,470
Cause Unknown	1,237
Noxious Aquatic Plants	998

How does the 303(d) listing process help to improve water quality?

For many states, identifying waters on a 303(d) list is the first step towards achieving water quality goals. Listing a waterbody on a 303(d) list requires states to review their water quality standards, evaluate available monitoring data and determine if adequate controls are in place for point and nonpoint sources of pollutants. States use this information to identify those waters not meeting the applicable water quality standards (referred to as "impaired waters") or having declining trends (referred to as "threatened waters"), after pollution controls are in place. By identifying threatened waters, states take a more proactive "pollution prevention" approach to water quality management.

In many respects, the 303(d) list acts as a "trigger" signaling the need for immediate management actions to address water quality impairments. Section 303(d) of the CWA also requires states to identify those water quality-limited waters needing TMDLs and to organize its list of waters in a prioritized schedule for TMDL development. Using the impaired waters listing process, states have readily available data and determinations on current water quality impairments, and therefore are able to set management priorities for addressing such impairments accordingly. A 303(d) list effectively influences and guides many appropriate courses of action for restoring and protecting the waters of the U.S.

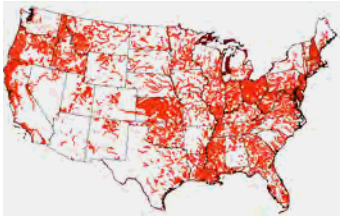
Program Results through 303(d) Listings of Impaired Waters

- **Guidance to States**
  - EPA first provided guidance for states developing 303(d) lists in the 1992 issuance of Guidance for Water Quality-Based Decisions: The TMDL Process.
  - EPA continues to provide guidance to states through various Integrated Reporting Guidances (issued for reporting cycles 2002, 2004, 2006, 2008 and 2010), with the 2006 Integrated Reporting Guidance providing the most comprehensive level of detail on using the 5 categories.
  - Additionally, EPA recognizes unusual listing challenges, such as in listing and addressing waters impaired due to atmospheric sources of mercury, and has developed specific guidance appropriate to these challenges (see: Listing Waters Impaired by Atmospheric Mercury).

- **Timely Submission and Review of 303(d) Lists/Integrated Reports**
  Over the past two years, EPA has worked with states to anticipate and address potential issues with the 303(d) list early on in an effort to streamline the 303(d) list submission process. EPA saw a substantial jump in the number of 303(d) List/Integrated Report submissions for the 2008 Integrated Report Cycle. Over three times as many lists were received by the deadline month compared with the 2006 Cycle. Similarly, EPA has made considerable progress in the amount of time the Agency takes in issuing a final action (approve/disapprove) on a State's list.

- **National Information about 303(d) Listed Waters Online**
  EPA has consolidated several years of states' 303(d) listing into the ATTAINS data system, providing publicly available information on over 40,000 tracked waters and user-friendly access to data at scales from local to statewide to national.

- **National GIS (Mapped) Data on Geo-Referenced Impaired Waters Online**
  EPA indexes state spatial data to the National Hydrography Dataset Plus (NHD*Plus*) to provide a nationally consistent reference layer. The indexed data is housed in EPA's Reach Address Database (RAD). EPA provides access to a static national shapefile of 303(d) listed waters, as well as dynamic access to individual state or watershed-level shapefile downloads as new data become available. The spatial data downloads can be related to tabular data extracted from ATTAINS via the WATERS Expert Query tool.



Additional Resources:

- For more information on **CWA Section 303(d) lists** visit: http://www.epa.gov/owow/tmdl/overview.html
- For more information on **EPA's 303(d) Listing Guidance, including the recommended "Integrated Reporting"** for reporting under Sections 303(d) and 305(b) visit: http://www.epa.gov/owow/tmdl/guidance.html#2
- For a national summary or state-by-state data on listed threatened and impaired waterbodies visit **EPA's Assessment and TMDL Tracking and Implementation System (ATTAINS)**: http://www.epa.gov/waters/ir/index.html
- For tabular state data on 303(d) listed impaired waterbodies visit **EPA's WATERS Expert Query Tool**: http://www.epa.gov//waters/tmdl/expert_query.html
- For **Geographic Information Systems (GIS) Downloads** visit EPA's Reach Address Database (RAD): http://epamap32.epa.gov/radims/ or visit the WATERS Data Download page: http://www.epa.gov/waters/data/downloads.html
- For more information on the TMDL Program Results Analysis Project visit: http://www.epa.gov/owow/tmdl/results or contact the project leader at norton.douglas@epa.gov

Overview of Identifying and Restoring Impaired Waters under Section 303(d) of the CWA

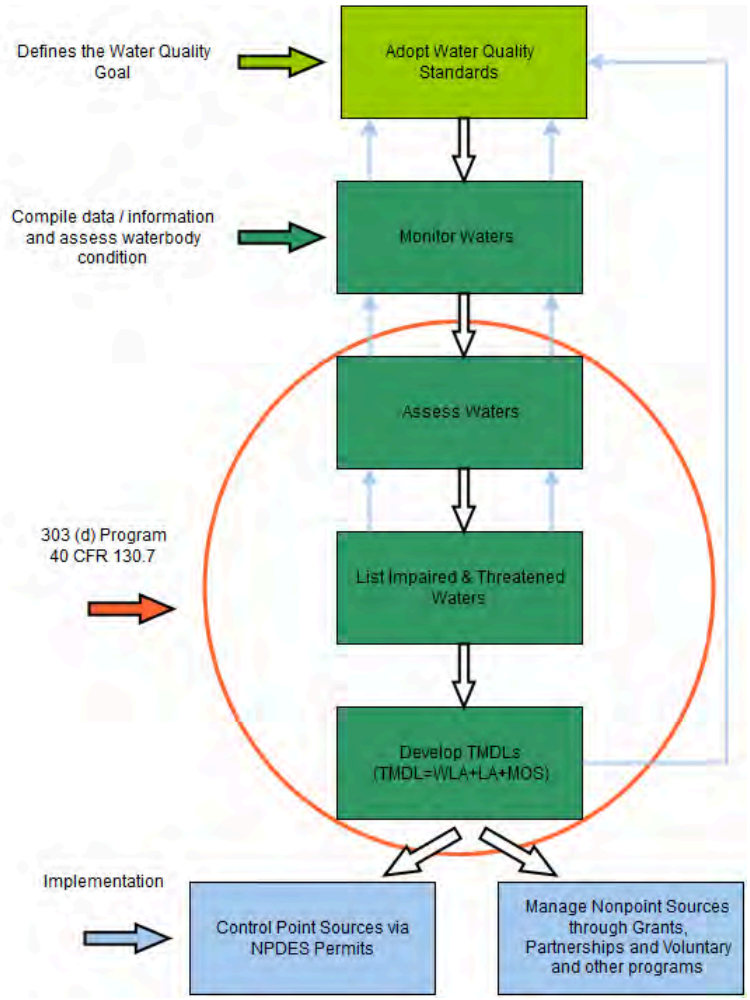
The Impaired Waters and Total Maximum Daily Load (TMDL) Program is an important component of the Clean Water Act's (CWA) framework to restore and protect our Nation's waters. The program is comprised primarily of a two part process. First, states identify waters that are impaired or in danger of becoming impaired (threatened) and second, for these waters, states calculate and allocate pollutant reduction levels necessary to meet approved water quality standards.

What is Section 303(d) of the Clean Water Act?

The goal of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C §1251(a)). Under section 303(d) of the CWA, states, territories and authorized tribes, collectively referred to in the act as "states," are required to develop lists of impaired waters. These are waters for which technology-based regulations and other required controls are not stringent enough to meet the water quality standards set by states. The law requires that states establish priority rankings for waters on the lists and develop Total Maximum Daily Loads (TMDLs) for these waters. A TMDL includes a calculation of the maximum amount of a pollutant that can be present in a waterbody and still meet water quality standards.

How does the 303(d) Impaired Waters and TMDL Program Fit into the Clean Water Act?

As part of the CWA, states must establish water quality standards (WQS) for waters within their borders. Such standards designate the use of the particular waterbody (e.g., recreation or protection of aquatic life), establish water quality criteria to protect the waterbody, and adopt requirements to protect and maintain healthy waters.



Water Quality-Based Approach of the Clean Water Act

Under Section 303(d) of the Act, states are required to evaluate all available water quality-related data and information to develop a list of waters that do not meet established WQS (impaired) and those that currently meet WQS, but may exceed it in the next reporting cycle (threatened). States then must develop a TMDL for every pollutant/waterbody combination on the list. An essential component of a TMDL is the calculation of the maximum amount of a pollutant that can occur in waterbody and still meet WQS. Within the TMDL the state allocates this loading capacity among the various point sources and non-point sources. Permits for point sources are issued through EPA's National Pollutant Discharge Elimination System, or NPDES program.

States are required to update and resubmit their impaired waters list every two years. This process ensures that polluted waters continue to be monitored and assessed until applicable water quality standards are met.

For additional information:

- Overview of Listing Impaired Waters <https://epa.gov/tmdl/overview-listing-impaired-waters-under-cwa-section-303d>
- Overview of TMDLs <https://epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls>