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CURRENT ENVIRONMENTAL ISSUE

2026

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

STUDY RESOURCES

PART A

ENVIROTHON

MISSISSIPPI 2026

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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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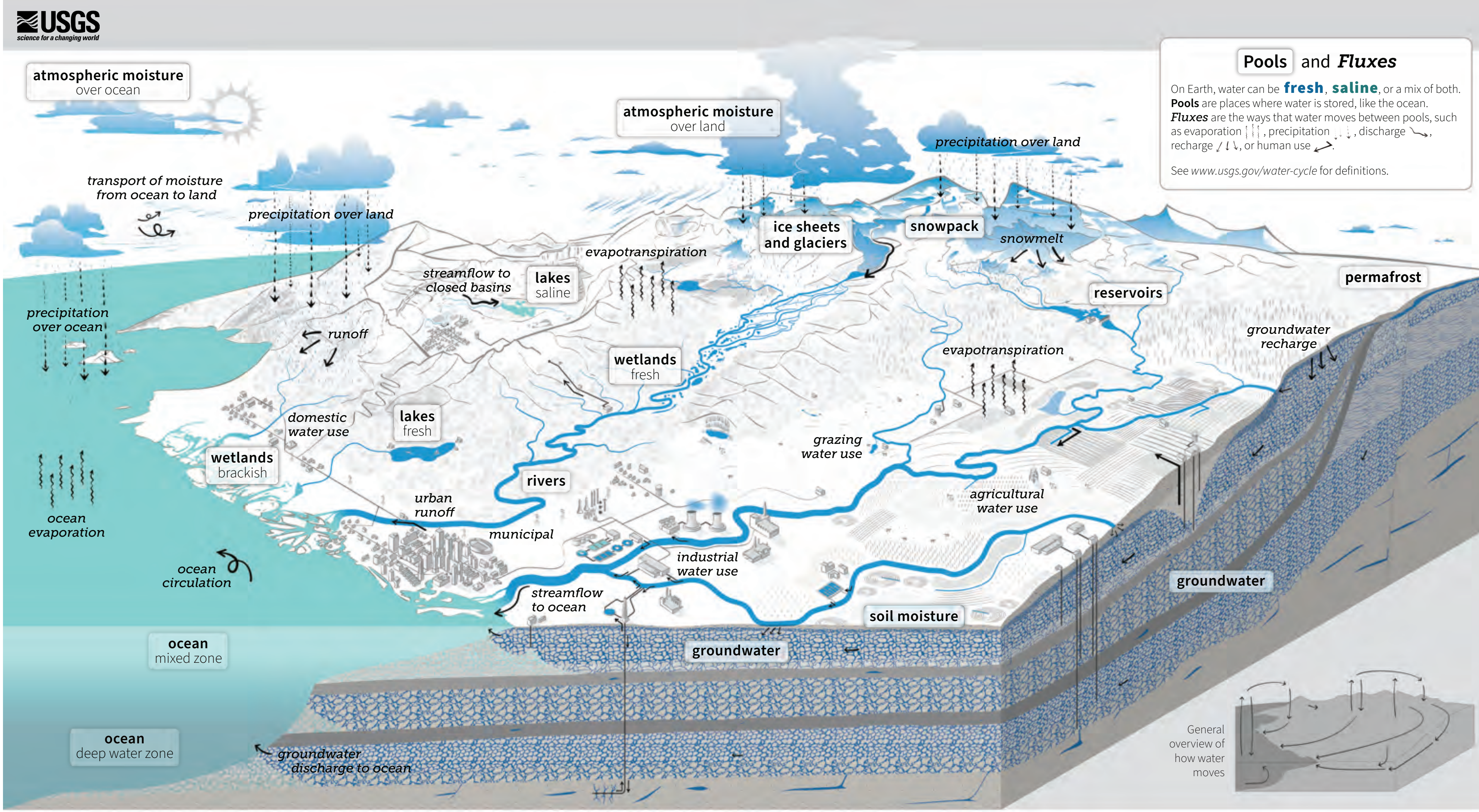
Please Note: Any hyperlinks within the study resources, except for those specifically mentioned as a resource on the Key Topics pages and with a dedicated page in the resources (*i.e., YouTube videos*), are supplemental material ONLY. They may be used for additional information but are not required study 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).



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.

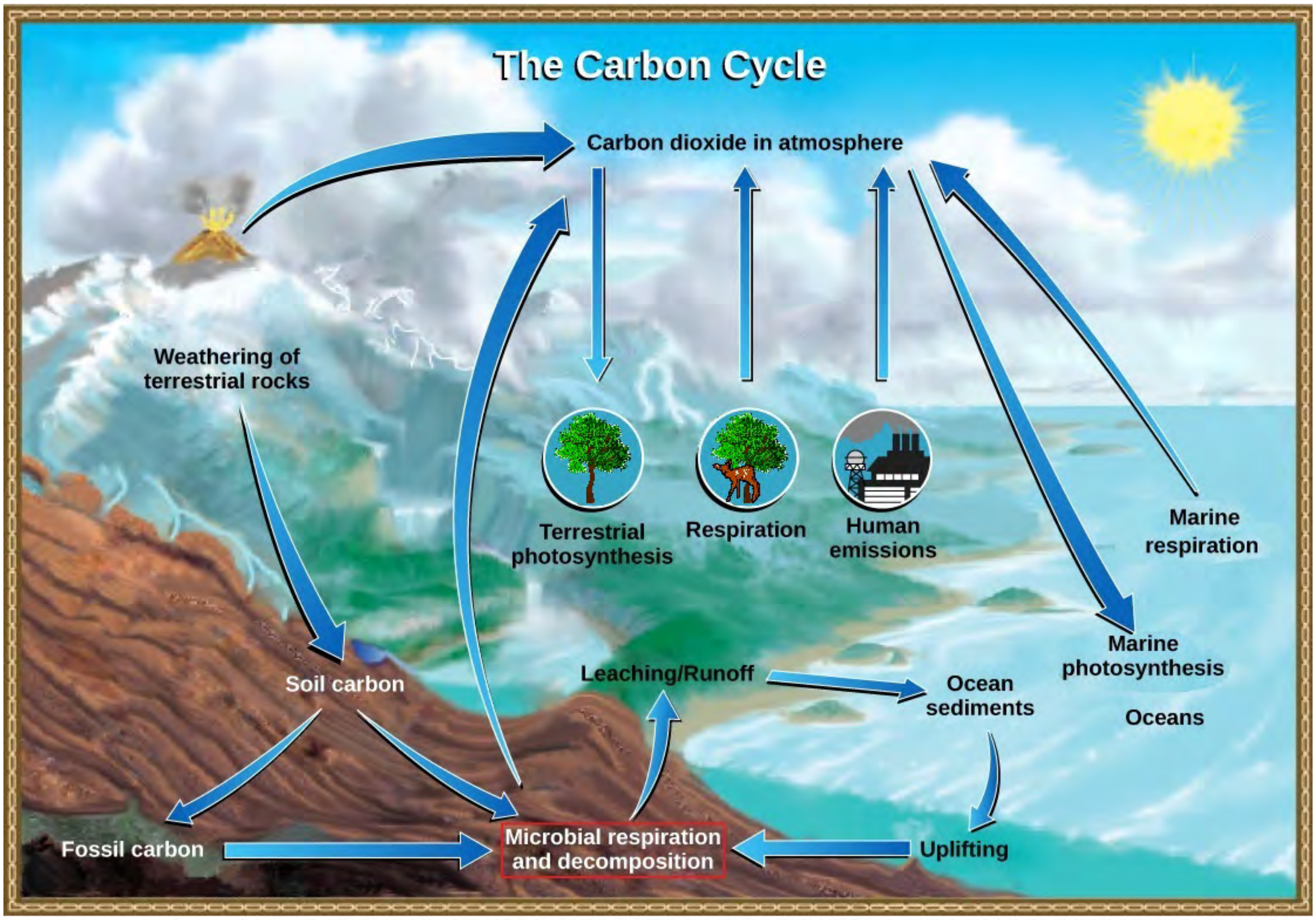


Figure 7.3.a: Carbon dioxide in the atmosphere is converted to organic carbon through photosynthesis by terrestrial organisms (like trees) and marine organisms (like algae). Respiration by terrestrial organisms (like trees and deer) and marine organisms (like algae and fish) release carbon dioxide back 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.

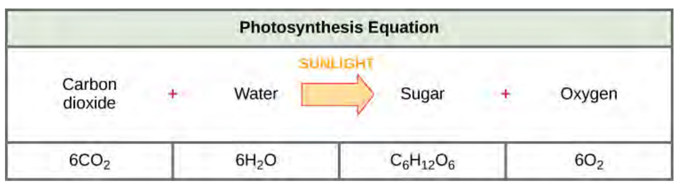


Figure $7.3.c$: This equation means that six molecules of carbon dioxide (CO_2) combine with six molecules of water (H_2O) in the presence of sunlight. This produces one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O_2).

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).

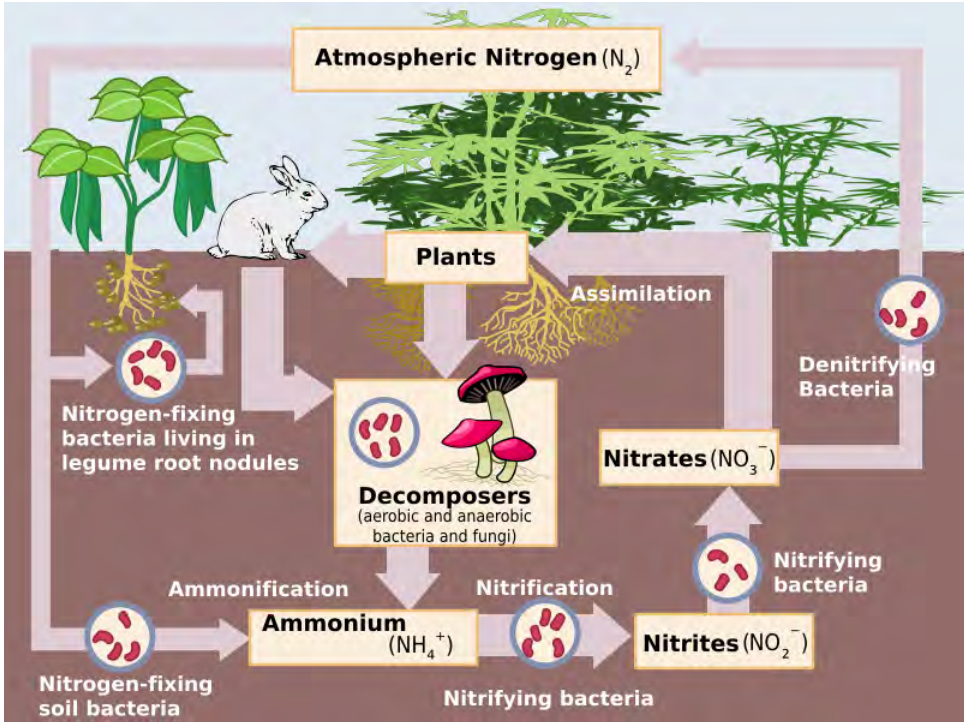


Figure 7.3.f: In the nitrogen cycle, nitrogen-fixing bacteria in the soil or legume root nodules convert nitrogen gas (N_2) from the atmosphere to ammonium (NH_4^+). Nitrification occurs when bacteria convert ammonium to nitrites (NO_2^-) and then to nitrates (NO_3^-). Nitrates re-enter the atmosphere 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.

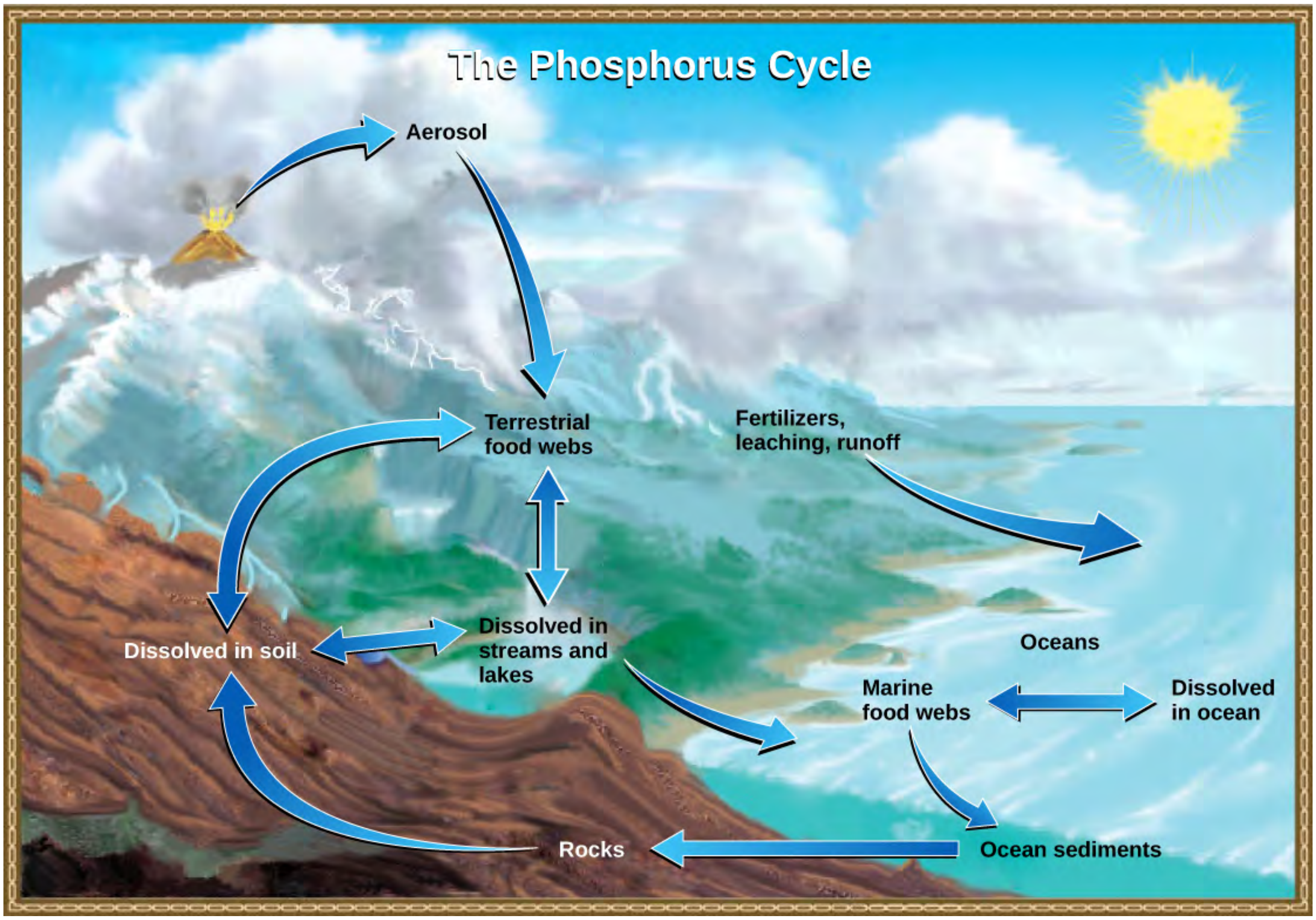


Figure 7.3.*i*: In nature, phosphorus exists as the phosphate ion (PO_4^{3-}). Phosphate enters the atmosphere from volcanic aerosols, which precipitate to Earth. Weathering of rocks also releases phosphate into the soil and water, where it becomes available to terrestrial food webs. Some of the phosphate 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.

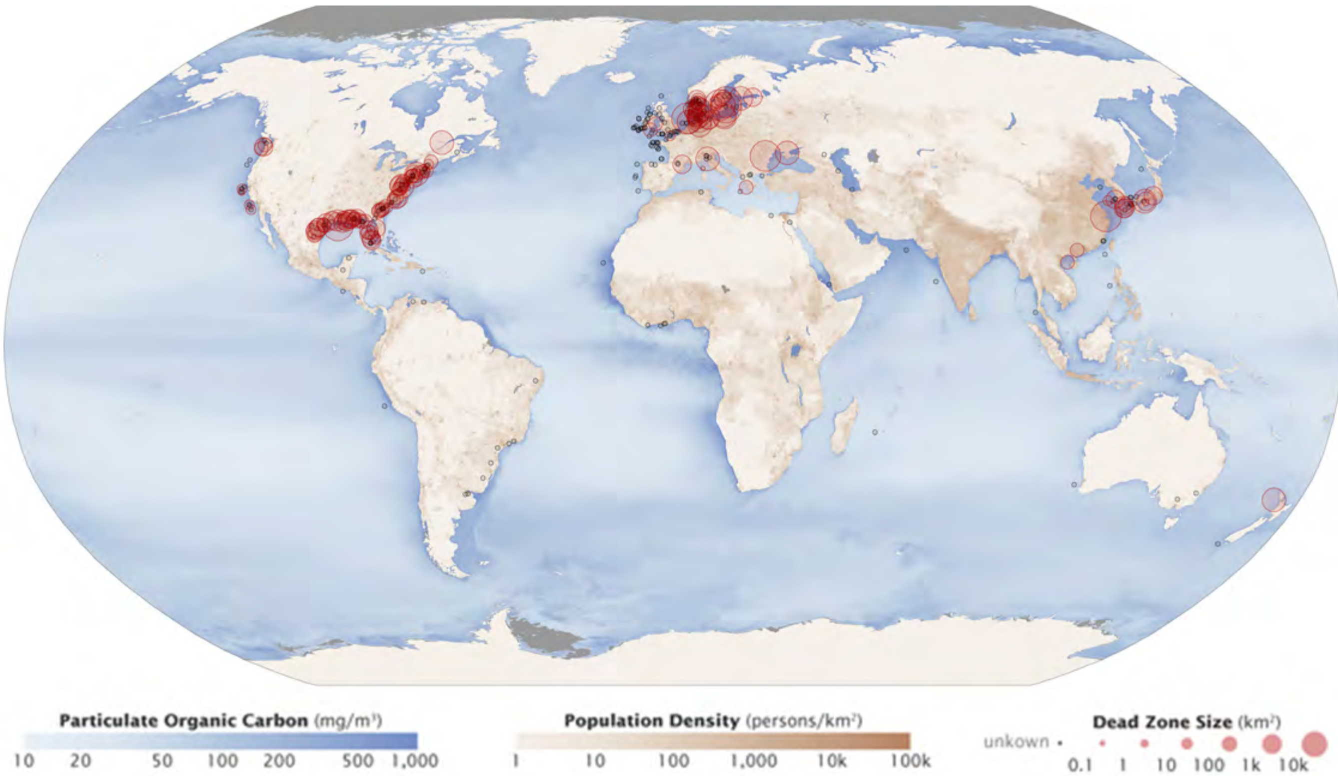


Figure $7.3.j$: Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. This map shows dead zones around the world in 2008. Worldwide, large dead zones are found in coastal areas of high population density. (credit: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

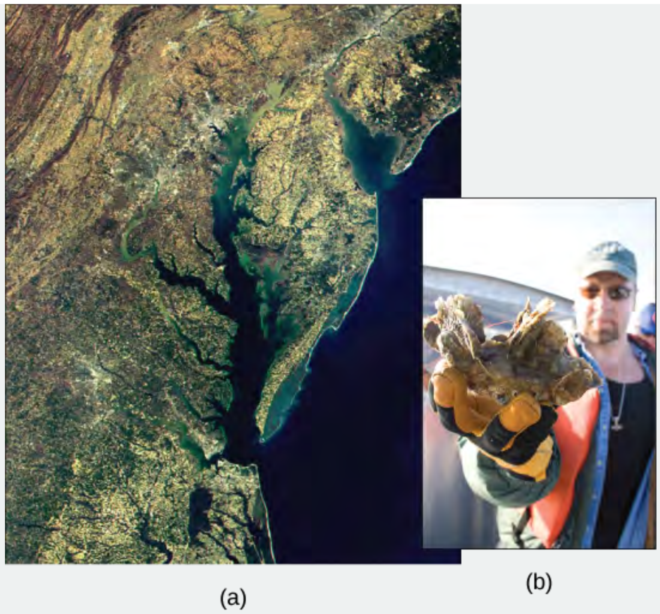


Figure $7.3.k$: This (a) satellite image shows the Chesapeake Bay, an ecosystem affected by phosphate and nitrate runoff. A (b) member of the Army Corps of Engineers holds a clump of oysters being used as a part of the oyster restoration effort in the bay. (credit a: modification of work by NASA/MODIS;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

STREAM ECOLOGY
physical
water cycle
watersheds
river continuum
basic hydrology
geomorphology
chemical
dissolved gases
dissolved solids
pH
salinization
biological
organic matter
primary production
decomposition
nutrient dynamics
habitat
autotrophs
macroinvertebrates
fish

Home : Understanding : Stream Ecology Primer : Nutrient Dynamics

Nutrient Dynamics

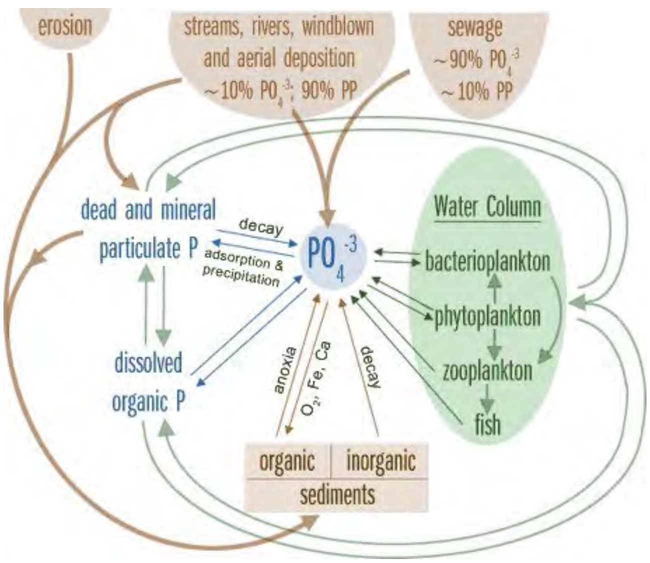
Solutes in rivers and streams are influenced by interactions with the streambed, streambanks, and the land as they travel downstream. This ongoing process interests stream ecologists because some of those solutes are essential to the lives of organisms, most notably phosphorus and nitrogen. Their uptake, 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)

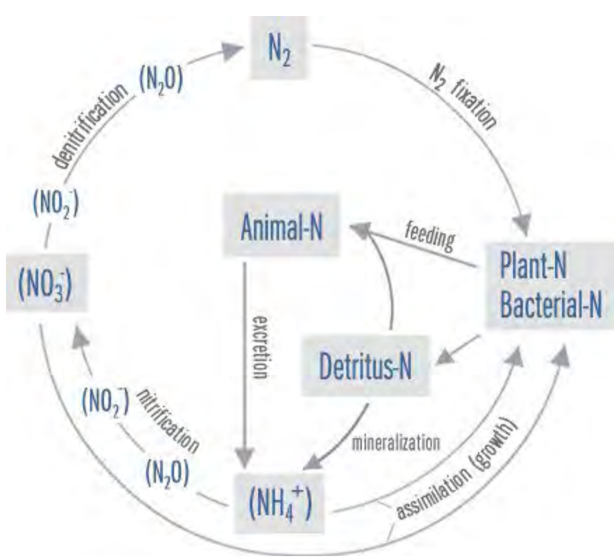
General availability of phosphorus is not only shaped by its abundance in local rocks and soils, but also by physical-chemical transformations. Sorption of phosphate ions onto charged clay or organic particles occurs when dissolved inorganic phosphorus (DIP) concentrations are relatively high, while 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.

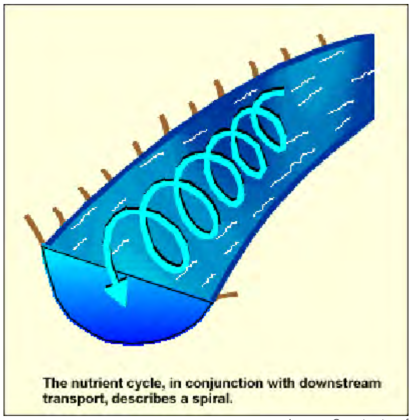


Image Courtesty of: Hebert, P.D.N, ed. Canada's Aquatic Environments [Internet]. CyberNatural Software, University of Guelph. Revised 2002.
www.aquatic.uoguelph.ca

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
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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.

In This Training Session

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.**

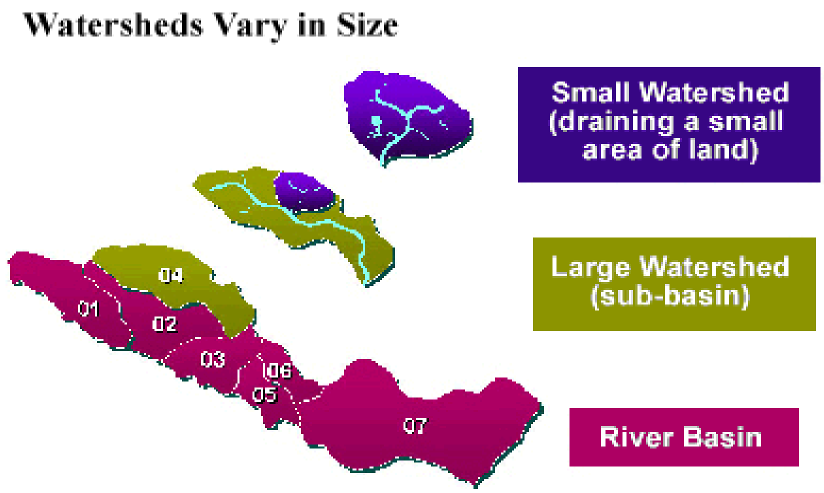
***Watershed Hydrology*, 1996, Peter Block.**

***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.

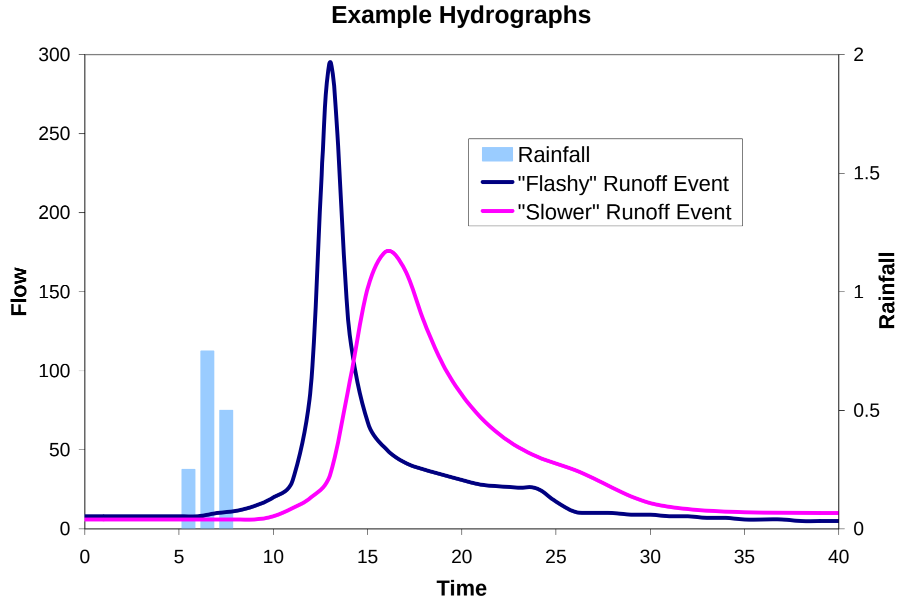


Figure 8: Sample Hydrograph

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.

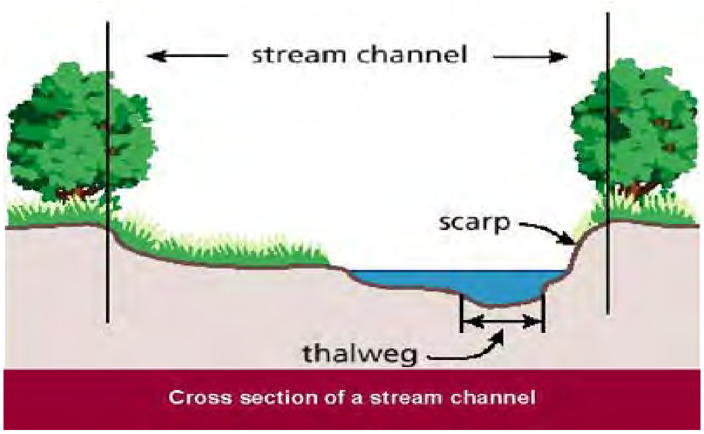


Figure 9: Cross section of a stream channel
(EPA, 2007)

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)

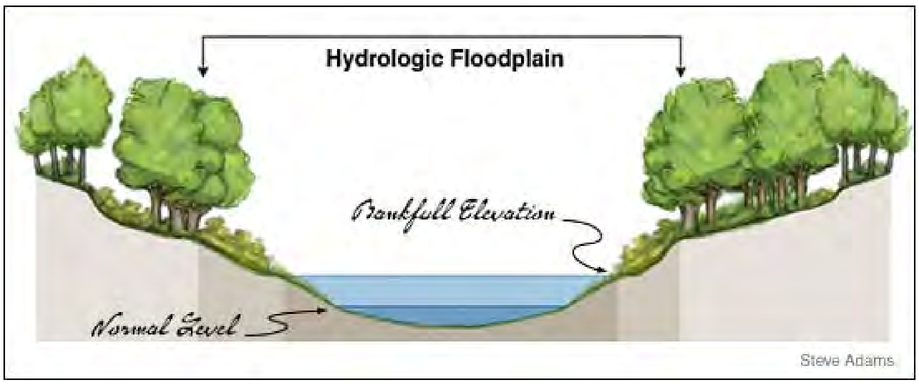


Figure 10: Stream Channel Shape
(MDNR, 2005)

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:

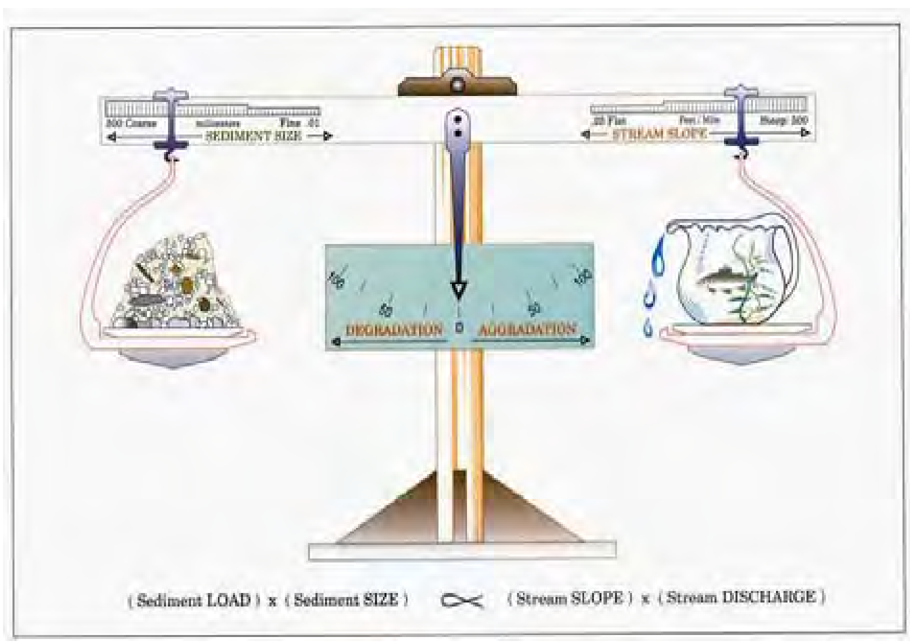


Figure 11: Relationships involved in maintaining a stable channel balance (from Lane 1955, based on Rosgen 1980)

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.

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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.

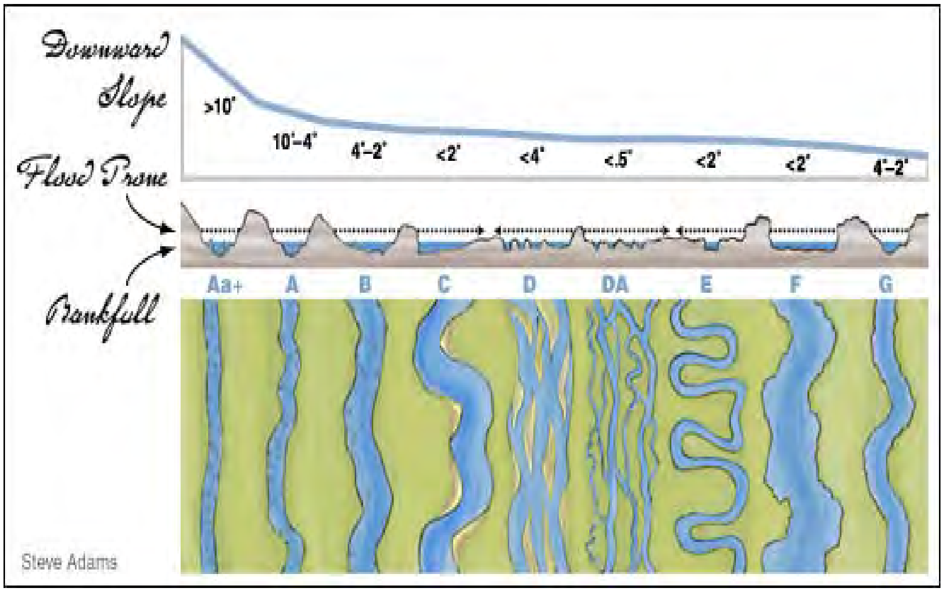


Figure 12: Rosgen Stream Classification (MDNR, 2005)

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

211 Designated Uses and Why They are Important

4 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.

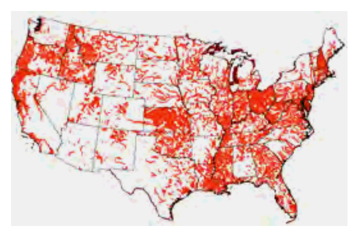
Program Results through 303(d) Listings of Impaired Waters

- **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

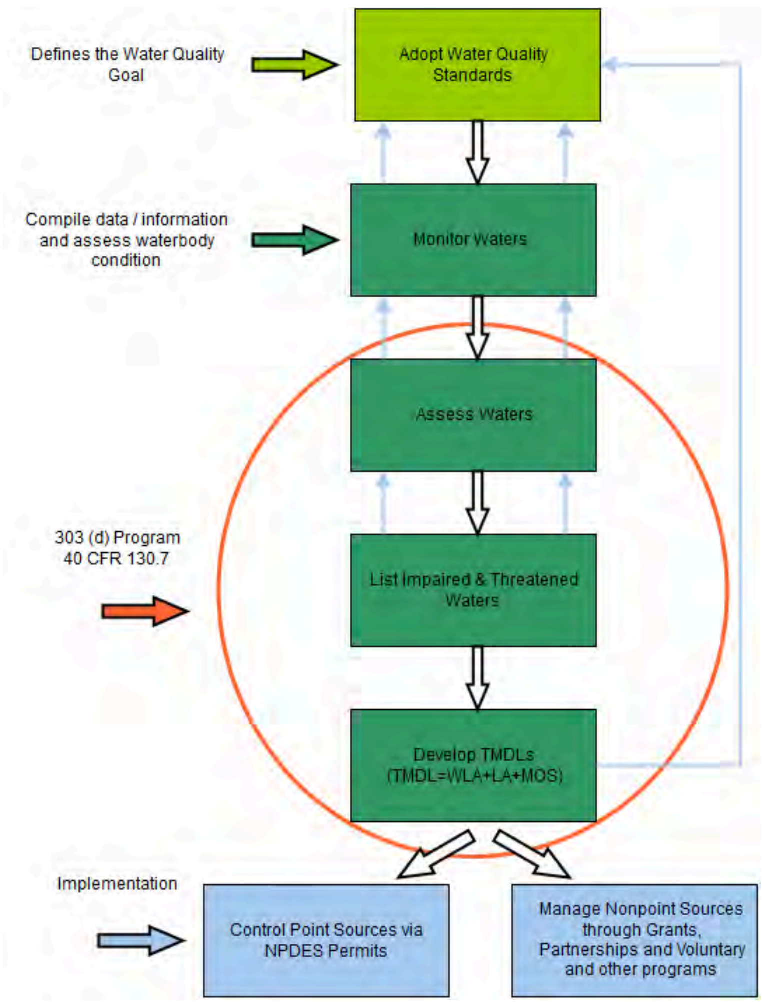
◊ For tabular state data on 303(d) listed impaired waterbodies visit **EPA's WATERS Expert Query Tool**: http://www.epa.gov//waters/tmdl/expert_query.html

◊ 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>

Key Topic #2: NPS in a Growing World and Your Role in It

Learning Objectives

1. **Explain** how population growth, urban expansion, and agricultural intensification contribute to increased non-point source pollution globally and locally.
2. **Compare** the effects of land use types (e.g., urban, suburban, agricultural) on runoff volume and pollutant loading.
3. **Identify** common products or practices in daily life that contribute to non-point source pollution through indirect pathways (e.g., fertilizers, car washing, pet waste).
4. **Illustrate** the concept of a personal environmental footprint as it relates to NPS pollution, using tools such as footprint calculators.

Resource Title	Source	Located on
Land Use	*U.S. EPA*	Page 47-49
Protecting Water Quality from Urban Runoff	*U.S. EPA February 2003)*	Page 50-51
Protecting Water Quality from Agricultural Runoff	*U.S. EPA (March 2005)*	Page 52-53
A regional examination of the footprint of agriculture and urban cover on stream water quality, *abstract and introduction*	*Roshelle Chan et. Al., Science of the Total Environment, June 21,2024*	Page 54-57
Calculating Stormwater and Nitrogen Loading Reduction/ Prevention	*National Fish and Wildlife Foundation*	Page 58-61
Best Management Practices to Control Nonpoint Source Pollution, *Introduction and Chapters 1-3*	*New Hampshire- Dept. of Environmental Services, January 2024*	Page 62-80
Water Footprint Calculator	*EcoRise (5/13/2017)*	Page 81-82

Land Use

What are the trends in land use and their effects on human health and the environment?

- Definition of Land Use
- Effects of Land Use Changes
- ROE Indicators

Definition of Land Use

"Land use" is the term used to describe the human use of land. It represents the economic and cultural activities (e.g., agricultural, residential, industrial, mining, and recreational uses) that are practiced at a given place. Public and private lands frequently represent very different uses. For example, urban development seldom occurs on publicly owned lands (e.g., parks, wilderness areas), while privately owned lands are infrequently protected for wilderness uses.

Land use differs from land cover in that some uses are not always physically obvious (e.g., land used for producing timber but not harvested for many years and forested land designated as wilderness will both appear as forest-covered, but they have different uses).

Effects of Land Use Changes

Land use changes occur constantly and at many scales, and can have specific and cumulative effects on air and water quality, watershed function, generation of waste, extent and quality of wildlife habitat, climate, and human health.

EPA is concerned about different land use activities because of their potential effects on the environment and human health. Land development and agricultural uses are two primary areas of concern, with a wide variety of potential effects.

Land Development

- Land development creates **impervious surfaces** through construction of roads, parking lots, and other structures. Impervious surfaces:
  - Contribute to nonpoint source water pollution <https://epa.gov/nps/basic-information-about-nonpoint-source-nps-pollution> by limiting the capacity of soils to filter runoff.
  - Affect peak flow and water volume, which heighten erosion potential and affect habitat and water quality.
  - Increase storm water runoff, which can deliver more pollutants to water bodies that residents may rely on for drinking and recreation.[1] Storm runoff from urban and suburban areas contains dirt, oils from road surfaces, nutrients from fertilizers, and various toxic compounds.
  - Affect ground water aquifer recharge.
- **Point source discharges** from industrial and municipal wastewater treatment facilities can contribute toxic compounds and heated water.
- Some **land development patterns**, in particular dispersed growth such as "suburbanization," can contribute to a variety of environmental concerns. For example:
  - Increased air pollution due to vehicle use results in higher concentrations of certain air pollutants in developed areas that may exacerbate human health problems such as asthma.[2]
  - Land development can lead to the formation of "heat islands," domes of warmer air over urban and suburban areas that are caused by the loss of trees and shrubs and the absorption of more heat by pavement, buildings, and other sources. Heat islands can affect local, regional, and global climate, as well as air quality.[3]

Agricultural Uses

- Agricultural land uses can affect the **quality of water and watersheds**, including:
    - The types of crops planted, tillage practices, and various irrigation practices can limit the amount of water available for other uses.
    - Livestock grazing in riparian zones can change landscape conditions by reducing stream bank vegetation and increasing water temperatures, sedimentation, and nutrient levels.
    - Runoff from pesticides, fertilizers, and nutrients from animal manure can also degrade water quality.
- Agricultural land use may also result in **loss of native habitats** or increased wind erosion and dust, exposing humans to particulate matter and various chemicals.[4]
- Some land uses can accelerate or exacerbate the **spread of invasive species**. For example:
    - Certain agricultural land use practices, such as overgrazing, land conversion, fertilization, and the use of agricultural chemicals, can enhance the growth of invasive plants.[5] These plants can alter fish and wildlife habitat, contribute to decreases in biodiversity, and create health risks to livestock and humans.
    - Introduction of invasive species on agricultural lands can reduce water quality and water availability for native fish and wildlife species.

Research is beginning to elucidate the connections between land use changes and infectious disease. For example, some studies indicate that spread of vector-borne disease may be influenced by land use and/or other environmental change.[6]

Other studies indicate that fragmentation of forest habitat into smaller patches separated by agricultural activities or developed land increases the “edge effect” and promotes the interaction among pathogens, vectors, and hosts.[7]

In some cases, changes in land use may have positive effects, such as increasing habitat (as a result of deliberate habitat restoration measures) and reclamation of previously contaminated lands for urban/suburban development.

ROE Indicators

The ROE presents two indicators providing information about land use trends: Land Use and Urbanization and Population Change. Available indicators in this area are limited because numerous circumstances (including lack of data; varying approaches to data classification and management, and difficulty in delineating land use) create significant challenges and limitations in tracking trends in and effects of land use.

- **Lack of data:**
    - No indicators are available to assess the effects that trends in land use have on human health, as effects have not been shown or quantified on a national basis. Researchers have conducted site-specific studies on individual land uses, but little is known about overall national trends in land use and potential impacts on human health.
    - An additional challenge is that a variety of state and local laws, regulations, and practices govern the use of land. There are few state-level efforts to organize land use data; most activities occur over specific local, usually urbanizing, geographic areas.

      This means that land use records are not maintained statewide or nationally, as they are in other nations. This contributes to challenges in tracking and monitoring land use changes. It also means that efforts to coordinate land use across jurisdictions are difficult to develop.

- **Varying approaches to data classification and measurement:** Estimates of the extent of various land uses differ across data sources, and each source uses different classifications, measurement approaches, methodologies for analysis and interpretation, and sampling time frames. The data are collected by many different agencies that manage land for many different purposes.

  Some data collection efforts arise out of specific interests, such as tracking changes in the extent of agricultural land or farmland, or understanding how much land is used for timber production. These data collection efforts tend to develop their own classifications and categorization, making it difficult to integrate the data over time, across inventories, or as a national picture.

- **Difficulty in delineating land use:** Finally, the difficulty of actually delineating land use presents a challenge in developing data to determine trends. Land use is generally a function of laws, policies, or management decisions that may not always be possible to infer by examining the ground via surveys. Analysis of zoning maps or property records at the local level may be necessary to understand land use.

EPA
United States Environmental Protection Agency
EPA 841-F-03-003

Protecting Water Quality *from* URBAN RUNOFF

Clean Water Is Everybody's Business

In urban and suburban areas, much of the land surface is covered by buildings and pavement, which do not allow rain and snowmelt to soak into the ground. Instead, most developed areas rely on storm drains to carry large amounts of runoff from roofs and paved areas to nearby waterways. The stormwater runoff carries pollutants such as oil, dirt, chemicals, and lawn fertilizers directly to streams and rivers, where they seriously harm water quality. To protect surface water quality and groundwater resources, development should be designed and built to minimize increases in runoff.

The most recent National Water Quality Inventory reports that runoff from urbanized areas is the leading source of water quality impairments to surveyed estuaries and the third-largest source of impairments to surveyed lakes.

Did you know that because of impervious surfaces like pavement and rooftops, a typical city block generates more than 5 times more runoff than a woodland area of the same size?

How Urbanized Areas Affect Water Quality

Increased Runoff

The porous and varied terrain of natural landscapes like forests, wetlands, and grasslands traps rainwater and snowmelt and allows them to filter slowly into the ground. In contrast, impervious (nonporous) surfaces like roads, parking lots, and rooftops prevent rain and snowmelt from infiltrating, or soaking, into the ground. Most of the rainfall and snowmelt remains above the surface, where it runs off rapidly in unnaturally large amounts.

Storm sewer systems concentrate runoff into smooth, straight conduits. This runoff gathers speed and erosional power as it travels underground. When this runoff leaves the storm drains and empties into a stream, its excessive volume and power blast out streambanks, damaging streamside vegetation and wiping out aquatic habitat. These increased storm flows carry sediment loads from construction sites and other denuded surfaces and eroded streambanks. They often carry higher water temperatures from streets, roof tops, and parking lots, which are harmful to the health and reproduction of aquatic life.

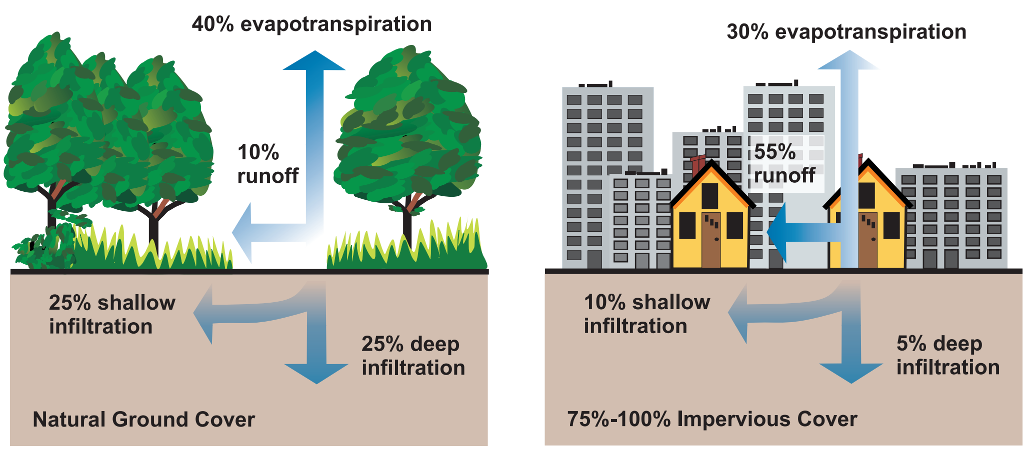
The loss of infiltration from urbanization may also cause profound groundwater changes. Although urbanization leads to great increases in flooding during and immediately after wet weather, in many instances it results in lower stream flows during dry weather. Many native fish and other aquatic life cannot survive when these conditions prevail.

Increased Pollutant Loads

Urbanization increases the variety and amount of pollutants carried into streams, rivers, and lakes. The pollutants include:

- Sediment
- Oil, grease, and toxic chemicals from motor vehicles
- Pesticides and nutrients from lawns and gardens
- Viruses, bacteria, and nutrients from pet waste and failing septic systems
- Road salts
- Heavy metals from roof shingles, motor vehicles, and other sources
- Thermal pollution from dark impervious surfaces such as streets and rooftops

These pollutants can harm fish and wildlife populations, kill native vegetation, foul drinking water supplies, and make recreational areas unsafe and unpleasant.



Relationship between impervious cover and surface runoff. Impervious cover in a watershed results in increased surface ruunoff. As little as 10 percent impervious cover in a watershed can result in stream degradation.

Managing Urban Runoff

What Homeowners Can Do

To decrease polluted runoff from paved surfaces, households can develop alternatives to areas traditionally covered by impervious surfaces. Porous pavement materials are available for driveways and sidewalks, and native vegetation and mulch can replace high maintenance grass lawns. Homeowners can use fertilizers sparingly and sweep driveways, sidewalks, and roads instead of using a hose. Instead of disposing of yard waste, they can use the materials to start a compost pile. And homeowners can learn to use Integrated Pest Management (IPM) to reduce dependence on harmful pesticides.

In addition, households can prevent polluted runoff by picking up after pets and using, storing, and disposing of chemicals properly. Drivers should check their cars for leaks and recycle their motor oil and antifreeze when these fluids are changed. Drivers can also avoid impacts from car wash runoff (e.g., detergents, grime, etc.) by using car wash facilities that do not generate runoff. Households served by septic systems should have them professionally inspected and pumped every 3 to 5 years. They should also practice water conservation measures to extend the life of their septic systems.

Controlling Impacts from New Development

Developers and city planners should attempt to control the volume of runoff from new development by using low impact development, structural controls, and pollution prevention strategies. Low impact development includes measures that conserve natural areas (particularly sensitive hydrologic areas like riparian buffers and infiltrable soils); reduce development impacts; and reduce site runoff rates by maximizing surface roughness, infiltration opportunities, and flow paths.

Controlling Impacts from Existing Development

Controlling runoff from existing urban areas is often more costly than controlling runoff from new developments. Economic efficiencies are often realized through approaches that target "hot spots" of runoff pollution or have multiple benefits, such as high-efficiency street sweeping (which addresses aesthetics, road safety, and water quality). Urban planners and others responsible for managing urban and suburban areas can first identify and implement pollution prevention strategies and examine source control opportunities. They should seek out priority pollutant reduction opportunities, then protect natural areas that help control runoff, and finally begin ecological restoration and retrofit activities to clean up degraded water bodies. Local governments are encouraged to take lead roles in public education efforts through public signage, storm drain marking, pollution prevention outreach campaigns, and partnerships with citizen groups and businesses. Citizens can help prioritize the clean-up strategies, volunteer to become involved in restoration efforts, and mark storm drains with approved "don't dump" messages.

Related Publications

Turn Your Home into a Stormwater Pollution Solution!

www.epa.gov/nps

This web site links to an EPA homeowner's guide to healthy habits for clean water that provides tips for better vehicle and garage care, lawn and garden techniques, home improvement, pet care, and more.

National Management Measures to Control Nonpoint Source Pollution from Urban Areas

www.epa.gov/owow/nps/urbanmm

This technical guidance and reference document is useful to local, state, and tribal managers in implementing management programs for polluted runoff. Contains information on the best available, economically achievable means of reducing pollution of surface waters and groundwater from urban areas.

Onsite Wastewater Treatment System Resources

www.epa.gov/owm/onsite

This web site contains the latest brochures and other resources from EPA for managing onsite wastewater treatment systems (OWTS) such as conventional septic systems and alternative decentralized systems. These resources provide basic information to help individual homeowners, as well as detailed, up-to-date technical guidance of interest to local and state health departments.

Low Impact Development Center

www.lowimpactdevelopment.org

This center provides information on protecting the environment and water resources through integrated site design techniques that are intended to replicate preexisting hydrologic site conditions.

Stormwater Manager's Resource Center (SMRC)

www.stormwatercenter.net

Created and maintained by the Center for Watershed Protection, this resource center is designed specifically for stormwater practitioners, local government officials, and others that need technical assistance on stormwater management issues.

Strategies: Community Responses to Runoff Pollution

www.nrdc.org/water/pollution/storm/stoinx.asp

The Natural Resources Defense Council developed this interactive web document to explore some of the most effective strategies that communities are using around the nation to control urban runoff pollution. The document is also available in print form and as an interactive CD-ROM.

For More Information

U.S. Environmental Protection Agency
Nonpoint Source Control Branch (4503T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
www.epa.gov/nps

February 2003

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United States Environmental Protection Agency

EPA 841-F-05-001

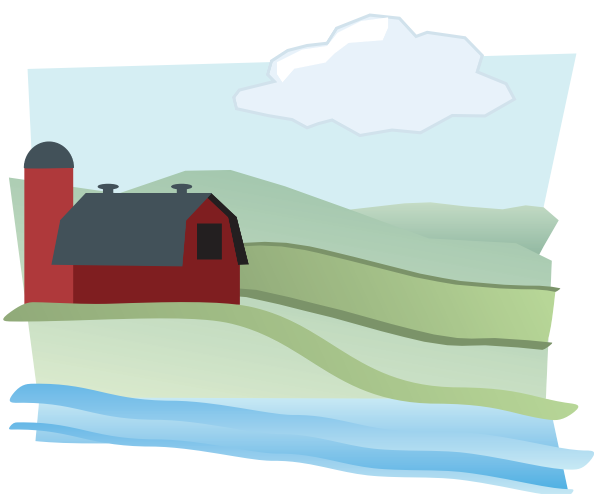
Protecting Water Quality *from* AGRICULTURAL RUNOFF

Clean Water Is Everybody's Business

The United States has more than 330 million acres of agricultural land that produce an abundant supply of food and other products. American agriculture is noted worldwide for its high productivity, quality, and efficiency in delivering goods to the consumer. When improperly managed however, activities from working farms and ranches can affect water quality.

In the 2000 *National Water Quality Inventory,* states reported that agricultural nonpoint source (NPS) pollution is the leading source of water quality impacts on surveyed rivers and lakes, the second largest source of impairments to wetlands, and a major contributor to contamination of surveyed estuaries and ground water. Agricultural activities that cause NPS pollution include poorly located or managed animal feeding operations; overgrazing; plowing too often or at the wrong time; and improper, excessive, or poorly timed application of pesticides, irrigation water, and fertilizer.

Pollutants that result from farming and ranching include sediment, nutrients, pathogens, pesticides, metals, and salts. Impacts from agricultural activities on surface water and ground water can be minimized by using management practices that are adapted to local conditions. Many practices designed to reduce pollution also increase productivity and save farmers and ranchers money in the long run.



What Is Nonpoint Source Pollution?

Nonpoint source (NPS) pollution, unlike pollution from point sources such as industrial and sewage treatment plants, comes from many diffuse sources. Polluted runoff 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 watersheds through lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water.

Did you know that runoff from farms is the leading source of impairments to surveyed rivers and lakes?

There are many government programs available to help farmers and ranchers design and pay for management approaches to prevent and control NPS pollution. For example, over 40 percent of section 319 Clean Water Act grants have been used to control NPS pollution from working farms and ranches. Also, many programs funded by the U.S. Department of Agriculture and by states provide cost-share, technical assistance, and economic incentives to implement NPS pollution management practices. Many local organizations and individuals have come together to help create regional support networks to adopt technologies and practices to eliminate or reduce water quality impacts caused by agricultural activities.

Sedimentation

The most prevalent source of agricultural water pollution is soil that is washed off fields. Rain water carries soil particles (sediment) and dumps them into nearby lakes or streams. Too much sediment can cloud the water, reducing the amount of sunlight that reaches aquatic plants. It can also clog the gills of fish or smother fish larvae. In addition, other pollutants like fertilizers, pesticides, and heavy metals are often attached to the soil particles and wash into the water bodies, causing algal blooms and depleted oxygen, which is deadly to most aquatic life. Farmers and ranchers can reduce erosion and sedimentation by 20 to 90 percent by applying management practices that control the volume and flow rate of runoff water, keep the soil in place, and reduce soil transport.

Nutrients

Farmers apply nutrients such as phosphorus, nitrogen, and potassium in the form of chemical fertilizers, manure, and sludge. They may also grow legumes and leave crop residues to enhance production. When these sources exceed plant needs, or are applied just before it rains, nutrients can wash into aquatic ecosystems. There they can cause algae blooms, which can ruin swimming and boating opportunities, create foul taste and odor in drinking water, and kill fish by removing oxygen from the water. High concentrations of nitrate in drinking water can cause methemoglobinemia, a potentially fatal disease in infants, also known as blue baby syndrome. To combat nutrient losses, farmers can implement nutrient management plans that help maintain high yields and save money on fertilizers.

Animal Feeding Operations

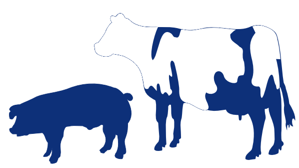
By confining animals in small areas or lots, farmers and ranchers can efficiently feed and maintain livestock. But these confined areas become major sources of animal waste. An estimated 238,000 working farms and ranches in the United States are considered animal feeding operations, generating about 500 million tons of manure each year. Runoff from poorly managed facilities can carry pathogens such as bacteria and viruses, nutrients, and oxygen-demanding organics and solids that contaminate shellfishing areas and cause other water quality problems. Ground water can also be contaminated by waste seepage. Farmers and ranchers can limit discharges by storing and managing facility wastewater and runoff with appropriate waste management systems.

Livestock Grazing

Overgrazing exposes soils, increases erosion, encourages invasion by undesirable plants, destroys fish habitat, and may destroy streambanks and floodplain vegetation necessary for habitat and water quality filtration. To reduce the impacts of grazing on water quality, farmers and ranchers can adjust grazing intensity, keep livestock out of sensitive areas, provide alternative sources of water and shade, and promote revegetation of ranges, pastures, and riparian zones.

Irrigation

Irrigation water is applied to supplement natural precipitation or to protect crops against freezing or wilting. Inefficient irrigation can cause water quality problems. In arid areas, for example, where rainwater does not carry minerals deep into the soil, evaporation of irrigation water can concentrate salts. Excessive irrigation can affect water quality by causing erosion, transporting nutrients, pesticides, and heavy metals, or decreasing the amount of water that flows naturally in streams and rivers. It can also cause a buildup of selenium, a toxic metal that can harm waterfowl reproduction. Farmers can reduce NPS pollution from irrigation by improving water use efficiency. They can measure actual crop needs and apply only the amount of water required. Farmers may also choose to convert irrigation systems to higher efficiency equipment.



Pesticides

Insecticides, herbicides, and fungicides are used to kill agricultural pests. These chemicals can enter and contaminate water through direct application, runoff, and atmospheric deposition. They can poison fish and wildlife, contaminate food sources, and destroy the habitat that animals use for protective cover. To reduce contamination from pesticides, farmers should use Integrated Pest Management (IPM) techniques based on the specific soils, climate, pest history, and crop conditions for a particular field. IPM encourages natural barriers and limits pesticide use and manages necessary applications to minimize pesticide movement from the field.

Farm Bill Conservation Funding

In May 2002 President Bush signed the Farm Bill, providing up to $13 billion for conservation programs for six years. This Farm Bill represents an 80 percent increase above current levels of funding available for conservation programs designed to prevent polluted runoff. For more information, visit www.usda.gov/farmbill.

Related Publications and Web Sites

National Management Measures to Control Nonpoint Source Pollution from Agriculture

epa.gov/nps/agmm

This technical guidance and reference document is for use by state, local, and tribal managers in the implementation of nonpoint source pollution management programs. It contains information on effective, readily available, and economically achievable means of reducing pollution of surface and ground water from agriculture.

Agricultural Nonpoint Source Pollution Management Web Site

epa.gov/nps/agriculture.html

This web site features a collection of links to helpful documents, federal programs, partnerships and nongovernmental orrganizations that convey advice and assistance to farmers and ranchers for protecting water quality.

National Agriculture Compliance Assistance Center

epa.gov/agriculture or call toll-free: 1-888-663-2155

EPA's National Agriculture Compliance Assistance Center is the "first stop" for information about environmental requirements that affect the agricultural community.

Animal Feeding Operations (AFO) Web Sites

AFO Virtual Information Center: epa.gov/npdes/afovirtualcenter
Overview of regulations and helpful links: epa.gov/npdes/afo

Funding Sources

Searchable Catalog of Federal Funding Sources for Watershed Protection

epa.gov/watershedfunding

Agricultural Management Assistance Database

www.nrcs.usda.gov/programs/ama

Clean Water Act Section 319(h) funding (epa.gov/nps/319hfunds.html) is provided to designated state and tribal agencies to implement approved nonpoint source management programs.

Environmental Quality Incentives Program (www.nrcs.usda.gov/programs/eqip) offers financial, technical, and educational assistance to install or implement structural, vegetative, and management practices designed to conserve soil and other natural resources.

Conservation Reserve and Conservation Reserve Enhancement Programs (www.fsa.usda.gov/dafp/cepd/default.htm) implemented by the U.S. Department of Agriculture provide financial incentives to encourage farmers and ranchers to voluntarily protect soil, water, and wildlife resources.

For More Information

U.S. Environmental Protection Agency
Nonpoint Source Control Branch (4503T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460

epa.gov/nps

Revised
March 2005

A regional examination of the footprint of agriculture and urban cover on stream water quality

Abstract and Introduction

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ABSTRACT

Freshwater systems in cold regions, including the Laurentian Great Lakes, are threatened by both eutrophication and salinization, due to excess nitrogen (N), phosphorus (P) and chloride (Cl^-) delivered in agricultural and urban runoff. However, identifying the relative contribution of urban vs. agricultural development to water quality impairment is challenging in watersheds with mixed land cover, which typify most developed regions. In this study, a self-organizing map (SOM) analysis was used to evaluate the contributions of various forms of land cover to water quality impairment in southern Ontario, a population-dense, yet highly agricultural region in the Laurentian Great Lakes basin where urban expansion and agricultural intensification have been associated with continued water quality impairment. Watersheds were classified into eight spatial clusters, representing four categories of agriculture, one urban, one natural, and two mixed land use clusters. All four agricultural clusters had high nitrate-N concentrations, but levels were especially high in watersheds with extensive corn and soybean cultivation, where exceedances of the 3 mg L^{-1} water quality objective dramatically increased above a threshold of ~30 % watershed row crop cover. Maximum P concentrations also occurred in the most heavily tile-drained cash crop watersheds, but associations between P and land use were not as clear as for N. The most urbanized watersheds had the highest Cl^- concentrations and expansions in urban area were mostly at the expense of surrounding agricultural land cover, which may drive intensification of remaining agricultural lands. Expansions in tile-drained corn and soybean area, often at the expense of mixed, lower intensity agriculture are not unique to this area and suggest that river nitrate-N levels will continue to increase in the future. The SOM approach provides a powerful means of simplifying heterogeneous land cover characteristics that can be associated with water quality patterns and identify problem areas to target management.

1. Introduction

Non-point sources of contaminants, including runoff from agricultural and urban landscapes, are the most common sources of water quality impairment globally (Patterson et al., 2013; Lintern et al., 2020). Of the many contaminants that are found in urban and agricultural runoff, phosphorus (P) and nitrogen (N, especially as nitrate-N; NO3-N), are two of the most reported chemicals that routinely exceed thresholds for the protection of water resources (Omernik et al., 2016; Powers et al., 2016; Abbott et al., 2018). Likewise, chloride (Cl^-) is frequently measured at concentrations that exceed guidelines for aquatic life in seasonally snow-covered regions where winter road salt is applied, and salinity levels that approach seawater have been reported in some systems (Dugan et al., 2017; Kaushal et al., 2021). While Cl^- enrichment of waterways is almost always attributed to an urban origin, attribution of the sources of N and P is often more difficult, especially in heterogeneous, mixed land use watersheds that dominate most developed areas of the world (e.g., Kandler ¨ et al., 2017; Zeiger and Hubbart, 2017; Xue et al., 2023). For example, P enrichment is common in both agricultural and urban runoff (Macintosh et al., 2018), with high P exports in urban areas attributed to their 'flashy' hydrology, which enhances erosional losses as well as multiple, P-enriched sources in urban landscapes (e.g., Winter et al., 2007; Duan et al., 2012). Likewise, elevated P losses from agricultural landscapes are associated with P enrichment of soil due to long-term fertilizer and manure inputs (Beaulac and Reckhow, 1982), with much of the P in agricultural streams present in the particulate form (Reid et al., 2018; Sandstrom ¨ et al., 2020). In contrast, N in agricultural runoff tends to be dominated by dissolved inorganic NO_3-N and is frequently associated with fertilized cropland (Beaulac and Reckhow, 1982; Stets et al., 2015; Liu et al., 2022); although some studies have reported high NO3-N levels in urban runoff as well (Yang and Lusk, 2018). Even Cl^- attribution is not always straightforward, as Cl− is a component of fertilizer (i.e., potash; KCl) and Cl− enrichment has been reported in agricultural drainage waters (David et al., 2015). These ambiguities in source attribution are problematic for water quality protection, as best management practices will only be effective if they target the correct source.

Further complicating water resource protection is the dynamic nature of human land use, with both urban expansion and agricultural intensification being the primary culprits for persistent water quality impairments in inland and coastal systems around the globe (Brooks et al., 2016; Paerl et al., 2018; Basu et al., 2022). Indeed, agricultural intensification has been associated with urbanization, since urban expansion often occurs at the expense of peripheral agricultural land, which puts pressure on remaining agricultural landscapes to produce more from less (Hofmann, 2001). As well, changes in agricultural management practices like tillage type, fertilizer application, tile drainage, and crop rotation affect the amounts and forms (dissolved vs. particulate) of P and N losses to waterways. For example, conservation tillage practices that minimize mechanical disturbance of surface soil are associated with declines in overland runoff as well as particulate P losses via erosion (Bundy et al., 2001). However, some studies have suggested that the absence of mechanical mixing, especially in fine textured soils where fertilizers are surface broadcast, may unintentionally enhance losses of NO_3-N and soluble reactive P (SRP) by allowing surface-enriched nutrients to leach from soils via macropores (e.g., cracks and biopores) that persist year-round and provide conduits for dissolved nutrients to bypass the soil matrix (Joosse and Baker, 2011; Jarvie et al., 2017). This is of particular concern in tile-drained croplands, where bypass flow has the potential to leach nutrients directly to drainage tiles from where they can be delivered relatively conservatively to downstream aquatic ecosystems (Williams et al., 2016).

As contaminants are generated from a wide range of human activities dispersed across extensive areas, non-point source pollution is difficult to monitor and control and the relative influence of major sources such as agriculture and urban land uses can be challenging to distinguish from each other (Eimers et al., 2020). Models are useful tools for disentangling the complex spatial relationships between water quality, land cover and land use, and can inform management efforts by identifying 'hot spots' of contaminant release to waterways. Many previous modelling studies have focused on broad land cover categories (e.g., total agriculture; Tran et al., 2010; Nielsen et al., 2012; Mooney et al., 2020), or have aggregated urban and agriculture together into a 'developed' land category (Basu et al., 2022). However, this can obscure many aspects of land use management and shifts over time that are important predictors of water quality. Furthermore, past approaches have relied on conventional statistical methods due to their simplicity, whereas more recent advances in artificial intelligence, such as machine and deep learning methods, have greatly expanded the potential for evaluating non-linear relationships between spatial land cover with water quality (Maier and Dandy, 2000; Basu et al., 2022). In particular, self-organizing maps (SOM), an unsupervised artificial neural network, have been effective for explaining water quality patterns associated with land use and socio-environmental management (Kim et al., 2016; Neumann et al., 2017; Zhang et al., 2018; Gu et al., 2019).

Here, we apply a SOM approach to evaluate the contributions of various forms of land cover to water quality impairment in southern Ontario, a population-dense, yet highly agricultural region in the Laurentian Great Lakes basin where urban expansion and agricultural intensification have been associated with continued water quality impairments in Lakes Ontario and Erie, respectively (Thomas et al., 2018; DeBues et al., 2019; Sorichetti et al., 2022). The frequently complementary relationship between urban expansion and agricultural intensification is not unique to this area and affects many developed regions around the globe (Bren d'Amour et al., 2017). As such, results from this study may be viewed as a harbinger of what might be expected in other regions. The overall objective of this analysis was to evaluate the contribution of different types of land cover (urban vs. agriculture), land use (e.g., row crop agriculture vs. pasture) and agronomic practices (e.

g., conservation tillage, tile drainage) to water quality impairment, to ultimately inform management practices. Relationships between stream NO_3-N with row crop agriculture and related land use practices (e.g., fertilizer and manure application, tile drainage) were predicted, even across a broad geographic scale due to the high solubility and mobility of

NO3-N and the strong influence of N inputs associated with row crop production. Agricultural watersheds with a greater proportion of livestock production were expected to have the highest TP concentrations, and both types of agricultural watersheds were expected to have higher N and P levels compared with urban watersheds. Lastly, as elevated Cl^- levels are commonly associated with de-icing activities, the enrichment

of streams with Cl^- was predicted to be pervasive across all types of watersheds due to the ubiquitous presence of roads; however, Cl^- concentrations were expected to be highest in the most urbanized watersheds with higher human population densities.

Calculating Stormwater and Nitrogen Loading Reduction/ Prevention

Pollution Load Estimation Tool (PLET) See PLET
PLET employs simple algorithms to calculate nutrient and sediment loads from different land uses, and the load reductions that would result from the implementation of various best management practices.

The tool employs simple algorithms to calculate:

- nutrient and sediment loads from different land uses, and
- the load reductions that would result from the implementation of various best management practices.

Pollutant Load Reduction Calculator
From New York State Department of Environmental Conservation (DEC) to ensure consistency when estimating potential load reductions for selected Best Management Practices. DEC has developed the Pollutant Load Reduction Calculator with accepted efficiencies for nitrogen and phosphorus for commonly implemented practices. The method used to estimate load reductions does not account for soil information, slope, or other site specific factors that may influence potential pollution reductions for a practice. This additional information would impact the practice efficiencies. All best management practices have been assigned the same efficiencies, based on the efficiencies in DEC's Stormwater Management Design Manual.

Model My Watershed See Model My Watershed
Model My Watershed can be used in several ways to address nitrogen and stormwater reduction. Numbers 1 & 3 are really easy and intuitive to use – they make it feasible to look any many options fairly quickly. Number 2 takes more work and knowledge but can give you more precise estimates.

1. Use the multi-year model for average annual loads of N, P and sediment. You can use the Infiltration/Bioretention practice, based on total acres of implementation in the selected watershed area.
2. If you want to get a little more sophisticated, you can utilize the "multi-year model worksheet", which is significantly more complicated, but allows more control and manipulation of the details of land use and bmp functions.
3. You can also use the "Site Storm Model" option. This tool is a hybrid of the SLAMM, TR 55, and STEPL models and is primarily used for smaller, more developed areas. The model allows you to outline specific BMP areas, using your mouse, these include rain gardens, porous paving, green roof, vegetated basin, etc. The model also allows you to model changes to land cover, including assorted densities of development, forest, grassland, etc. The site storm model allows you to look at the impacts of different storm events (i.e. ½ inch rainfall vs 2 inch rainfall vs 5 inch rainfall) in different development or BMP scenarios. This tool provides outputs for the different storm events rather than the annual load estimates predicted by the multi-year model.

Calculating Pollution Prevent and Reduction from Tree Planting

US Forest Service i-Tree. See: MyTree calculator

The University of New Hampshire Stormwater Center – New England Stormwater Retrofit Manual See Stormwater Retrofit Manual
The manual presents the US EPA (Environmental Protection Agency) **Stormwater Control Measures (SCMs) Performance Curves as a tool to quantify water quality benefit (i.e. pollutant removal credit) for a range of sizes and types of SCMs** to aid in the selection process and justify the retrofit.The manual takes practitioners through the fundamental approach for retrofit, sizing, design and performance characterization, an introduction of performance curves and stormwater control measure design criteria including detailed sizing requirements and guidance.

The University of New Hampshire Stormwater Center - Pollutant Removal Credits for Buffer Restoration in MS4 Permits.
Sound management of buffer areas is an effective approach to protecting water quality in New Hampshire as well as other New England states. However, regulators and communities lack synthesized, scientifically justified guidance on how to quantify the water quality benefits of buffers and compare them to those derived from other structural Best Management Practices (BMPs). The *Credit for Going Green* project helped address this need by using an expert panel process to develop consensus-based recommendations for pollutant load reduction performance curves for restored or constructed buffers. These curves are intended to meet in-stream pollution reduction targets in development, redevelopment, restoration, or other land use change projects. This report describes the work and findings of the project's expert panel from January 2018 to March 2019.

Natural Resources Conservation Service (NRCS) Soil Web Survey
The New England Stormwater Retrofit Manual by the University of New Hampshire Stormwater Center and the NRCS Web Soil Survey were used to estimate nutrient and sediment loading reduction.

Green Values Stormwater Calculator
This tool was developed by the Center for Neighborhood Technology in collaboration with the US Environmental Protection Agency's Office of Wetlands, Oceans, and Watersheds. **It aligns with methodology used for many regulatory requirements and provides a quick way to compare pre-development and post-development conditions using both conventional and various green infrastructure improvements**. Additionally, the tool displays construction costs, maintenance costs, and additional environmental benefits. The calculator allows you to define one or more properties and then evaluate what combination of Green Infrastructure Best Management Practices (BMPs) meet the necessary volume capacity capture goal in a cost-effective way. See Green Values Calculator

National Stormwater Management Calculator:
EPA's National Stormwater Calculator (SWC) is a software application tool that **estimates the annual amount of rainwater and frequency of runoff from a specific site using green infrastructure as low impact development controls.** The SWC is designed for use by anyone interested in reducing runoff from a property, including site developers, landscape architects,

urban planners, and homeowners. **The tool is free to use and offers a range of low-impact development practices that the user can model by modifying basic design properties**. The tool also offers construction and maintenance cost estimates, which can be useful in informing development design. See National Stormwater Management Calculator

Green Infrastructure Flexible Model (GIFMod)

A computer program that can be used to evaluate the performance of urban stormwater and agricultural green infrastructure practices. It allows users to build conceptual models of green infrastructure practices to predict hydraulic and water quality performance under given weather scenarios. Some examples of GI techniques include: Cisterns/Rain Barrels, Bioretention, Vegetated (Green) Roofs, Infiltration Practices (Basins, Trenches, Dry Wells), Pervious Pavement with Infiltration, and Vegetated Swales. See GIFMod

Visualizing Ecosystems for Land Management Assessment (VELMA) Model

A computer software model that regional planners and land managers can use to quantify the effectiveness of natural and engineered green infrastructure management practices for reducing nonpoint sources of nutrients and contaminants in streams, estuaries, and groundwater. These practices include riparian buffers, cover crops, and constructed wetlands. See VELMA

Estimating Stormwater Runoff

This chapter discusses the easiest methods to determine the stormwater treatment volume. Estimating stormwater runoff is a basic initial step in the design of the stormwater management system as well as the erosion control plan. This chapter presents several commonly used methods and procedures used in this process.

Stormwater Management and Calculations

From North Carolina this chapter provides runoff coefficient determined by estimating the area of different land uses within each drainage area. It provides formulas and calculations for various land types.

Computing Stormwater Runoff and Volumes

From NJ - **discusses the fundamentals of computing stormwater runoff rates and volumes from rainfall through the use of various mathematical methods.** To do so effectively, the chapter also describes the fundamentals of the rainfall-runoff process that these methods attempt to simulate. Guidance is also provided in the use of the **Natural Resources Conservation Service, Rational, and Modified Rational Methods/**

NY State DEC Stormwater Management Design Manual Runoff Reducation Worksheets – Farm Design Example

New York State Stormwater Management Design Manual Chapter 4: Unified Stormwater Sizing Criteria

This chapter presents a unified approach for sizing green infrastructure for runoff reduction and stormwater management practices to meet pollutant removal goals, **reduce channel erosion, prevent overbank flooding, and help control extreme floods.**

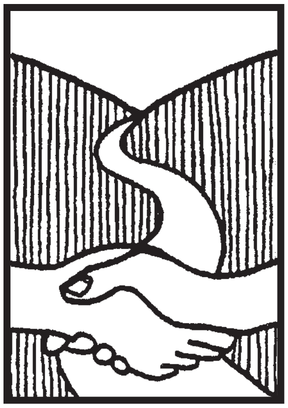
General Information about Green Infrastructure Resources

- EPA's Green Infrastructure Wizard, or **GIWiz**, provides access to tools and resources that can support and promote water management and community planning decisions including:
    - **Quick Links** – Customized access to thousands of green infrastructure tools & resources.
    - **Explore** – Access to an interactive database of green infrastructure tools & resources, based on your individualized specifications

Preventing N Loading at Treatment Plants

EPA Nutrient Control Design Manual
Design for WWTF and WWTP.

WD-03-42



Best Management Practices to Control Nonpoint Source Pollution

A Guide for Citizens and Town Officials

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NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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INTRODUCTION

Residents and visitors alike will attest that New Hampshire's waters are an ideal place to swim, fish, and sail. Many people feel strongly that future generations should also have access to clean water. However, all freshwater lakes, rivers, and streams in New Hampshire are currently listed as "impaired" because of a fish consumption advisory for mercury contamination. Additionally, the state has 10,505 acres of lakes and 1,178 miles of rivers classified as threatened or impaired by other pollution sources. Fortunately, this is a small percentage of lakes and rivers in New Hampshire. Although there have been great advances in reducing pollution from industrial discharges and sewage treatment plants in the last 25 years, according to the EPA about half the water quality problems nationwide now are associated with nonpoint source pollution. Polluted runoff from the land is called nonpoint source (NPS) pollution. It occurs when rain or snowmelt flows over land as runoff, or through the ground as groundwater, picks up pollutants, and eventually discharges to a body of water.

Urban and suburban land uses, construction, forestry, septic systems, recreational boating, agriculture, and physical changes to stream channels are potential sources of NPS pollution. NPS pollution is widespread and we all contribute to it by driving a car, applying fertilizer to a lawn, converting land for a new home or business, and sometimes even taking a pet for a walk.

The purpose of this guide is to describe the causes of NPS pollution and to suggest ways that NPS pollution can be prevented or at least reduced. Best management practices (BMPs), which are land treatment or operational techniques used to prevent or reduce pollution, are listed along with references for more information. **Section 1** provides background information on water resources and how they can be impacted by NPS pollution. **Section 2** describes water resource impacts from existing and new development, provides suggested BMPs, references applicable laws and regulations, and lists additional resources. **Section 3** describes specific land use activities that could affect water resources, provides suggested BMPs, references applicable laws and regulations, and lists additional resources. **Section 4** describes how to get involved in local watershed organizations and volunteer water monitoring

What is a BMP?

There are multiple terms associated with the control of non-point source pollution. This document uses the term BMPs, which are individual practices that serve specific functions.

BMPs can be structural, such as a fence for excluding livestock or a buffer strip to reduce sediment in runoff, or non-structural such as street sweeping.

BMPs are designed to reduce the pollutants that are generated at and/or delivered from a source to a water body.

It is important to acknowledge that the term "best" is highly subjective and the appropriateness of certain practices may vary regionally or depending on land use.

BMPs, in general, control the delivery of NPS pollutants to water bodies in the following three ways:

- source reduction by minimizing pollutants available in the first place;
- retarding the transport of pollutants by reducing water transported or by retaining pollutants; and
- remediating or intercepting the pollutants before or after they are delivered to the water resource by chemical or biological transformation. ■

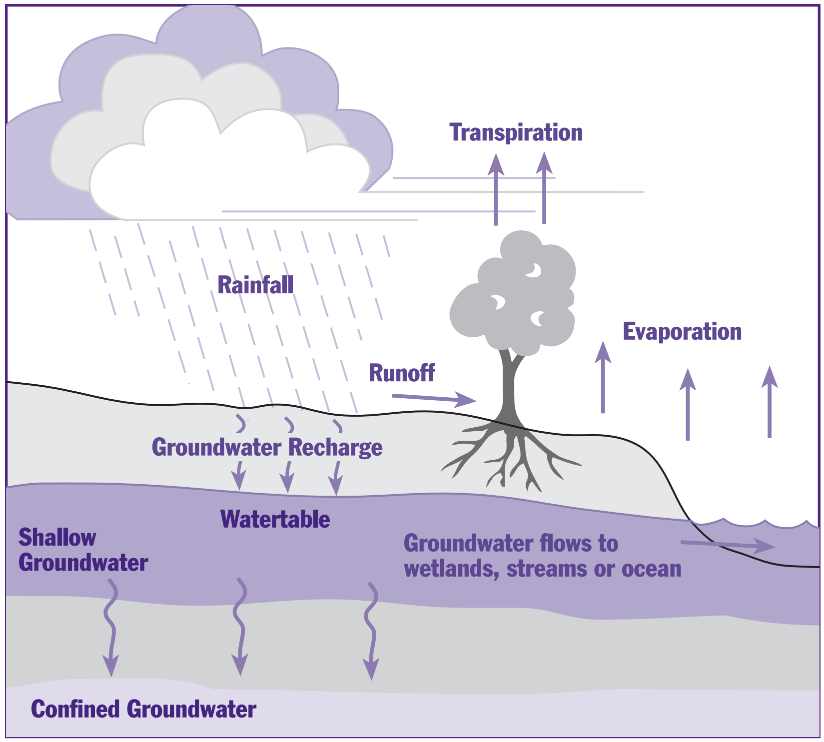
activities. Funding opportunities for efforts to reduce NPS pollution are listed in **Section 5**. Finally, the appendix lists contact information for agencies referenced in this guide.

The New Hampshire Department of Environmental Services (DES) is working to reduce non-point source pollution in New Hampshire in several ways. Many of our efforts are linked to the *New Hampshire Nonpoint Source Management Plan*, which was developed in October, 1999 and is available online at www.des.nh.gov/wmb/npsplan.pdf. This plan contains a five-year action plan and lists NPS types in order of priority. Anyone with further questions should contact the DES Watershed Assistance Section at (603) 271-2457. Many of the DES references listed in this guide can be accessed on our website at www.des.nh.gov.

1 WATER RESOURCES AND NONPOINT SOURCE POLLUTION

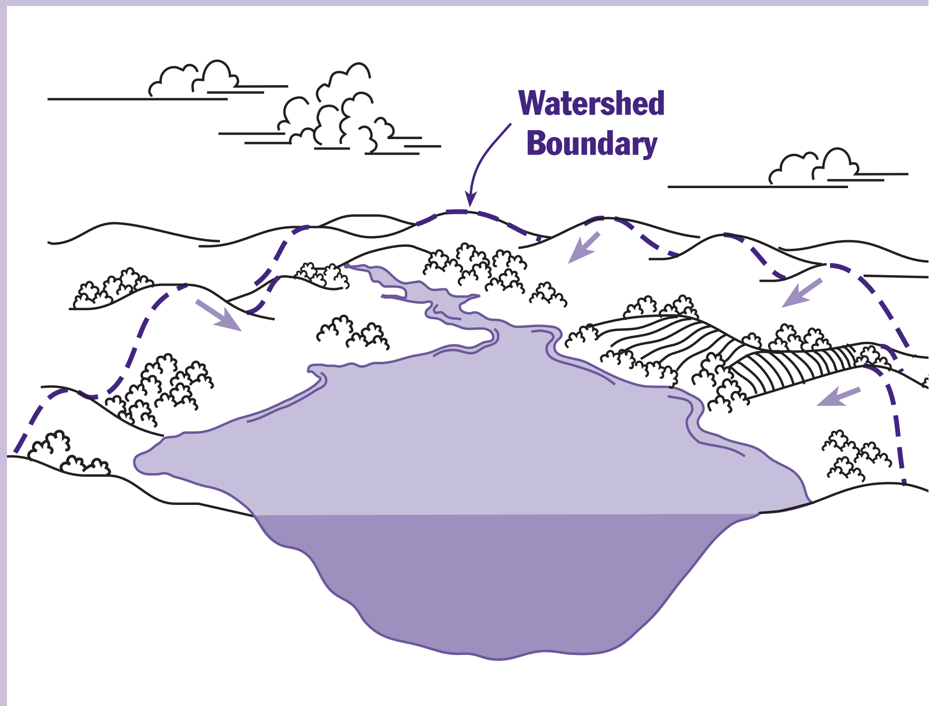
The Water Cycle and Pollution

Water in oceans, lakes, ponds, rivers, streams, wetlands, groundwater, ice sheets, and the atmosphere are all linked by the hydrologic cycle, the movement of water from one system to another. The atmosphere holds large quantities of water vapor, which falls as rain or snow. This precipitation falls directly into surface water bodies (such as a lake or river) or onto land surfaces, where much of it seeps into the ground and eventually becomes groundwater. Lakes, streams, and wetlands are formed where the slowly moving groundwater intercepts the ground surface. In fact, about 50 percent of the water in New England streams is groundwater discharge. Eventually, all of this water finds its way back to the ocean, where it will evaporate into the atmosphere, become rain or snow, and continue through the cycle.



The term "water pollution" often evokes an image of large pipes delivering unsightly wastewater from factories into rivers and streams. Public awareness of this problem and strict federal laws enacted during the past 30 years have made it rare today to find such obvious examples of water pollution. Yet water pollution remains a problem, due in part to nonpoint source pollution. Pollutants follow the paths water takes in the hydrologic cycle and affect the quality of our waterbodies. For example, pollutants from septic systems may impact the same groundwater that is tapped for water supply wells, or pollutants may move with the groundwater before discharging into a stream. Oil leaking from cars is carried with surface runoff from parking lots and is discharged into streams. Sulfur dioxide and nitrogen oxides emitted into the air from power plants and combustion engines are converted in the atmosphere to sulfuric acid and nitric acid and are deposited on the earth with precipitation. This acid deposition can cause several ecological problems, such as fish deaths. Similarly, tiny amounts of mercury enter our atmosphere from sources such as incinerators and power plants; the mercury attaches to rain drops and dry particles and follows the pathways of the water cycle. Mercury concentrations increase up the food chain from water to plankton to fish and to animals that eat fish. High concentrations of mercury in fish have caused many states, including New Hampshire and all New England states, to issue health warnings about freshwater fish consumption.

The Watershed Approach



A watershed is defined as the geographic area in which all water running off the land drains to a given stream, lake, wetland, or other waterbody. A watershed can be thought of as a funnel with the waterbody at the bottom of the funnel and the high points, such as mountains, at the top. The size of the drainage area can be as small as your backyard or as large as several thousand square miles. Nonpoint source problems can originate anywhere in a watershed.

There are five major watersheds in New Hampshire; these include the Coastal/Piscataqua River, the Merrimack River, the Connecticut River, the Saco River, and the Androscoggin River. These five watersheds are made up, in turn, of many smaller watersheds defined by each of the rivers, lakes, ponds, and streams that feed into the bigger rivers. It is most effective and easiest to work in the smallest watershed unit possible when addressing water quality problems.

Tackling water quality issues using a watershed perspective makes a lot of sense because water quality problems often result from a number of smaller sources that cumulatively have a measurable, negative impact on receiving waters. Moreover, good water quality is best protected by managing land use practices in the watershed. The challenge of using a watershed approach to manage water quality, however, is that watershed boundaries do not typically follow town, state, or international borders. Organizations and citizens within a watershed must often come together from across municipal boundaries to design creative management solutions. ■

Another form of nonpoint source pollution is hydrologic modification. This term refers to activities that affect the natural pathways of surface water, such as stream channel modification and channelization, dam construction and operation, and streambank and shoreline erosion. Although these activities don't seem like forms of pollution, they nevertheless are considered to be part of the NPS pollution problem. Many rivers and streams have natural flood control areas, such as oxbows, adjacent wetlands, and riparian zones. When these areas are modified or removed, significant changes in the ecological functions of surrounding lands are likely to occur. Channel modifications frequently degrade instream and riparian habitat for fish and wildlife. Other impacts include erosion and the reduction of the system's ability to filter pollutants. Similarly, increased development around the perimeters of lakes and ponds can change surface hydrology and reduce natural buffers.

2 BEST MANAGEMENT PRACTICES FOR DEVELOPED OR DEVELOPING LAND

This section discusses water quality issues related to previously-developed areas and developing areas, and offers management practices to reduce nonpoint source pollution for both types of areas.

Areas of New Development

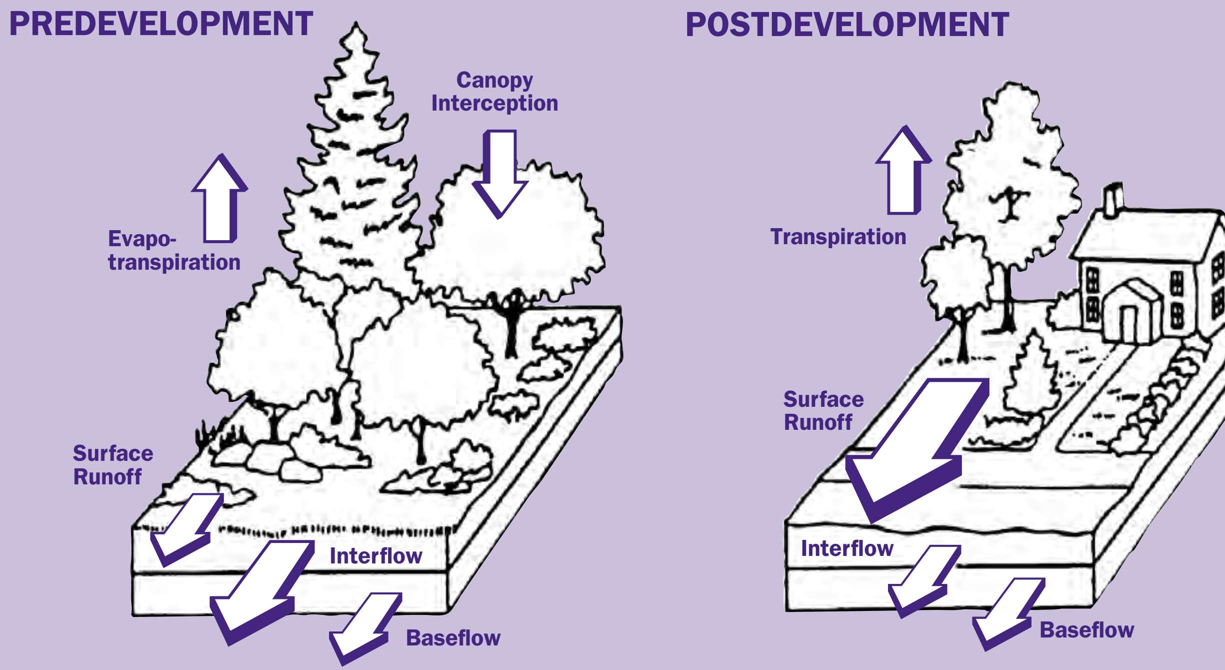
The rural character of New Hampshire is something many people cherish and wish to preserve. Nevertheless, it is obvious that the state is undergoing development and growth, particularly in the southern part and the Seacoast region. Between 1990 and 2000, the population of New Hampshire increased by 11.4 percent, which made it the fastest growing state in New England. Vacation homes comprised 10 percent of the residential units in the state in 2000, and as the regional and national population increases, the interest in New Hampshire as a place to have a second home will likely continue to grow. New Hampshire will have to accommodate new residents and vacationers with more houses, office buildings, shopping centers, schools, and roads. As land is converted from forests or farm fields to a house, road, or parking lot, there are inevitable effects on water quality and quantity.

New residential, commercial and industrial development can increase NPS pollution for many reasons, including the greater use of chemicals on developed land (e.g., fertilizer, pesticides, oil, detergents), the greater potential for erosion due to the disturbance and use of the site, and the increase in impervious cover, which results in more runoff. In addition, development often reduces the amount of vegetated areas that buffer the impact of the increased runoff and higher pollution levels.

Development can also impact the movement of water or hydrologic functions of a watershed. Such impacts can include

Impact of Impervious Cover

Development involves the construction of hard surfaces, such as roofs, roads, sidewalks, and parking lots, that water cannot penetrate. These types of surfaces are collectively referred to as “impervious cover.” Impervious cover increases the amount of water that will run off land during a rainstorm or as snow melts, which can lead to increased NPS pollution. Numerous studies have examined the relationship between the amount of impervious cover in a watershed and the health of waterbodies in that watershed. These studies find that the quality of streams, wetlands, and other waterbodies declines sharply when the impervious cover within the watershed exceeds just 10 percent. Land use practices that reduce runoff or intercept runoff before it reaches a waterbody help reduce the impacts associated with impervious cover. Allowing water to infiltrate into the ground helps clean the water and restore groundwater levels, which is especially important during times of drought. ■



changes in the rate of flow of water, reduced amount of recharge or infiltration, and increased volume of water during storm events. Alterations to watershed hydrology can negatively affect aquatic habitat by lowering the water table, reducing base flows, increasing water temperatures, reducing shading of streams and rivers, and reducing the accumulation of natural biomass in streams and rivers.

Conventional stormwater management systems, including curbs, gutters, storm drains and piping, paired with a large structural BMP, such as a retention/detention pond, can help control peak flows and reduce water quality impacts. But, typically this does little to maintain natural hydrologic functions on the site, including natural infiltration rates or direction of water flow. Additionally, such traditional stormwater management systems are expensive and involve extensive earthwork and installation of materials.

Alternatively, a more innovative stormwater management approach can provide increased opportunities for stormwater to infiltrate, better maintain natural watershed hydrology, and limit impacts to habitat. The alternative approach uses open, grassed channels to hold and convey water along with numerous smaller-scale BMPs and landscape features dispersed throughout a developed area to regulate water flow and remove pollutants. Vegetation is recommended as part of any stormwater management approach to stabilize soil, filter out pollutants, and reduce runoff volume; it can be as simple as vigorous plantings around new construction.

In addition to providing for effective stormwater management, new developments can also be located and designed in ways that minimize NPS pollution. Municipalities can develop an education program and use their local planning and site plan and subdivision review processes to encourage the use of practices that minimize nonpoint source pollution.

BMPs for Areas of New Development

Both designing and locating new development offer opportunities to use BMPs to minimize NPS pollution.

Designing New Development

Conservation design minimizes the amount of land disturbed for development, maintains significant ecological areas in a natural state, and reduces the amount of impervious surface created. Energy and water efficiency also are maximized.

Following these practices provides other benefits in addition to protecting surface water quality. For example, the practices listed below help maintain groundwater supplies by increasing infiltration of water into the ground; help protect wildlife habitat by maintaining undisturbed land, especially along wetlands, streams, and other riparian areas; and help reduce air pollution from vehicle travel by encouraging more compact development that supports walking and biking and reduces vehicle use. Encouraging non-motorized transport through changes in design improves human health by improving air quality and by engaging people in physical activity. Improved human health in turn reduces medical costs associated with bad air quality (such as asthma) and inactivity (such as obesity and heart disease), which saves money for all of us.

Low-Impact Development Design

An alternative, more innovative stormwater management approach—called "low-impact development (LID) design"—can provide increased opportunities for stormwater to infiltrate, better maintain natural watershed hydrology, and limit impacts to habitat. LID focuses on:

1. site design techniques that reduce runoff and maintain existing hydrologic features; and
2. site-level or "at-source" stormwater controls.

The fundamental LID site planning concepts include:

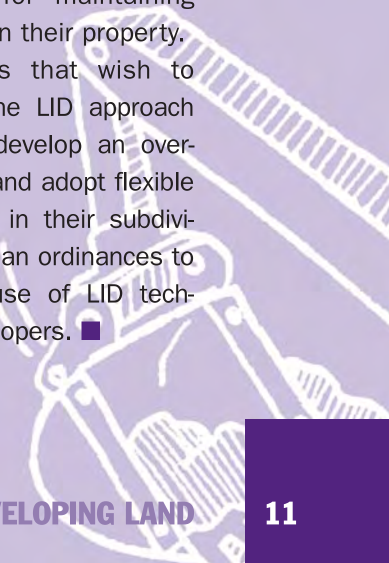
- using hydrology as a basis for designing new development;
- thinking "micromanagement" for stormwater control;
- controlling stormwater at the source;
- using simplistic, nonstructural stormwater control methods when feasible; and
- creating a multi-functional landscape and infrastructure.

Hydrology is integrated into the site planning process by first identifying and protecting the following areas important to the natural hydrology of the site: streams and their buffers, floodplains, wetlands, steep slopes, high-permeability soils, and woodland conservation zones. Future development is then located in remaining areas that are less sensitive to disturbance or have lower value in terms of hydrologic function. The development is then designed to minimize clearing and grading, minimize and disconnect impervious surfaces, minimize the quantity and velocity of surface runoff, and provide for on-site/on-lot management of runoff. Additionally, the existing topography and drainage pattern is maintained to disperse flow paths.

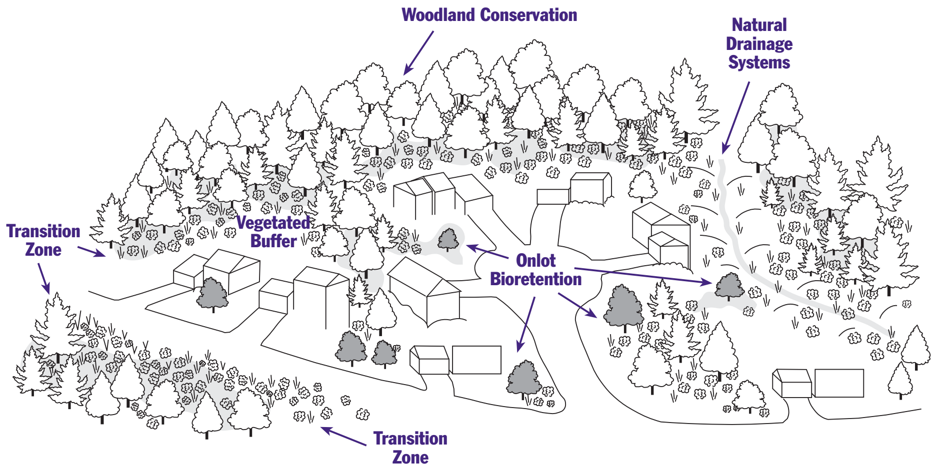
Whenever possible, LID designs use open, vegetated drainage systems in lieu of conventional storm drains. LID flow and conveyance systems are designed to maximize overland sheet flow, involve wider, rougher, and longer flow paths, and include pockets of vegetation (trees and shrubs) in the flow path. In addition, flows from large paved surfaces are dispersed in multiple directions, using sheet flow when feasible.

In addition to the above design considerations, LID involves micromanagement of stormwater using small-scale integrated management practices (IMPs) distributed throughout the site. Example IMPs include on-lot bioretention facilities, dry wells, filter/buffer strips, grassed swales, bioretention swales, wet swales, rain barrels, cisterns, and infiltration trenches. These techniques are used to control runoff at its source. As with other BMPs, IMPs also require monitoring and periodic upkeep, including trash removal and maintenance of vegetation. But with education on the purpose and proper care for IMPs, private property owners can often assume responsibility for maintaining IMPs located on their property.

Communities that wish to benefit from the LID approach may need to develop an oversight program and adopt flexible zoning options in their subdivision and site plan ordinances to facilitate the use of LID techniques by developers. ■



Locating New Development



- Locate development close to existing developed areas.
  - Provide a greater chance of connecting to a sewer system, which reduces the possibility of NPS pollution from individual septic systems.
  - Require less pipe to connect to the sewer system, which lowers the chance for leakage of untreated wastewater, and lowers the cost of the project as well.
  - Shorten the distance to shopping and other services/activities to reduce vehicle travel, thereby reducing local air pollution, and increasing opportunities to walk or bike. This can also reduce NPS pollution from the deposition of air pollutants.
- Locate close to existing roadways.
  - In addition to the above benefits, a shorter access road and/or driveway will reduce the amount of impervious surface created by the development.
- Locate away from surface waters.
  - Increase opportunities for treatment of runoff before it reaches surface water.

Principles of Conservation Design

- Use narrower and shorter streets, driveways, and rights-of-way.
- Put sidewalks on only one side of the street.
- Allow for smaller lots and narrower setbacks and frontages to reduce the amount of land “disturbed” by development, maximize the amount of land retained in open space, and require less roadway and driveway.
- Reduce the size of parking areas and use permeable surfaces for overflow parking areas.
- Reduce the amount of area maintained as lawn, and use drought-tolerant species of grass to reduce watering needs where grass is desired.
- Disconnect impervious surfaces (e.g., slope driveways towards lawns or other vegetated areas rather than the street).
- Maintain significant vegetated buffers for surface waters and do not mow to the edge of the water.
- Use open, grassed swales to convey stormwater rather than a curb and gutter system.
- Use all available natural resource information in designing the development.
- Integrate smaller-scale BMPs and landscape features throughout the site to manage stormwater and control NPS pollution.
- Require enhanced performance septic systems or regular septic system inspections when a development is not served by sewer.
- Encourage onsite collection or infiltration of rainfall/runoff from individual homesites (e.g., install rain barrels and cisterns to collect roof runoff, incorporate small bioretention areas or ‘raingardens’ on home sites to manage rainwater). ■

Previously-Developed Areas

Many people think that urban areas are found only in large cities and towns, but many of New Hampshire's villages and small towns also have areas that are densely developed. Pockets of development in rural towns, such as shopping centers, have some of the same water quality issues that cities do. The practices discussed in this section apply to any developed area.

Developed areas typically have higher amounts of impervious surfaces and existing stormwater drainage systems. Many older stormwater drainage systems collect water and pollutants from impervious surfaces and discharge them directly to a stream, river, or other surface water body. As a result, watershed hydrology is impacted and pollutant loads increase.

To reduce NPS pollution, management of developed areas can take steps to prevent pollutants from entering stormwater. Additionally, urban and developed areas can be retrofitted by installing structural BMPs to reduce, collect, and treat stormwater. Redevelopment and renovation of existing sites provides excellent opportunities for improving stormwater management and reducing NPS pollution. DES has written a guide summarizing innovative retrofit BMPs called *Innovative Stormwater Treatment Technologies: Best Management Practices Manual.*

DES has produced other BMP manuals specifically for developed areas, *Best Management Practices for Urban Stormwater Runoff* and *Stormwater Management and Erosion and Sediment Control Handbook for Urban and Developing Areas in New Hampshire.* The first guide covers the BMPs required by the DES Alteration of Terrain Permit Program. The second is a comprehensive reference for structural and vegetative BMPs, such as detention basins, level spreaders, grassed waterways, and others.

An additional guidance document, *Managing Stormwater as a Valuable Resource: A Message for New Hampshire Municipalities and Water Suppliers,* provides information on managing stormwater to protect water supply resources and the conditions under which artificial infiltration BMPs, such as infiltration trenches and infiltration basins (or ponds), can be used.

Planning boards may need to enlist professional engineering services to review development proposals. Such services may be available through county conservation districts, regional planning agencies, and private consultants.

BMPs for Previously-Developed Areas

The following practices and structural BMPs can reduce NPS pollution from existing developed areas:

General Guidelines

- Use vegetation extensively to filter runoff before it enters surface waterbodies.
- Divert runoff around sites where pollutants could be picked up by surface flow (e.g., gas stations).

- Inspect areas periodically to make sure that potential pollutants, such as raw materials for an industrial process, are not left in areas where they can be transported by runoff into waterbodies.
- Keep parking areas, outdoor storage areas, and streets clean of debris. Street sweeping can be used to remove sediment, debris and trash from streets and parking areas.
- Clean out catch basins and other flow control devices regularly to prevent backup and overflow of sediments and pollutants.

Specific Structural BMPs

- **Bioretention Area**

  A practice to manage and treat stormwater runoff by using a conditioned planting soil bed and planting material to filter runoff stored within a shallow depression. The system can include the following components: a pretreatment filter strip of grass in an inlet channel, a shallow surface water ponding area, a bioretention planting area, a soil zone, an underdrain system, and an overflow outlet structure. For example, vegetated islands in parking lots can be recessed, rather than raised, and designed as bioretention areas.

- **Grassed Swale**

  An engineered grassed channel to transport stormwater. Dry swales facilitate quality and quantity control by allowing for infiltration. Wet swales use retention time and natural growth of water-tolerant vegetation to regulate flow and quality of stormwater before discharge.

- **Infiltration Trench**

  An excavated trench that is backfilled with stone to form a subsurface basin. Water is slowly infiltrated into the soil, usually over several days. Most effective when combined with some form of pretreatment, such as a filter strip, to reduce the amount of sediment reaching the trench.

- **Infiltration Basin or Pond**

  A grassed, flat-bottomed basin preceded by a sediment forebay or riprap apron to slow the flow of water and trap sediment. Water is slowly infiltrated into the soil, usually over several days.

- **Dry Well**

  A small excavated pit backfilled with aggregate, usually pea gravel or stone. Used to infiltrate runoff from building rooftops and in modified catch basins, where the inflow is direct surface runoff.

- **Stormwater Treatment Chamber**

  An underground, divided chamber used to remove sediment, oil and debris from stormwater. Such chambers are typically used in conjunction with a stormwater retention or infiltration BMP.

Laws and Regulations For Developed or Developing Land

All state laws in New Hampshire can be searched online at **gencourt.state.nh.us/rsa/html/indexes/default.html**

As of March, 2003, the National Pollutant Discharge Elimination System (NPDES) Stormwater Phase II rule ("Phase II") requires operators of small municipal separate storm sewer systems (called MS4s), operators of municipally-owned industrial activities, and operators of small construction sites (one acre or more) to implement programs and practices to control polluted stormwater runoff. More information on these regulations can be found at www.des.nh.gov/stormwater.

Local planning boards are authorized to regulate subdivisions and nonresidential and multi-family residential site development under **RSA 674:35** and **674:43**, respectively. The requirements for developing a local master plan are found under **RSA 674:1-4**. Zoning ordinances are covered under **RSA 674:17-20**. Innovative land use controls are described under **RSA 674:21**.

The Comprehensive Shoreland Protection Act (**RSA 483-B**) establishes minimum standards for the future subdivision, use, and development of the shorelands within 250 feet of the state's public waters. When repairs, improvements, or expansions are proposed to existing development, the law requires these alterations to be consistent with the intent of the Act. DES is responsible for enforcing the standards within the protected shoreland, unless a community adopts an ordinance or shoreland provisions that are equal to or more stringent than the Act. In addition to the standards of the Act, development within the protected shoreland must always comply with all applicable local, state, and federal regulations.

Site excavation is governed by **RSA 485-A:17**, known as the Alteration of Terrain or Site Specific Permit Program. Development as well as redevelopment activities may require a permit under this program. Please see page 23 for more information.

RSA-482-A and the rules promulgated under that law (**Env-Wt 100-700**) require that projects be designed to avoid and minimize impacts to wetlands and other jurisdictional areas. The impacts that are proposed must be only those that are unavoidable. It is the responsibility of the applicant to document these considerations in the application for a permit.

RSA 485-A gives DES the authority to regulate septic systems. Design, operating, and permit requirements are found in Administrative Rule **Env-Ws 1000**. The regulations require all subdivisions creating lots smaller than five acres to obtain approval from DES. If the site lies within a protected shoreline area, all lots, regardless of size, require approval from DES (**RSA 483-B**). Any developed waterfront property on great ponds and tidal waters with an on-site subsurface system must be assessed for compliance with current standards prior to the execution of a purchase-and-sale agreement (**RSA 485-A:39**).

What the Implementation of Phase II Means

For regulated MS4s, six minimum control measures must be implemented within five years of receiving the Phase II permit. Permittees must submit an annual report to EPA summarizing their progress toward achieving specific measurable goals in the six categories.

EPA has issued guidance on recommended BMPs and developing measurable goals and conducted a series of workshops on the Phase II requirements. DES is providing technical and financial support whenever possible.

Six Minimum Control Measures

1. Public education and outreach
2. Public participation and involvement
3. Illicit discharge detection and elimination
4. Construction site runoff control
5. Post-construction runoff control
6. Pollution prevention and good housekeeping

3 BEST MANAGEMENT PRACTICES BY LAND USE/ACTIVITY

This section identifies some of the land uses that generate NPS pollution, lists ways to control pollution by land use, and provides a list of resources.

Households

See BMP Resources on page 36

Reducing NPS Pollution Around Your Home

There are a number of BMPs that a household can employ to reduce their contributions to NPS pollution. Although each individual household may contribute only minor amounts of NPS pollution, the cumulative effects of household-level action to reduce pollution by an entire neighborhood or region of households can be significant.

Potential household contributions to NPS pollution include:

- bacteria, chemical, and nutrient discharges from septic systems;
- chemical use, storage, and disposal;
- sediments, chemicals, and nutrients from lawn and garden activities;
- runoff from impervious surfaces (e.g., driveways, roofs, patios);
- pet waste; and
- air pollution contributions, from energy use and vehicle use.

Septic Systems

A proper, well-maintained septic system will adequately treat your sewage. If it is not taken care of, a septic system may become clogged and overflow on the ground or cause wastewater to back up into the house. A failed system is unhealthy, expensive to replace, and may contaminate nearby ground and/or surface waters, including nearby wells. Taking a few precautions can avoid costly septic system problems.

- Know the location of your septic tank and leaching area; mark the tank cover(s) with partially buried bricks.
- Have your tank inspected yearly. If the sludge and surface scum combined are as thick as one third the liquid depth of your tank, have the tank pumped out by a licensed septage hauler.
- Keep bulky items such as disposable diapers, sanitary pads, cigarettes, or paper towels out of the system. These will clog the leaching system.
- Keep toxic materials such as paint thinner, pesticides, or chlorine out of your system. These chemicals may kill the necessary bacteria in the tank.
- Do not use septic tank additives. They may cause harm by killing essential bacteria.
- Repair leaking fixtures promptly; use water-reducing fixtures wherever possible to reduce the amount of water the system must treat.
- Avoid putting food waste and grease into the system or using a garbage disposal. Food waste will not only fill your septic tank rapidly and require more frequent pumping, but will also float and can eventually clog the leaching system.
- Keep deep-rooted trees and bushes away from the leach field.
- Keep vehicles, livestock, or heavy foot traffic away from the leach field, as the weight may compress the soil too much or break the pipes.
- Minimize the use of detergents and bleaches; use alternative cleaning products such as baking soda, borax, or non-chlorine scouring powders. Many cleaning products such as toilet bowl cleaners contain chlorine and strong acids that will kill the necessary bacteria in the septic system.

Chemical Use, Storage and Disposal

Hazardous household products such as cleaners, paint thinner, spot remover, oven cleaner, furniture polish, drain opener, pool chemicals, and even hair spray can be found in most home storage cabinets. Hazardous products can usually be identified by a warning label on the container. These products, when handled improperly, can contaminate a well, poison a stream, or disrupt the proper functioning of a septic system.

- Buy nontoxic alternatives whenever possible.
- Read the label carefully before buying, using, or disposing of products.
- Buy only the quantity that you need and use only the recommended amount.
- Store and label wastes safely, then bring them to a local household hazardous waste day collection (contact DES at 271-2047 for locations near you). Many towns also accept used oil for recycling.
- Hazardous chemicals should NOT be poured on the ground or down the drain, discarded in the trash, buried, or burned!

Lawn and Garden Activities

Landscaping and gardening practices can contribute to NPS pollution through lawn chemicals, fertilizers, silt, and sand. However, with a few minor changes, backyards can actually play an active role in improving water quality.

- Test your soil to know what it actually needs before you apply fertilizer or lime (contact your county UNH Cooperative Extension office for information on soil testing).
- When fertilizer is necessary, select a slow-release fertilizer to avoid excess nutrients running into the water. Under the Shoreland Protection Act, a 25-foot fertilizer-free buffer must be maintained around wetlands and surface water.
- Plant natural, native plant species instead of non-native plants (plants that were introduced for agricultural purposes or by accident). Native plants generally require much less water, herbicides, fertilizers, or trimming.
- When possible, reduce the size of your lawn by planting low-maintenance groundcovers, trees, flowers, and shrubs to help water infiltrate into the ground and prevent soil erosion.
- For new lawns, use 6-12 inches of topsoil to encourage deeper root growth
- For waterfront or wetland areas, maintain or plant a natural vegetation buffer at least 100 feet wide between the lawn and the water to hold soil in place, absorb pollution before reaching the water, and provide wildlife habitat. Some species of wildlife require more than 100 foot buffers.
- Start composting in your backyard and use compost on your gardens and lawns and around trees and bushes. Composting your yard and food waste is easy and will reduce the need for fertilizers and water by adding nutrients and helping the soil retain moisture.
- Refrain from using pesticides near surface water.
- Read pesticide labels carefully.

Impervious Surfaces

Runoff from stormwater washes across yards, driveways, roads, and patios, picking up loose soil, pet wastes, fertilizers, pesticides, oil, soaps, and other pollutants and depositing them into streams, rivers, and lakes. Water directed to pervious surfaces will help filter many of these possible contaminants before entering our surface waters in addition to recharging our groundwater supplies.

- Limit the amount of impervious surface on your property (impervious surfaces include sidewalks, roofs, driveways, and patios).
- Replace impervious surfaces with natural ground cover or with material that allows some water to seep into the ground, such as gravel, brick, stepping stones, wood chips, or other porous surface.
- Direct runoff from impervious surfaces to areas on your property where the water can seep into the ground. For example, direct roof downspouts away from the driveway or the storm drainage system and into a gravel swale or grassed area, or collect roof runoff in a screened-top rain barrel and use to water plants around your yard.
- Maintain or restore natural vegetated areas as buffers along river, lake, and coastal waterfronts.
- Sweep driveways and walkways instead of hosing them down.

Pets

Scooping your pooch's poop isn't just a neighborhood courtesy; it is also the healthy and environmentally sound thing to do. Pet waste may be a source of bacteria and nutrients in water. Just as we don't want human sewage in our water, it is important to prevent pet waste from littering our towns and being carried into our waterways. People drinking and swimming in water contaminated by pet waste could ingest harmful pathogens.

- Pick up pet waste and flush it down the toilet, bury it in the yard, or put it in the trash. Another option is to install an underground pet waste digester that works like a small septic tank. Some local laws or neighborhood rules may restrict their use.
- Do not put pet waste into storm drains.

Air Pollution – Acid Deposition

Through rain or snow, acid deposition deposits acids and acidifying compounds to the Earth's surface, which then move through soil, vegetation, and surface waters. Acid deposition is formed when emissions of sulfur dioxide and nitrogen oxides react with other substances in the atmosphere to form the acidic compounds. Sulfur dioxide and nitrogen oxides are emitted primarily from power plants and motor vehicles as a result of burning fossil fuels.

Acid Deposition leads to adverse impacts such as increased mortality among sensitive species, decreased visibility, and stunted forest growth. In addition, soils that are saturated with nitrogen have little capacity to buffer acid rain before it enters streams. The use of nitrogen fertilizers, nitrogen-fixing crops, and fossil fuels has doubled and continues to increase the rate of nitrogen entering the land.

- Reduce your use of electricity (turn off lights, turn down thermostats, hang laundry to dry, take quick showers, etc.).
- Drive your car less by carpooling, biking, walking, and combining trips.
- Maintain your car's pollution control equipment, keep your tires properly inflated, and keep your engine tuned.
- When buying a new appliance, such as a refrigerator or clothes dryer, put energy efficiency at the top of your list of desirable features and look for the Energy Star label indicating the item is energy efficient.
- When buying a new vehicle, ask the car dealer for a Granite State Clean Car and look for the Clean Cars Label indicating the vehicle meets lower emission standards and better fuel economy.
- Contact your electric utility to see what it is doing to reduce emissions.

Laws and Regulations

A complete copy of the rules governing septic systems in New Hampshire **Env-Ws 1000**, Subdivision and Individual Sewage Disposal System Design Rules is available at www.des.nh.gov/rules/envws1000.pdf. Hardcopy available at DES, 29 Hazen Drive, Concord, NH 03301, (603) 271-2975 for $10.

More information on the **Shoreland Protection Act** is available at www.des.nh.gov/cspa.

Under **RSA 261:153(V)** and **RSA 149-M:18**, city treasurers and town clerks can assess a fee to pay for collection and disposal fees of motor oil, car batteries, and car tires. A Vehicle Registration Fees fact sheet is available at www.des.nh.gov/sw.htm or call DES at (603) 271-2975.

After January 1, 2005, owners of on-premise heating oil tanks must meet DES "Best Management Practices for the Installation or Upgrading of On-Premise-Use Heating Oil Tank Facilities." On-premise-use facilities include heating oil tanks and piping located at single family homes, apartments, commercial buildings, and industrial facilities. Failure to achieve compliance by that date will prevent access to the state cleanup funds should an oil release occur. To assist owners in meeting this new requirement, **RSA 146-E** authorizes a grant program (up to $1,000) for owners who demonstrate a financial need. For more information, see DES fact sheet *OIL-24: Best Management Practices for the Installation and Upgrading of On-Premise-Use Heating Oil Tank Facilities* at www.des.nh.gov/factsheets/oil/oil-24.htm.

All state laws in New Hampshire can be searched online at **gencourt.state.nh.us/rsa/html/indexes/default.html**

Site Excavation and Road Construction

See BMP Resources on page 38

Site excavation and development, road construction, and road maintenance activities may not last long, but erosion and sedimentation from any earth moving can have long-term impacts on water quality. Towns may face financial impacts from removing sediments from ditches, culverts, and drains.

The road building process is more susceptible to erosion problems than other types of construction. Drainage ditches and channels built along roads to carry stormwater will erode easily before they are properly stabilized. Site excavation and development may make soil and attached chemicals more available, resulting in polluted lakes and streams. Bare soil particles are dislodged by rainfall and can be transported down slope to streams, lakes, and wetlands. The extent of erosion is influenced by exposure, rainfall intensity and duration, soil type, vegetation, topography, and season.

The sedimentation or deposition of material eroded by water from site excavation or road construction and maintenance activity can have significant negative effects on water quality and aquatic habitats from increased sedimentation. In addition to habitat losses for fish and invertebrates, wetlands can fill in and vegetation can be smothered; culverts and ditches can be plugged; and recreational potential can be reduced when soil loss from excavation activities is high. Nutrients and chemicals can be released from sediment that enters a waterbody. Released phosphorus can cause algal blooms in lakes and encourage eutrophication.

Construction sites may use numerous chemicals at the site, such as pesticides, fertilizers, petroleum products and construction chemicals. Solid wastes and sometimes hazardous wastes may also be handled on site. The "Chemicals and Petroleum Products" section of this document discusses BMPs for preventing NPS pollution from these sources.

BMPs for Marinas

- Use only phosphate-free detergents and establish a wash area over an infiltration trench or a vegetated swale. If possible, use a high-pressure sprayer with no detergents, or wait until the boat is out of the water to clean it.
- Perform periodic engine maintenance (e.g., changing oil, winterizing) out of the water. Propylene glycol should be substituted for ethylene glycol antifreeze when winterizing engines. The oxidation of propylene glycol yields pyruvic and acetic acids, which are not toxic to aquatic organisms.
- Scrape, sand, sandblast, and paint boats away from the open where dust, paint chips, or paint spray can be blown into the water. Whenever these types of practices are conducted, appropriate containment devices should be used.
- Install containment booms at fueling stations. Institute weekly inspections to ensure facilities are maintained in good condition.
- Divert clean runoff and install infiltrating catch basins around boat launches to prevent pollutants from washing down the ramp and entering the lake.
- Provide public rest rooms and pumpout facilities to eliminate the potential discharge of wastewater to waterbodies.

Laws and Regulations

RSA 482-A and the administrative rules of the Wetlands Bureau (**Env-Wt 100-800**) regulate the construction of docks and marinas. Piers, floats, tie-off piles, and mooring buoys in navigable waters of the U.S. typically fall under the State Programmatic General Permit process, which is a cooperative program with the U.S. Army Corps of Engineers.

Moorings are regulated by the Department of Safety under authority of **RSA 270** and administrative rules **Saf-C 400-413**.

RSA 487:2 prohibits the operation of boats constructed to discharge wastewater upon waters of the State.

RSA 485-A:55, 56 prohibits the sale of detergents, except dishwasher detergents, that contain more than a trace amount of phosphorus.

The Clean Vessel Act was passed by Congress in 1992 and reauthorized in 1998 to help reduce pollution from vessel sewage discharges. The Act established a five-year federal grant program administered by the U.S. Fish and Wildlife Service. All recreational vessels must have access to pumpouts under the Clean Vessel Act. Funds are provided to states for the construction, renovation, operation, and maintenance of pumpout stations for pumping waste out of recreational boat holding tanks and dump stations for emptying portable toilets. For a directory of New Hampshire boat pumpout locations and information about boat pumpout service see www.des.nh.gov/wmb/cva.

All state laws in New Hampshire can be searched online at **gencourt.state.nh.us/rsa/html/indexes/default.html**

Agriculture and Golf Courses

See BMP Resources on page 42

There are approximately 2,900 commercial and small-scale farms and 100–110 golf courses in New Hampshire, according to the 1997 USDA Census of Agriculture and the N.H. Golf Association. In addition, there are countless backyard hobby farms throughout the state. Farming depends on maintaining the productivity of the land, yet its activities can also contribute nonpoint source pollution. Golf courses generally require intensive turf management, which often means chemical applications. The three primary nonpoint source concerns from agricultural and golf course land use activities are soil loss or sedimentation, nutrients, and pesticides.

Runoff from bare fields can pick up soil particles, causing erosion of the land and sedimentation of waterbodies. Excessive irrigation on managed turf can sometimes result in deep percolation and runoff. Soil particles suspended in surface water

reduce the amount of sunlight available to aquatic plants; impair the gills of fish, shellfish, and aquatic insects; and diminish the in-stream habitat for aquatic organisms. Soil particles not only affect stream or lake sediment loads, but can also introduce pollutants to the system, because pollutants attach to the particles.

Runoff from fertilized fields and golf courses can cause algal blooms and related problems by introducing unnatural concentrations of nitrogen and phosphorus to an aquatic ecosystem. Nutrient runoff can increase the productivity of aquatic plants that will eventually die and decay. The bacteria decomposing the dead organic matter can deplete the oxygen supply in the water and cause unpleasant odors for recreational users of lakes and streams. Runoff from manure is also a source of bacteria, which can adversely affect human health.

Pesticides, fungicides, and herbicides applied to farmlands, lawns, and golf courses can also degrade water resources. Exposure to certain chemicals can cause poisoning to people and wildlife, through direct exposure and drinking water.

BMPs for Agriculture and Golf Courses

Although the activities are different, the basic goals of BMPs for agriculture and golf courses are very similar. They are as follows:

- Reduce the off-site transport of sediment, nutrients, and pesticides.
- Control the rate, method, and type of nutrients and chemicals being applied.
- Reduce the total chemical loads by use of integrated pest management (IPM), economic thresholds, alternative pest control, and soil testing.

Several BMPs for agriculture and golf courses are listed below by pollution source. Many of these can also be applied to home use. For new golf courses, several problems can be avoided if the designer fits the course to the existing terrain as much as possible, and takes into consideration waterbodies, wetlands, and steep slopes at the site. Most of these BMPs are applicable to agriculture. The BMPs that are also applicable to golf courses are marked with the symbol ▲.

Managing sedimentation

- Minimize tillage when farming and minimize extensive earth-moving when designing a golf course. ▲
- Plant a cover crop and/or allow crop residue to remain on the soil after harvest.
- Plant vegetative filter strips along surface waters and between fields and fairways.▲
- Protect the soil with rotational grazing.
- Rotate crops that provide limited ground cover with those that provide generous ground cover.
- Plant crops along contour lines when possible.
- Construct and stabilize diversions to control runoff across cropland and gully erosion. ▲
- Reduce erosion and sedimentation by barring access by livestock on bare streambanks.

Managing nutrients effectively

- Monitor the level of nutrients in soils by regular soil testing. ▲
- Divert, collect, or store runoff water from buildings and yards. ▲
- Install a vegetative filter along surface waters, feedlots, and edges of fields. ▲
- Avoid spreading manure or fertilizer during winter. ▲
- Incorporate manure into soil as soon as possible after spreading to minimize runoff during rainstorms.
- Prevent or control livestock access to waterbodies and implement "pasture pumps" or other watering systems next to heavy use areas and feed bunks.
- Diversify crop rotations and plant cover crops after harvesting that use residual nutrients.
- Determine manure application rates and timing according to nutrient needs of the crop.
- Set realistic yield goals.

Reducing pesticide use

- Apply pesticides only when needed. ▲
- Use insect-resistant crop or turf varieties. ▲
- Spot-treat insect infestations when possible. ▲
- Conserve beneficial insects.▲
- Select the least-toxic pesticide and use organic pesticides. ▲
- Observe setback zones. ▲
- Store, handle, and dispose of chemicals safely, according to state and federal regulations. ▲
- Manage crops to compete aggressively with weeds.
- Control weeds with cover crops.
- Use crop rotation and plant diversity to control insects.
- Plant pest-repelling plants next to crop plants (e.g., marigolds next to tomatoes).
- Contact the N.H. Department of Agriculture or your local county Cooperative Extension office (listed in the phone book) for assistance or advice on IPM programs, which use biological and nonchemical controls to reduce pesticide use. ▲

Laws and Regulations

The N.H. Department of Agriculture Division of Pesticide Control enforces state pesticide laws affecting sale, storage, and application of all registered pesticides. The N.H. Pesticides Controls law, **RSA 430:28-48**, requires pesticide applicators to obtain permits from or to be licensed by the Division of Pesticides Control prior to application. Pesticides must be registered with the state, and applicators must submit reports of pesticide usage annually. Commercial applicators are also required to pass an exam that covers label protocol, chemical safety, environmental consequences, pest types, and use of application equipment. See rules **Pes 100-1000** (www.state.nh.us/agric/pecorl.html) for more information on certification, storage of pesticides, application, and setbacks from water resources.

The Comprehensive Shoreland Protection Act stipulates that no fertilizer, except limestone, shall be used within 25 feet of the high water line of a waterbody. See www.des.nh.gov/cspa/483B.htm.

The Manure, Agricultural Compost, and Chemical Fertilizer Handling Law, **RSA 431:33-35**, required the N.H. Department of Agriculture, Markets, and Food to develop BMPs for handling these materials and to investigate complaints of mismanagement. If the investigation finds that BMPs are not used, the department will notify operators in writing and require them to submit plans for compliance if the corrections are not made within 10 days.

The federal National Pollutant Discharge Elimination System (NPDES) program requires concentrated animal feeding operations (CAFOs) to obtain discharge permits. Large CAFOs are determined by the number of animals on the site, and the threshold is specific to the type of animal. Medium CAFOs are determined by the number of animals and whether or not the facility discharges to surface water. Small facilities can be designated as CAFOs at the discretion of the permitting authority (EPA). For more information on the CAFO final rule, see EPA's website at http://cfpub.epa.gov/npdes/home.cfm?program_id=7.

Nutrient Runoff and Land Use

Which type of land use has higher amounts of nutrients in runoff – agricultural land or developed (urban, suburban, industrial, and commercial)? You might think agriculture, given the application of manure and fertilizers. But modeling studies in the Chesapeake Bay watershed and the Lake Champlain basin have shown that runoff from developed areas can produce just as much, or up to three times more, phosphorus and nitrogen per acre of land. Maintaining farmland in your community may be better for water quality than developing land! For information on incorporating agriculture into land use planning, see the technical bulletin *Preserving Rural Character: The Agricultural Connection.* Available online at www.state.nh.us/osp/planning/guide/docs/Tech Bulletin6.pdf)

All state laws in New Hampshire can be searched online at **gencourt.state.nh.us/rsa/html/indexes/default.html**

What Is a Water Footprint?

It is important for individuals, households, businesses and countries to ask "What is a water footprint?" as they do an assessment of water use patterns at different levels.

An Assessment of Water Use Patterns at Different Levels, Both Direct and Virtual.

Fresh water is vital to life, but as the world's population grows, so does its use of water. It takes water – a lot of it – to **produce food**, to **make energy** and to **manufacture consumer products**. This is what's known as **virtual water** and it's important to do an assessment of water patterns at different levels of water use.

Globally, the increase is due primarily to increasing virtual water use, as more people consume more water-intensive food, electricity and consumer goods, putting increasing pressure on water resources. Strained resources are a source of both concern and conflict in the arid parts of the world – including the US – where food is grown, goods are manufactured and water is already in short supply. Entities at many levels have started doing an assessment of water use patterns at different levels and asked, "What is a water footprint?"

By the year 2030, experts predict that global demand for water will **outstrip supply by 40 percent** [PDF]. Impacts from climate change have already led to changes to the water cycle, leading to prolonged periods of drought (and, conversely, more extreme rainfall) in some areas. Reduced water supplies could add to water insecurity both in the US and in other countries.

Water footprints help individuals, businesses and countries because they reveal water use patterns, from the individual level all the way to the national level. They shine a light on the water used in all the processes involved in manufacturing and producing our goods. They also account for the amount of water contaminated during manufacturing and production.

These footprints give everyone – from individuals to business managers to public officials – a solid frame of reference that helps the world be more efficient and sustainable with water use. By **understanding our water footprints**, we can appreciate the role water plays in everyone's lives.

Blue, Green or Grey Water Footprints – How Are They Measured?

A water footprint is measured in terms of the volume of water consumed, evaporated and polluted. The Water Footprint Network, whose research provides the data splits water footprints into **three corresponding categories**:

Blue Water Footprint: The amount of surface water and groundwater required (evaporated or used directly) to produce an item.

Green Water Footprint: The amount of rainwater required (evaporated or used directly) to make an item.

Grey Water Footprint: The amount of freshwater required to dilute the wastewater generated in manufacturing, in order to maintain water quality , as determined by state and local standards.

Examples of how each of these contributes to a food item's total water footprint can be found in the **Water Footprint of Food Guide**. To explore food as well as some other items, go to the Water Footprint Network's **Product Gallery**.

Who Created the Concept of Water Footprints?

The concept, sources and methodology come from the **Water Footprint Network** (WFN). The concept was created by **Dr. Arjen Hoekstra** who, along with the others at the WFN, developed the framework and established the international organization as the foremost research network in the discipline.

Calculate your footprint ›

Key Topic #3: The role of the Individual/Community in NPS issues and solutions

Learning Objectives

1. **Describe** the role that individuals, families, and local communities can play in reducing NPS pollution through behavior change and local initiatives.
2. **Identify** examples of community-based solutions to NPS pollution (e.g., storm drain marking campaigns, rain garden installations, stream cleanups).
3. **Compare** the effectiveness of individual vs. collective actions in mitigating NPS pollution at the watershed scale.
4. **Demonstrate** how to design or participate in a local outreach or monitoring project that addresses NPS pollution, such as conducting a stormwater audit or organizing a pollution prevention campaign.
5. **Interpret** the benefits and limitations of volunteerism, citizen science, and public- private partnerships in addressing NPS issues.

Resource Title	Source	Located on
Overview (*summary*)	*Rodrigue, Paul, USDA NRCS and U.S. EPA*	Page 84-85
Nonpoint Source: Urban Areas, *excerpts*	*U.S. EPA*	Page 86
Benefits of Low Impact Development	*U.S. EPA Factsheet, 2012*	Page 87-88
Costs of Low Impact Development: LID Saves Money and Protects Your Community's Resources	*U.S. EPA Factsheet, 2012*	Page 89-90
Effectiveness of Low Impact Development	*U.S. EPA Factsheet, 2012*	Page 91-92
Large Volume Storms and Low Impact Development	*U.S. EPA Factsheet, 2017*	Page 93-96
Space Limitations and Low Impact Development	*U.S. EPA Factsheet, 2018*	Page 97-99
Revising Local Codes to Facilitate Low Impact Development	*U.S. EPA Factsheet, 2021*	Page 100-107
Urban Runoff: Model Ordinances to Prevent and Control Nonpoint Source Pollution	*U.S. EPA*	Page 108-111

Overview

Individuals play a significant role in nonpoint source (NPS) pollution, as their everyday actions can contribute to the problem. While NPS pollution is often associated with diffuse sources like agricultural runoff and urban stormwater, individual behaviors such as improper disposal of waste, overuse of lawn chemicals, and improper vehicle maintenance can all contribute to the problem.

Here's a breakdown of how individuals contribute to NPS pollution:

1. Improper Waste Disposal:
    - **Littering:** Discarded trash can be carried by wind or stormwater into waterways.
    - **Improper disposal of household chemicals:** Pouring chemicals like oil, paint, or cleaning products down the drain or on the ground can contaminate soil and water.
    - **Pet waste:** Animal waste left on the ground can be washed into storm drains and pollute nearby water bodies.

2. Excessive Use of Lawn and Garden Chemicals:

- **Fertilizers and pesticides:**

  Over-application of these products can lead to runoff that pollutes nearby water sources with excess nutrients and chemicals.
- **Improper application:**
  Applying these chemicals before rain or in excessive amounts can increase runoff and contamination.

3. Poor Vehicle Maintenance:
    Leaking oil, antifreeze, and other vehicle fluids can be washed into storm drains and pollute water.
    Disposing of used oil, antifreeze, and other automotive fluids improperly can contaminate the environment.

4. Erosion and Sedimentation:
    Construction activities:
    Improper management of construction sites can lead to soil erosion and runoff, contributing to sedimentation of waterways.
    Bare soil:
    Areas of bare soil on residential properties can easily erode during rain, carrying sediment into nearby water bodies.

5. Inadequate Septic Systems:
    - **Failing septic systems:** Malfunctioning septic systems can release untreated sewage into the ground and potentially contaminate groundwater.

How Individuals Can Help:

- **Properly dispose of waste:** Recycle, compost, and dispose of trash and chemicals properly.
- **Use lawn and garden chemicals responsibly:** Apply them sparingly and only when necessary, following label instructions.
- **Maintain vehicles properly:** Fix leaks promptly and dispose of used fluids properly.
- **Control erosion:** Plant vegetation, use mulch, and manage construction activities to minimize soil erosion.
- **Ensure septic systems are functioning correctly:** Have them inspected and pumped regularly.
- **Participate in community cleanups:** Help remove litter and debris from local waterways.
- **Promote awareness:** Educate others about the impact of NPS pollution and encourage responsible practices.

By taking these steps, individuals can significantly reduce their contribution to nonpoint source pollution and help protect water quality.

Nonpoint Source: Urban Areas

Introduction:

Urbanization increases the variety and amount of pollutants carried into our nation's waters. In urban and suburban areas, much of the land surface is covered by buildings, pavement and compacted landscapes. These surfaces do not allow rain and snow melt to soak into the ground which greatly increases the volume and velocity of stormwater runoff. In addition to these habitat-destroying impacts, pollutants from urban runoff include:

- Sediment
- Oil, grease and toxic chemicals from motor vehicles
- Pesticides and nutrients from lawns and gardens
- Viruses, bacteria and nutrients from pet waste and failing septic systems
- Road salts
- Heavy metals from roof shingles, motor vehicles and other sources
- Thermal pollution from impervious surfaces such as streets and rooftops

These pollutants can harm fish and wildlife populations, kill native vegetation, foul drinking water, and make recreational areas unsafe and unpleasant.

Low Impact Development

The term *low impact development* (LID) refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat. EPA currently uses the term green infrastructure to refer to the management of wet weather flows that use these processes, and to refer to the patchwork of natural areas that provide habitat, flood protection, cleaner air and cleaner water. At both the site and regional scale, LID/GI practices aim to preserve, restore and create green space using soils, vegetation, and rainwater harvest techniques. LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. There are many practices that have been used to adhere to these principles such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions.

Benefits of Low Impact Development

How LID Can Protect Your Community's Resources

What Is Low Impact Development (LID)?

LID includes a variety of practices that mimic or preserve natural drainage processes to manage stormwater. LID practices typically retain rain water and encourage it to soak into the ground rather than allowing it to run off into ditches and storm drains where it would otherwise contribute to flooding and pollution problems (see **www.epa.gov/nps/lid**).

A green roof absorbs rainwater, reduces energy costs and offers wildlife habitat in urban Portland, Oregon.

Why Should My Community Adopt LID?

LID Reduces Stormwater Runoff by Emphasizing Infiltration

As a community grows, so does the amount of surface area covered by parking lots, roads and rooftops (Figure 1). Rainfall cannot soak through these hard surfaces; instead, the rain water flows quickly across them—picking up pollutants along the way—and enters ditches or storm drains, which usually empty directly and without treatment into local waterways. Local streams in urban areas are overwhelmed by frequent urban flash flooding and stream habitats are smothered by sediments carried by the excessive flows.

Contrast this to an undeveloped watershed, where vegetation-covered soil soaks up rainfall rather than allowing it to run off the land (Figure 2). Water filters through the soil before reaching the groundwater table or being released slowly into streams. An undeveloped watershed provides clean, safe water.

Fortunately, by adding LID solutions, communities can help their watersheds act more like undeveloped watersheds—despite the ever-expanding numbers of roads and rooftops. LID practices such as natural or man-made swales, depressions and vegetated areas capture and retain water onsite, allowing time for water to soak into the soil where it is naturally filtered.

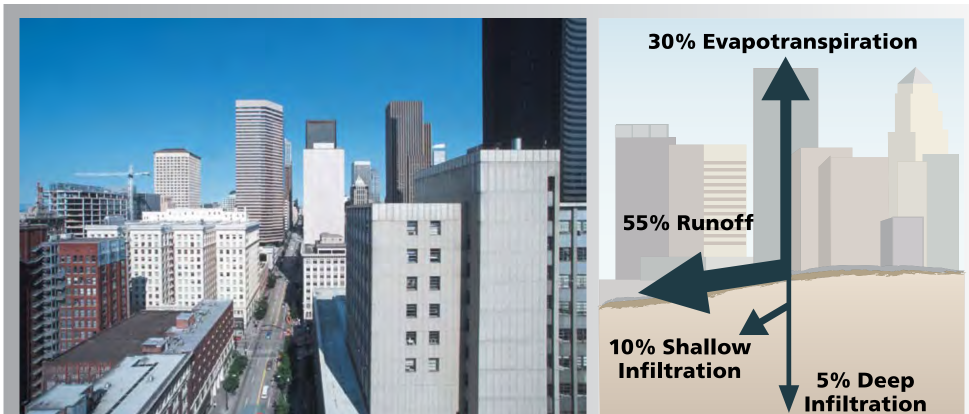


Figure 1. When roads, rooftops and parking lots cover much of the land, more than half of the rainfall runs off and flows directly into surface waters. In highly developed areas, such as in Seattle, Washington (above left), only 15 percent of rain water has the opportunity to soak into the ground.

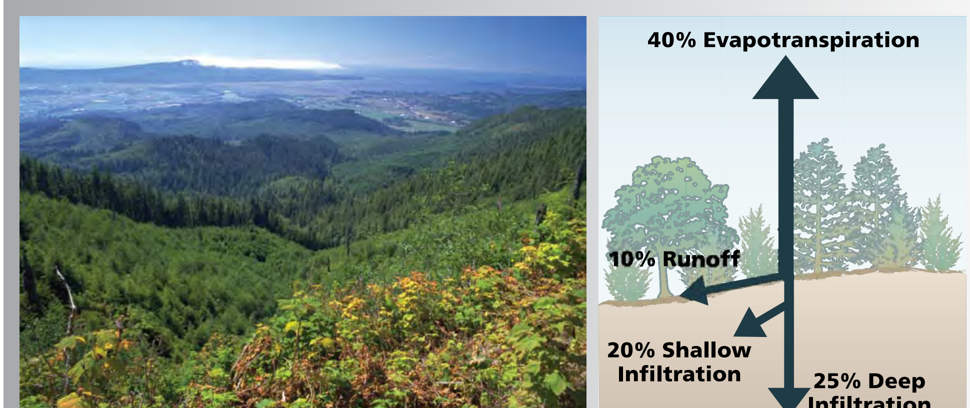


Figure 2. When vegetation and natural areas cover most of the land, such as in Oregon's Upper Tillamook Bay watershed (above left), very little water (only 10 percent) runs off into surface waters. Nearly half of the rainfall soaks into the soil. The remaining water evaporates or is released into the air by vegetation.

LID Provides Many Environmental and Economic Benefits

- **Improved Water Quality**. Stormwater runoff can pick up pollutants such as oil, bacteria, sediments, metals, hydrocarbons and some nutrients from impervious surfaces and discharge these to surface waters. Using LID practices will reduce pollutant-laden stormwater reaching local waters. Better water quality increases property values and lowers government clean-up costs.
- **Reduced Number of Costly Flooding Events.** In communities that rely on ditches and drains to divert runoff to local waterways, flooding can occur when large volumes of stormwater enter surface waters very quickly. Holistically incorporating LID practices reduces the volume and speed of stormwater runoff and decreases costly flooding and property damage.
- **Restored Aquatic Habitat.** Rapidly moving stormwater erodes stream banks and scours stream channels, obliterating habitat for fish and other aquatic life. Using LID practices reduces the amount of stormwater reaching a surface water system and helps to maintain natural stream channel functions and habitat.
- **Improved Groundwater Recharge**. Runoff that is quickly shunted through ditches and drains into surface waters cannot soak into the ground. LID practices retain more rainfall on-site, allowing it to enter the ground and be filtered by soil as it seeps down to the water table.
- **Enhanced Neighborhood Beauty**. Traditional stormwater management infrastructure includes unsightly pipes, outfalls, concrete channels and fenced basins. Using LID broadly can increase property values and enhance communities by making them more beautiful, sustainable and wildlife friendly.

When implemented broadly, LID can also **mitigate the urban heat island effect** (by infiltrating water running off hot pavements and shading and minimizing impervious surfaces), **mitigate climate change** (by sequestering carbon in plants), **save energy** (from green roofs, tree shading, and reduced/avoided water treatment costs), **reduce air pollution** (by avoiding power plant emissions and reducing ground-level ozone), **increase property values** (by improving neighborhood aesthetics and connecting the built and natural environments), and **increase groundwater recharge**, potentially slowing or reversing land and well field subsidence.

LID Techniques Can Be Applied at Any Development Stage

- **In undeveloped areas, a holistic LID design can be incorporated in the early planning stages**. Typical new construction LID techniques include protecting open spaces and natural areas such as wetlands, installing bioretention areas (vegetated depressions) and reducing the amount of pavement.
- **In developed areas, communities can add LID practices to provide benefits and solve problems**. Typical post-development LID practices range from directing roof drainage to an attractive rain garden to completely retrofitting streets with features that capture and infiltrate rainwater.

A landscaped curb extension calms traffic and captures and infiltrates street runoff in Portland, Oregon.

Rainfall soaks through permeable pavement and into the ground below in this parking area in west Des Moines, Iowa.

Street runoff collects in stormwater planters in Portland, Oregon.

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Costs of Low Impact Development

LID Saves Money and Protects Your Community's Resources

Are Low Impact Development (LID) Practices More Economical Than Conventional Practices?

In many cases, the answer is yes. LID typically includes a variety of low-cost elements such as bioswales that retain rain water and encourage it to soak into the ground rather than allowing it to run off into storm drains where it would otherwise contribute to flooding and pollution problems. LID projects typically include smaller overall development footprints, reduce the amount of runoff generated and increase the amount of natural areas on a site, thereby reducing costs when compared to traditional stormwater management and flood control.

FAQ

Isn't LID too costly?

Barrier Busted!

Communities recognize that using LID can save money.

EPA's LID Barrier Busters fact sheet series...helping to overcome misperceptions that can block adoption of LID in your community

Example Economic Benefits of LID Elements

- Adding roadside bioswales, making roads narrower and designing smaller or porous parking lots with on-site runoff retention **saves money by reducing the amount of pavement, curbs and gutters needed**.
- Installing green roofs, disconnecting roof downspouts from impervious surfaces (driveways or streets), and incorporating bioretention areas to capture on-site runoff **saves money by eliminating the need for costly runoff detention basins and pipe delivery systems**.
- Designing more compact residential lots **saves money by reducing site grading and building preparation costs, and can increase the number of lots available for sale**.
- Preserving natural features in the neighborhood **can increase the value and sale price of residential lots**.
- Using existing trees and vegetation **saves money by reducing landscaping costs and decreasing stormwater volume**.

This 4-acre grassed overflow parking lot at a mall in West Hartford, CT cost $500,000—half the cost of a traditional parking lot.

Cost-Savings Nationwide: LID Case Studies

A U.S. Environmental Protection Agency study of 17 LID case studies around the country found that, in the majority of cases, total capital cost savings ranged from 15 to 80 percent when LID methods were used. (For details, see **www.epa.gov/nps/lid/costs07**.)

- **Sherwood, Arkansas:** Gap Creek subdivision included 23.5 acres of open, buffered natural drainage areas and traffic-calming circles that allowed the developer to reduce street widths. Results? The lots sold for $3,000 more and cost $4,800 less to develop than comparable conventional lots. The LID design required less land for stormwater control features, which allowed the developer to create and sell 17 additional lots.

Street drainage flows into this roadside bioswale in Lenexa, Kansas. The city found that on-site detention with LID practices cost 25 percent less than traditional stormwater management retrofits.

- **Seattle, Washington:** Seattle's 2nd Avenue Street Edge Alternative project redesigned an entire block with LID techniques such as bioswales in the rights-of-way. Results? Reducing street widths and sidewalks lowered paving costs by 49 percent. Overall, incorporating LID techniques cost $651,548—a savings of $217,255 compared to a conventional retrofit of the block, which would have cost an estimated $868,803.
- **Naperville, Illinois**: Developers at the 55-acre Tellabs corporate campus preserved much of the site's natural drainage features and topography, reducing grading and earthwork costs. They used bioswales and other infiltration techniques in parking lots to manage stormwater. They maximized the amount of natural areas, eliminating the need for irrigation systems and lowering maintenance costs when compared to turf grass. Results? As seen in the table below, total LID project costs were $461,510 less than a conventional design would have been.

A roadside swale captures and retains runoff in Seattle, Washington. The city saves money with LID by avoiding costly stormwater infrastructure and reducing paving costs.

Sample Costs: Comparing Conventional Stormwater Controls with LID Techniques in a Corporate Development (Tellabs) in Naperville, Illinois

Construction Item	Cost of Conventional Development	Cost When Using LID Practices	Dollars Saved with LID
Site preparation	$2,178,500	$1,966,000	$212,500
Stormwater management	$480,910	$418,000	$62,910
Landscape development	$502,750	$316,650	$186,100
Total	**$3,162,160**	**$2,700,650**	**$461,510**

This bioretention pond in Wilsonville, Oregon collects runoff from the rooftops, sidewalks and yards. The pond offers valuable aesthetic and wildlife habitat benefits while also reducing stormwater control costs.

LID Provides Added Value for Communities

Besides reducing the capital and other actual costs, using LID practices provides numerous additional economic benefits, some of which are difficult to quantify, including:

- Improved aesthetics for communities
- Expanded recreational opportunities
- Increased property values due to the desirability of the lots and their proximity to open space
- Increased marketing potential and faster sales for residential and commercial properties
- Reduced stream channel damage and pollutant loadings in downstream waters
- Reduced drinking water treatment costs
- Reduced costs associated with combined sewer overflows, where applicable

LID offers great flexibility for developing and re-developing properties. A wide range of LID technology choices are available to match the needs of individual sites and the desires of the parties developing or buying the property.

Philadelphia has been expanding its use of LID by implementing new policies and demonstration projects, such as this roadside bioswale that treats runoff from an adjacent parking lot. The city's use of LID has reduced stormwater runoff volume, saving approximately $170 million in combined sewer overflow costs since 2006.

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Effectiveness of Low Impact Development

Proven LID Technologies Can Work for Your Community

LID Barrier Busters Fact Sheet Series

Low Impact Development (LID) includes a variety of practices such as bioswales and porous paving that mimic natural processes by retaining rain water and allowing it to soak into the ground. Studies have shown that LID practices offer significant environmental benefits over conventional stormwater management practices (where runoff is shunted quickly into detention basins or directly to streams). By holding water onsite, LID practices reduce the amount of runoff generated during a rainstorm, alleviating downstream erosion and stream habitat damage. In addition, LID practices filter out pollutants such as oil, bacteria, sediment and nutrients as the collected water seeps through vegetation and soil. The water that eventually reaches groundwater and surface water is much cleaner.

This fact sheet highlights the environmental benefits of several LID projects across the country. Separate fact sheets in EPA's *LID Barrier Busters* series focus on cost and aesthetic benefits achieved by LID.

FAQ

Isn't LID less effective than conventional stormwater management?

Barrier Busted!

LID successfully controls polluted runoff across the nation.

EPA's LID Barrier Busters fact sheet series… helping to overcome misperceptions that can block adoption of LID in your community

Case Studies: LID Environmental Successes Span the United States

Seattle, Washington

Seattle launched its Street Edge Alternatives (SEA Street) neighborhood demonstration project in 2000. The city incorporated LID practices to improve stormwater management on 600 linear feet of street (comprising a drainage area of 2.3 acres). The project reduced impervious surfaces by 11 percent when compared to a traditional street, provided surface detention in roadside swales, and added more than 1,200 new trees and shrubs.

Results? The volume of stormwater leaving the street declined by 99 percent. LID practices absorbed all dry season flow and 98 percent of wet season flow.

Seattle's SEA Street project (top of photo) uses numerous LID practices including rain gardens, vegetated swales and a narrow, winding street. A typical Seattle street (bottom of photo), by comparison, has a broad, wide street and flat yards with few natural depressions to capture and store stormwater runoff.

In 2003 Seattle implemented the Northwest 110th Cascade project, replacing 1,400 linear feet of existing ditches and culverts with a series of stair-stepped natural pools that slow damaging stormwater flows, encourage infiltration and trap pollutants from a 28-acre basin.

Results? The LID practices significantly reduce the amount of runoff that reaches a nearby creek. Discharge volumes declined between 48 and 74 percent. In fact, the basin released water into the creek in only 49 of 235 measurable storms. Monitoring showed that the LID practices also filtered out a lot of the pollution carried in the stormwater (Table 1).

For more information about the Seattle projects (including virtual tours), go to **www.seattle.gov** and type "natural drainage" into the search box.

Table 1. NW 110th Cascade Project: Pollutant Removal (2004–2006)

Pollutant	Pollutant Mass Loading Reductions[1]
Total suspended solids	84%
Total nitrogen	63%
Total phosphorus	63%
Total copper	83%
Dissolved copper	67%
Total zinc	76%
Dissolved zinc	55%
Total lead	90%
Motor oil	92%

[1] As compared to traditional street drainage

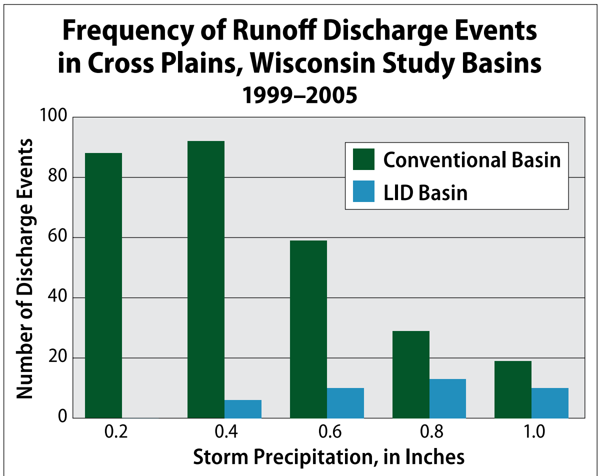
Source: Horner and Chapman, 2007. NW 110th Street Natural Drainage System Performance Monitoring (www.seattle.gov)

A stair-stepped pool slows runoff in Seattle's NW 110th Cascade project.

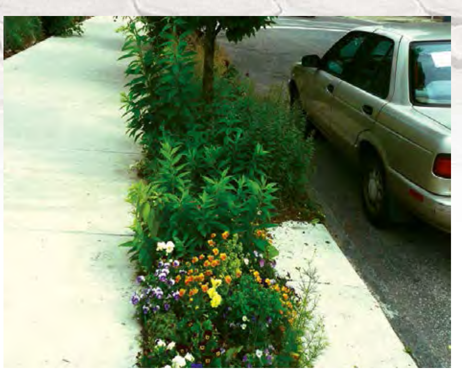
Cross Plains, Wisconsin

Between 1999 and 2005, the U.S. Geological Survey monitored water quality from two similar developments—one fitted with conventional drainage (wide streets, curbs, gutters and storm sewers leading to a detention basin) and the other with LID practices (grass swales, small detention areas followed by a large infiltration basin, infiltration trenches and narrow street widths).

Results? The LID basin reduced the frequency of discharge, runoff volume and peak flows for most storms, which also greatly reduced pollutant loads. Data show that for storms with precipitation depths of 0.4 inches or less, the LID basin discharged runoff only six times, compared to 180 times in the conventional basin (see chart). Overall, the LID basin released a total discharge volume roughly one-tenth that of the conventional basin.



(Adapted from Selbig, W.R., and Bannerman, R.T., 2008, A comparison of runoff quantity and quality from two small basins undergoing implementation of conventional- and low-impact-development (LID) strategies: Cross Plains, Wisconsin, water years 1999–2005: U.S. Geological Survey Scientific Investigations Report 2008–5008, 57 p.) (See *http://pubs.usgs.gov/sir/2008/5008*)



Stormwater planters in Philadelphia capture and filter stormwater runoff from an adjacent roadway.

A green roof on Philadelphia's Thin Flats housing units offers private green space for urban residents while also capturing rainwater.

Philadelphia, Pennsylvania

The city's sewer collection system includes 40 percent municipal separate storm sewer system (a pipe that carries stormwater runoff and empties into a local waterway) and 60 percent combined sewer (a pipe that carries both raw sewage and runoff to a treatment facility). In times of heavy rain, the runoff introduced into the combined sewer can overwhelm the collection system and lead to discharge of untreated sewage directly into surface waters. To reduce the amount of stormwater runoff reaching the combined sewer, Philadelphia is implementing LID practices such as stormwater planters, stormwater bump-outs, stormwater wetlands, rain gardens and porous paving, among others (see **www.phillywatersheds.org/BigGreenMap** for project locations).

Results? Over a two-year period the city replaced an estimated two square miles of impervious cover (e.g., parking lots, roads) with LID practices, reducing runoff during this time by a half billion gallons. Storing an equivalent amount of combined sewer overflow would have cost the city an estimated $340 million. One project, the Saylor Grove stormwater wetland, was designed by the Philadelphia Water Department to capture and filter the first 0.7 inch of every rainfall event falling over a 156-acre urban watershed—treating 70 million gallons of runoff and preventing approximately 13 tons of sediment from reaching the local creek each year. For a comprehensive look at benefits gained through Philadelphia's LID approach, see **http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_philadelphia_bottomline.pdf**.

Philadelphia constructed the one-acre Saylor Grove stormwater wetland in a park area to collect and treat 70 million gallons of urban stormwater generated in the storm sewershed each year.

An educational sign at Philadelphia's Saylor Grove stormwater wetland provides a diagram of the wetland and explains the benefits of natural stormwater management.

Need More Information to Share with Others?

The University of New Hampshire's Stormwater Center offers online presentations about the effectiveness of various types of LID practices (**www.unh.edu/unhsc/presentations**). For links to more LID resources, see **www.epa.gov/nps/lid**.

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Large Volume Storms and Low Impact Development

Using LID Practices in Areas with Intense Rainfall Events

People often think low impact development (LID) practices, which are designed to capture and treat the so-called first flush of polluted runoff, are not suited for areas subject to large volume storms because the practices could become overwhelmed with excess stormwater flow and fail. This is not the case. Properly sited and designed practices offer cost-effective treatment in a wide range of conditions and locations, and usually serve as an important first line of defense against high volume storm events.

Properly designed LID practices will allow excess water to bypass or flow through the system to avoid damage. Even in areas subject to high volume storms, LID practices successfully trap and filter a portion of the stormwater runoff—which helps alleviate pressure on existing stormwater conveyance systems and reduces downstream erosion, pollutant loadings, and damage to habitat in streams and riparian areas.

Frequently Asked Question

Is it true that LID practices don't work in areas that receive large volume storms?

Barrier Busted!

LID practices can be effective in areas subject to large volume storms if properly sited and designed to manage anticipated runoff volumes.

EPA's LID Barrier Busters fact sheet series… helping to overcome misperceptions that can block adoption of LID in your community

Equipping LID Practices with High Volume Flow Controls

The process of siting and selecting LID practices is influenced by soil type, land use, terrain, average rainfall and many other factors. Designers must consider a practice's hydraulic performance under both low-flow and high-flow conditions, and incorporate elements that can manage excess flow as needed.

An infiltration system such as a rain garden or permeable pavement is designed to treat a particular volume of water (also known as a water quality volume) over a prescribed period of time. Because these practices have a limited capacity to retain or treat excess volume, they are often built with features intended to protect the long-term function of the practices.

If the stormwater enters the practice at a low velocity and is not erosive, the excess runoff that ponds on the surface can be spilled into drainage systems built on the perimeter of the practice or discharged through overflow devices (Figure 1).

Other design features can be used to direct or convey high volume flows away from the practice and to alternative drainage systems. For example, in Figure 2, road runoff flows through curb cuts into a series of stormwater bioretention planters in Portland, Oregon. When all stormwater planters reach their maximum water capacity, water is forced to continue along the curb without entering the practice, bypassing it completely and flowing into an existing storm drain inlet.

Tetra Tech, Inc.

Figure 1. A parking lot bioretention area near Frederick, Maryland, is equipped with an overflow drain.

USEPA

Figure 2. Stormwater planters treat runoff and can bypass flows that exceed their treatment capacity.

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Figure 3. Street runoff enters the upper end of this bioretention area and fills the practice. The overflow volume exits through an opening on the lower end and drops into a storm drain.

Tetra Tech, Inc.

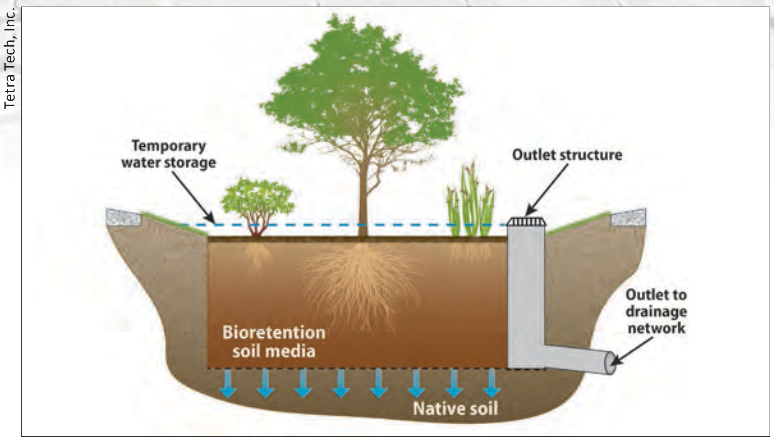

Figure 4. Overflow drain. Stormwater fills the practice and begins soaking through the bioretention soil media and into native soil. Excess water can spill through an outlet structure to an alternative drainage network.

Specific design elements incorporated in LID practices to convey excess flow through or around the practice include overflow and bypass devices, backup infiltration, and underdrains:

Overflow Devices

Overflow devices are typically used in online LID practices (i.e., practices that are placed within the normal stormwater runoff flow path). Online practices treat the water quality volume from smaller storm events and are designed to convey or partially detain flows from larger storm events. When the level of water rises to the height of the overflow structure within the practice, any excess runoff is discharged by gravity flow out of the practice and into another treatment practice or into a storm drain.

- **Overflow Channels.** If the runoff volume entering an online LID practice exceeds the water treatment design capacity, a downgradient opening such as a gravel channel or curb cut will allow excess flow to exit the system and proceed along the normal stormwater runoff flow path (Figure 3).
- **Overflow Drains.** A common design to control excess flow entering online LID practices is a vertical standpipe or box drain connected to an underground drainage system and topped by a grate or screen to prevent objects from entering the storm drain. The inlet of the overflow drain is set at the maximum allowable ponding elevation. The overflow control should be set at the downstream side, far away from the incoming flow (Figures 4 and 5).

USEPA

Figure 5. Overflow drain. Runoff water flows into this roadside bioretention channel, which is equipped with an overflow drain to prevent street flooding during high volume storm events.

USEPA

Figure 6. Bypass system. A curb cut allows street runoff to enter this sidewalk planter. If the planter fills completely, additional runoff water volume will be forced to bypass the practice and continue flowing down the road.

Bypass Devices

Bypass devices (i.e., diverters, splitters) are typically incorporated into offline LID practices that are sited outside of the normal runoff flow path (Figures 6 and 7). Offline practices are designed to receive and treat a specified water quality volume (e.g., the runoff generated from a 1-inch, 24-hour storm). In the case of roadside facilities (e.g., planter, bioretention cell), the size of the inlet opening and the depth of the LID practice controls the amount of runoff allowed to enter the practice. As a result, flow can be bypassed in two ways. First, because the offline practices are designed with an entrance that restricts the amount of water able to enter the practice (e.g., curb cuts, weirs), high volume flows are split so only a controlled amount of runoff enters the practice while the rest continues on its normal flow path. Second, the system accommodates a controlled amount of runoff until the LID practice has reached its water quality treatment design volume.

At that time, the system will redirect all excess stormwater back into the normal runoff flow path, which is often a conventional curb-and-gutter stormwater conveyance system.

Backup Infiltration

Backup infiltration approaches can be used when adjacent surface areas are available to provide additional infiltration capacity. For example, overflows from permeable pavements can be managed by placing a strip of exposed gravel downslope of the pavement (Figure 8). Excess runoff will flow into this gravel strip, which will discharge a non-erosive flow stream to nearby vegetated areas.

Underdrains

Underdrains are needed where soils don't percolate/drain well or where there's a high groundwater table or frequent inundation of the practice. An underdrain is installed near the bottom of the LID feature. Some practices are designed with underdrains in tandem with overflow and bypass systems to ensure acceptable dewatering times and to protect the long-term functioning of the practice. Avoiding long-term ponding within the system prevents mosquitos from breeding and helps protect the health of plants that treat the runoff. Where infiltration could deteriorate over time and drainage become compromised due to sediment deposition, underdrains can be designed with removable caps to allow access for cleaning.

If water retention is a performance requirement, underdrains can be installed above the bottom extent of the practice or designed with a 90-degree upturned pipe so that the system begins to drain only after the required water volume is retained (Figure 9). The water percolates down through the soil into the internal water storage (IWS) layer and is slowly released into the soil underneath the practice.

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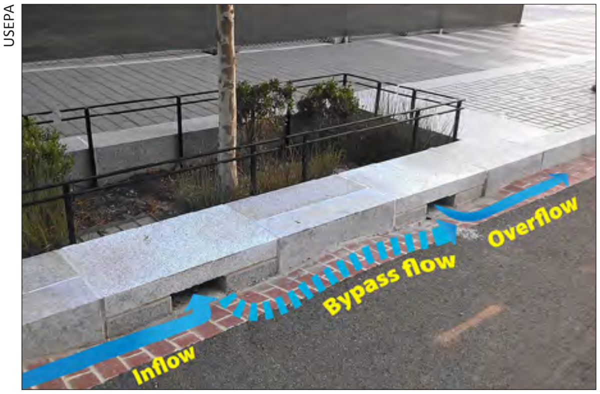

Figure 7. Bypass and overflow system. Runoff enters a planter box through a curb cut and collects until the practice's storage capacity is reached; additional water will either overflow through the second curb cut or will bypass the practice.

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Figure 8. Back up infiltration system. A gravel aggregate strip adjacent to a permeable pavement parking lot collects overflow and directs it into a storm drain or alternative drainage practice.

Tetra Tech, Inc.

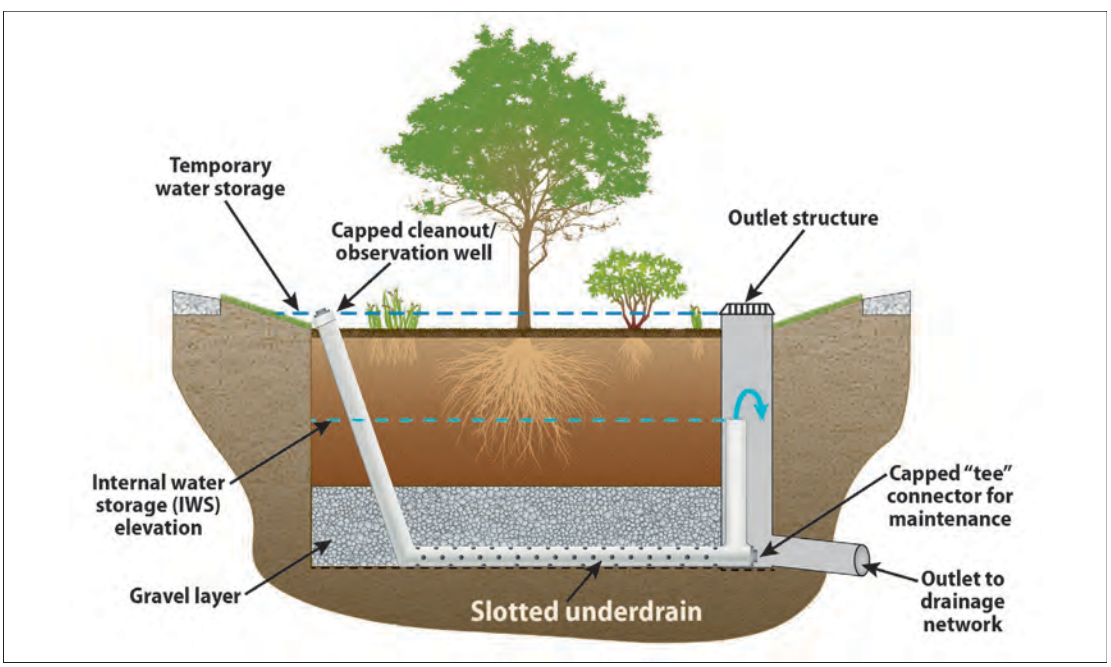

Figure 9. In this underdrain cross-section image, an upturned pipe design allows excess water to drain to an alternative drainage network while also ensuring a permanent internal water storage layer within the practice. An outlet structure can be included in the design to provide added protection against high volume flows.

Case Studies: Successfully Treating and Controlling Flow from Large and Small Storms with Diverse LID Practices

LID practices typically are designed to manage small- and medium-sized runoff events. Large storms will generally be diverted using bypass or overflow design features. The following case studies show how communities are balancing the need to convey and control peak stormwater flows with the need to treat and retain stormwater runoff.

Michigan Avenue Bioretention Planter Boxes, Lansing, Michigan

In 2006 bioretention planter boxes were installed along four blocks of Michigan Avenue, a busy five-lane street in Lansing, Michigan (Figure 10). The planters can treat the runoff from 1 to 4 inches of rain falling on the adjacent street and sidewalk. Water held in the soil is used by the plants, infiltrates to groundwater, or is released slowly through an underdrain. If the planter reaches its maximum volumetric capacity, the extra stormwater flows to the conventional curb-and-gutter street drainage system and into a storm drain.

Results

- Flow meters were used to monitor the system; model results show that about 90 percent of the total annual stormwater volume was treated by the planter box.
- The planters absorb/retain 16 percent and ultimately discharge 84 percent of the total volume of stormwater received. By collecting and filtering the stormwater, the planters delay discharge of the excess water into the local water body. The peak flow rate of the water released through the underdrain is lowered by 87 percent, thereby reducing the overall impact of the stormwater runoff.

Christian, D. and Novaes, V. 2011. Michigan Avenue Bioretention: Monitoring the Results Three Years Later. *In Proceedings of the Michigan Water Environment Association's 86th Annual Conference*, Bellaire, Michigan, June 26-29, 2011.

USEPA

Figure 10. Bioretention planter boxes in Lansing capture and treat much of the stormwater from roads and sidewalks.

Sterncrest Drive Bioswale and Rain Gardens, Cuyahoga County, Ohio

In 2007 the Chagrin River Watershed Partners received a U.S. Environmental Protection Agency grant to install nine rain gardens and replace 1,400 feet of roadside ditch with grassed bioswale (Figure 11). The U.S. Geological Survey monitored the site from 2008 to 2010 to assess the effect of green infrastructure on stormwater runoff. The rain gardens and bioswales were designed to handle a 0.75-inch rain falling on the adjacent roadway. Rainfall and runoff data were collected, along with overflow data, to determine how well the system performed. A 2-foot-square elevated grate (6 inches above the land surface) in the center of each rain garden allows excess stormwater runoff to overflow into to the storm sewer (an example of an overflow system installed in an online LID practice). A perforated underdrain prevents long-term saturation of the LID system.

Results

- Numerous rainfall events greater than 0.75-inch were absorbed by the bioswales and rain gardens.
- The bioswales and rain gardens performed better than expected. During three years of monitoring, the system overflowed only 19 times during 47 rain events when more than 0.75 inches of rain fell within a 96-hour span.

USGS

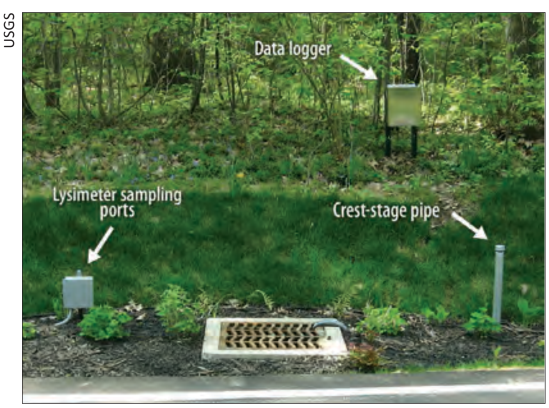

Figure 11. Roadside rain garden in Cuyahoga County is monitored for its effectiveness in absorbing stormwater.

Source: Darner, R.A., and Dumouchelle, D. H. 2011. Hydraulic characteristics of low-impact development practices in northeastern Ohio, 2008–2010. U.S. Geological Survey Scientific Investigations Report 2011-5165, 19 p.

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Space Limitations and Low Impact Development

LID Practices are Well-Suited for Small Spaces

LID Barrier Busters Fact Sheet Series

Low impact development (LID) practices, also referred to as green infrastructure, are designed to infiltrate, evaporate, filter, capture and facilitate the beneficial use of stormwater. These practices can enhance the aesthetic value of the site and reduce capacity needs in costly underground conveyance systems and treatment systems. Common LID practices include green roofs, rain gardens, sidewalk planters, curb extensions, street trees, permeable pavements and cisterns.

People often think LID practices are best suited for new development in large open spaces, possibly because the first publicized LID projects were suburban housing developments or conservation landscape designs. However, LID practices can be used almost anywhere, and small urban spaces are often the perfect places.

> FAQ
>
> Don't LID practices require a lot of space?
>
> ***Barrier Busted!***
> Multi-purpose LID practices can be used in small spaces such as sidewalks and parking areas.
>
> EPA's LID Barrier Busters fact sheet series... helping to overcome misperceptions that can block adoption of LID in your community

Meeting the Challenge of Small Spaces

Available space in many urban areas is limited; fortunately, the versatility of LID practices allows them to be integrated into existing urban landscape features and infrastructure to create multifunctional areas. Siting opportunities for LID include rooftops, parking lots, plazas, parks, and public right-of-way spaces such as streets and sidewalks. LID designs are easily adaptable to most spaces and can be used on greenfield, infill and redevelopment projects. Many communities are retrofitting existing rights-of-way with LID because the practices can be tailored to each site.

This bioretention cell was retrofitted into the right-of-way to capture stormwater from the street.

When selecting appropriate sites and choosing LID practices, planners and designers should consider existing and adjacent uses of the site, soil conditions, buried utilities, drainage challenges, and maintenance needs. They should also consider non-stormwater management-related goals, such as improving aesthetics, mitigating the urban heat island effect, creating wildlife habitat, increasing pedestrian safety, and promoting urban renewal. The strategic application of LID in tight urban spaces can help achieve these goals.

Benches provide public seating while also discouraging damaging foot traffic through the stormwater bioretention cell.

Benefits of LID in Small Spaces

- Bioretention practices can be placed in or next to rights-of-way in conjunction with traffic-calming practices such as curb extensions, chicanes (intentional build-outs within driving lanes) or traffic circles. Such practices can be designed to filter and retain stormwater and create safer, friendlier roadways for vehicles and pedestrians. If space allows, sidewalk planters or above-ground container boxes can be incorporated into public spaces such as along thoroughfares or in plazas and other open spaces.
- Permeable pavements such as porous asphalt, pervious concrete and interlocking pavers can be used instead of conventional pavements and are appropriate for use in most places where infiltrated

Stormwater runoff flows through roadside curb cuts into a sidewalk bioretention planter.

A permeable-paver parking lot allows stormwater to infiltrate while preserving parking spots.

runoff will not pose a problem. All or part of a paved surface can be permeable. Permeable pavements excel at reducing ice build-up, which can improve safety. These surfaces can be tinted in different colors and/or arranged in aesthetically pleasing designs.

- Green roofs are favored by many designers because the practice doesn't take up space at ground level. Green roofs can be designed to cover all or part of a rooftop, can serve as a visual amenity, and can provide wildlife habitat and accessible green space for building users.
- Trees can be planted alongside streets, in parking lot planter boxes and in open spaces. Tree species should be selected for planting based on the available space and the desired height and thickness of canopy. Trees create more livable and attractive communities while also absorbing water, providing shade, reducing cooling costs, mitigating urban heat island effects and filtering air pollutants.
- Rainwater harvesting practices can be placed anywhere a cistern will fit (e.g., on rooftops, in basements, next to buildings, buried underground). With the right designs and equipment, captured roof runoff can be used for irrigation, evaporative cooling systems, toilet flushing, non-potable wash water and landscaped water features. The capture and use of rainwater can reduce potable water management costs, energy use, stream erosion, pollutant loadings and combined sewer overflows.

LID in Action: Small Spaces, Big Impact

USEPA

Roof runoff enters bioretention flow-through planters for treatment and short-term storage.

Louis Cook, Philadelphia Water Dept.

A porous play surface made from recycled tires is surrounded by rain gardens and trees.

USEPA

A permeable interlocking concrete paver parking lane is adjacent to a sidewalk planter.

Louis Cook, Philadelphia Water Dept.

This stormwater curb bump-out intercepts stormwater runoff flowing down the street.

USEPA

A bioretention cell receives stormwater runoff through a curb cut and surface grate.

USEPA

Roof downspouts direct runoff water to rock swales between homes.

USEPA

A building's green roof captures rainfall, thereby reducing local runoff.

USEPA

Runoff flows into stormwater planters installed in the sidewalk adjacent to benches.

USEPA

A cistern collects rooftop runoff, which is used to water landscape areas around the building.

Portland South Waterfront District, Oregon

The south waterfront redevelopment project in Portland, Oregon, is being undertaken on a brownfield site and includes a mix of residential, retail, and office space. The project incorporates LID practices and other green elements throughout the 130-acre waterfront district to enhance livability of the neighborhood, encourage development, and manage stormwater to protect the health of the adjacent Willamette River.

A stormwater planter tucked along the edge of the roadway captures and treats street runoff while also providing an aesthetically pleasing green element within the urban waterfront district.

New residential units include permeable walkways and stormwater planters that capture and treat runoff from the rooftops and other hard surfaces.

This high-density, mixed-use development on the waterfront includes buildings with green roofs to capture rainfall and prevent stormwater runoff.

Albert M. Greenfield Elementary School, Philadelphia

Albert M. Greenfield Elementary School serves as a pilot site, testing how LID can reduce the number and volume of combined sewer overflows in Philadelphia, Pennsylvania. The school is within an urban corridor, and is bounded by busy streets. As a collaborative effort, a plan was created to transform the existing impervious schoolyard into a green space, complete with LID practices.

LID practices are incorporated into this Philadelphia schoolyard's permeable play surface and garden areas.

In 2010 the partners converted a portion of the hardscape into a porous rubber play area and directed the runoff from the remaining pavement to a woodland garden and a series of rain gardens installed along the playground's perimeter. Gardens are protected by innovative design features such as strategically placed nets/climbing structures (pictured)—an idea proposed by a student involved in the design process.

The school uses the outdoor space as a classroom area and has developed a curriculum that incorporates the stormwater practices as a learning module. Other educational amenities of this space include a weather station, photovoltaic solar array, herb garden and urban orchard.

This project offers green space for the students while capturing and infiltrating an estimated 97 percent of the annual runoff from the school yard. By working together, project partners are successfully sharing space to achieve mutual goals in a constrained urban setting.

Source: Michele Adams, President, Meliora Design, LLC; American Society of Landscape Architects; Schuylkill Action Network

United States Environmental Protection Agency • Office of Wetlands, Oceans, and Watersheds
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Revising Local Codes to Facilitate Low Impact Development

Creating LID–Local Development Code Connections Will Assist With Implementation

PART I: LID Barrier Busters Fact Sheet Series

Many municipalities now view low impact development (LID)—also known as green stormwater infrastructure—as an essential stormwater management tool. LID practices are designed to capture, filter and infiltrate runoff onsite using soils, vegetation and other media. So, why aren't rain gardens and vegetated swales popping up in every small city and town? Because complex local development codes, developed over decades, frequently stand in the way. Fortunately, a comprehensive review of local development codes can identify where and how the codes should be adjusted to work in tandem with and facilitate the use of LID.

FAQ

Don't development codes prevent the use of LID?

Barrier Busted!

Review of local codes can identify and remove obstacles to LID.

EPA's LID Barrier Busters fact sheet series... helping to overcome misperceptions that can block adoption of LID in your community

What's the Problem?

In many local governments, a disconnect exists between the development code and LID. Often, key stakeholders lack the information to grasp why this disconnect occurs, which can lead to confusion about the problem and its solutions (see sidebar on common myths). What's the source of the disconnect? Local codes are complex and ever-evolving. The different sections are often developed and modified over decades to address a web of local government departmental and operational needs, such as fire and public safety (e.g., street widths for emergency vehicle access), public works (e.g., street standards for stormwater management), and planning (e.g., open space and parking requirements). As a result, a typical development code can include provisions that inadvertently discourage, limit, or even prevent the use of LID.

Many codes require developers to build unnecessarily wide streets, which increases impervious pavement and runoff volume. The wording of existing codes sometimes prevents vegetative LID practices, such as rain gardens, from being used to comply with open space and landscaping requirements on a development site. If unable to count LID practices as required green elements, developers might be less likely to include LID because of possible increased costs/decreased profits and added delays.

Common Myths about LID Obstacles in Local Codes

Myth #1. *Most local development codes contain only a few obstacles to LID.* Not true. A review of local codes typically identifies numerous obstacles.

Myth #2. *Adopting a stormwater ordinance will solve the problem.* It's not that simple. Even if stormwater ordinances require the use of LID, they can be ineffective if blocked by conflicting code requirements elsewhere. For example, LID barriers often exist in the local development code's landscaping, open space, perimeter screening, street, parking and lot setback requirements.

Myth #3. *Government staff members can simply waive the conflicting code requirements.* Not likely. A costly approval procedure is required for each individual conflicting element, and a single LID project might present 15 to 20 conflicts.

Fear not! By educating key stakeholders and engaging them in the code review effort, you can facilitate greater LID use in your community. See pages 3-8 to learn how.

What's the Solution?

Performing a careful and comprehensive code review can help local government staff identify the code's top LID obstacles and modify them to allow LID and facilitate its use. **Help your community make the LID–local development code connection!**

Does Your Code Need Updating?

Can You Spot the LID Obstacle in these Codes?

Review the following examples of “typical” development code wording, then compare them to the photos. Which of the LID practices shown in the pictures would be illegal under these code requirements? (Hint: All of them.)

USEPA

Stormwater infiltration trench, Stafford County, Virginia

1. “A buffer strip of dense evergreens a minimum of five (5) feet in width shall be planted along the property line.” Did you spot the LID obstacle?

   Potential code solution: Including vegetated LID in the list of practices that may be built in the required perimeter screening areas.

A. Goldstein

Stormwater retention area, Saint Paul, Minnesota

2. “All shoulders and easements shall be graded smooth and established in grass.” Did you spot the LID obstacle?

   Potential code solution: Allowing LID practices, such as swales and curb cuts, to be constructed in the street right-of-way.

USEPA

Parking lot island with curb cuts, Portland, Oregon

3. “All parking lot islands shall be surrounded by a minimum five (5) inch continuous curb.” Did you spot the LID obstacle?

   Potential code solution: Allowing curb cuts in the parking lot islands so water can flow into a LID practice such as a bioretention area.

J. Wright, Tetra Tech

Permeable pavers, Los Angeles Zoo, California

4. “Street Materials: The base course shall consist of asphaltic concrete, which shall be primed with suitable asphaltic material. The roadway shall be surfaced with asphaltic concrete wearing surface.” Did you spot the LID obstacle?

   Potential code solution: Allowing the use of permeable surfaces (such as pavers) on parking areas, streets and/or alleyways.

You Are Not Alone—Code Reviews Are Happening Nationwide

A growing number of municipalities are reviewing their development codes to identify and remove obstacles to LID, including places such as Raleigh, N.C.; Alpharetta, Ga.; San Antonio, Texas; and Phoenix, Ariz. Using tools such as guidebooks, checklists and other resources, diverse communities across the country are working to make the LID–local development code connection, which is essential to building and maintaining a strong local LID program.

The next six pages describe important elements in the code review process. As noted on pages 3 and 4, this includes educating community members about the potential benefits of LID and explaining how existing local development codes can sometimes deter LID use. Once stakeholders understand the need for code revision, localities can use several tools (described on page 5) to identify specific elements of their development code that prevent or impede LID implementation. Pages 6 and 7 offer example language that localities can use to overcome the code constraints and, if desired, to offer incentives for LID use. Finally, page 8 emphasizes the need for localities to build the operational capacity necessary to implement the new code provisions and maintain a successful LID program.

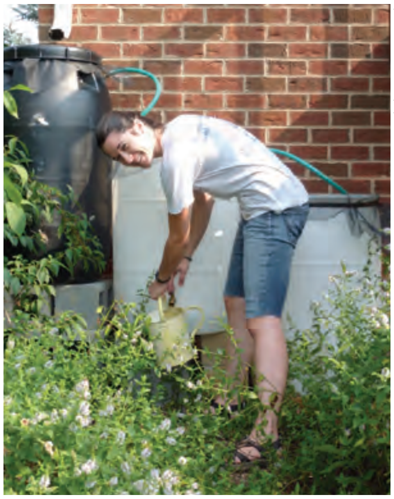
LID Barrier-Busting in Action: Overcoming Local Code Constraints

Creating the LID–Local Development Code Connection in Your Community

Getting Started: Educating Your Community

Before jumping into local code review and revision, share information with key stakeholders about the benefits of LID and how LID can support your community's values and goals.

- **Comprehensive Plan Policies.** Review your community's Comprehensive Plan. Does it include policies or actions that will implement LID? Are there other policies in the plan that would be strengthened by LID? Because the local development code is intended to reflect the Comprehensive Plan, these policies can help make the case for revising the local code.
- **Communicate LID's multiple benefits.** LID can provide benefits beyond stormwater management by providing recreation areas and green space, increasing property values, creating habitat for wildlife and birding, and keeping local waterways cleaner. Other fact sheets in EPA's LID Barrier Busters Fact Sheet Series can help readers understand the benefits of LID.
- **Highlight potential cost saving for developers.** Numerous studies show that LID can be more economical than conventional stormwater practices. See EPA's fact sheet on the Costs of LID.
- **Build support for LID by showing benefits through local demonstration projects.** Seeing a project in action helps residents understand that LID can aesthetically enhance the neighborhood and improve water quality. See EPA's fact sheet on the Aesthetics of LID.
- **Offer a local cost comparison.** Review a recent local development and "redesign" it with LID elements to compare the costs. Include local engineers/designers in the exercise. The city of San Antonio did this in 2014 as a part of a code review and found a 10 percent savings with LID.



K. Philips, Tetra Tech

Rain barrels provide water for garden and landscape plants, Mt. Crawford, Virginia

Communicating Code Complexity to Stakeholders

When communicating the benefits of revising development codes, it's a good idea to help stakeholders understand how the codes evolved and why they contain the requirements they do. Local codes are complex tools that were developed by communities over many decades to meet different local departments' operational needs or local government objectives. Changing the local code to promote or require LID isn't easy when it conflicts with other core goals or needs. To be successful, LID code revision efforts must consider other community goals, core departmental functions and development needs. Crafting proposed code revisions will require input and negotiations from multiple local government programs or divisions as well as representatives from the development and design community, homebuilders' associations, environmental groups and other key community stakeholders.

USEPA

Stormwater planters capture roof runoff and add beauty to an urbanized area, Emeryville, California

Helping Communities Overcome Common Misconceptions About LID and Local Codes

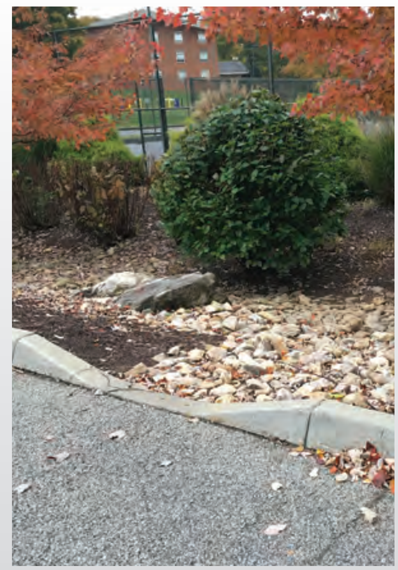
Local government representatives and community members often assume that removing obstacles to LID from their local codes is as simple as passing a stormwater ordinance or waiving a few conflicting restrictions. Unfortunately, the process is often more complicated. Before the code review process even begins, it's a good idea to provide local stakeholders with the relevant facts. The top three most common misconceptions about LID and local codes include:

1. **Stakeholders often believe that only a few obstacles to LID exist in local codes.**
   Typically, a local code review identifies numerous obstacles to LID woven throughout a local code. These obstacles include provisions that actively limit or prevent the use of LID; provisions that create ambiguity about the use of LID; and/or helpful provisions that do not yet exist, but could better enable or facilitate the use of LID, if added. The most common code obstacles identified include:
   - No allowance for vegetated LID practices to count toward open space and landscaping requirements.
   - No allowance for vegetated LID practices to be constructed in the parcel's designated open space, landscaping and perimeter screening.
   - Overly prescriptive requirements for off-street parking, landscaping and screening.
   - Requirements for overly large streets, rights-of-way and parking lots.
   - Rigid setback, side yard and rear yard requirements.
   - Insufficient stream buffer requirements.
   - Requirements for curbs and gutters. No allowance for curb cuts.

   Local code restrictions often force vegetated LID practices to compete with open space, landscaping, setbacks, screening, trees and other vegetation requirements on a development site, unnecessarily making LID an "extra cost." Taken together, these barriers affect the feasibility, effectiveness and cost of implementing LID.

2. **Many local governments assume it will be sufficient to revise their stormwater ordinance to facilitate or require LID practices and related stormwater BMP design standards.**
   In addition to revising the stormwater ordinance language, local planners will likely need to implement other changes to establish LID as a commonly used stormwater management tool, such as removing barriers to LID, adding incentives to make LID use a cost-effective development option, educating local government staff and cultivating a wider public acceptance of LID through outreach.

3. **People assume that local government staff can easily waive the specific elements of a development code that conflict with LID.**
   Local governments developed their codes over time to protect their community, and compliance is mandatory. A developer must apply to the local board of adjustment for a variance for each item in the development plan that does not comply with the existing code. For a development project proposing LID practices in a community where the code has not been revised to remove obstacles, 15 or more variance requests/applications might be needed. This process creates unacceptable uncertainty, time delays, and extra costs for developers, leading them to conclude that proposing LID is not worth the effort. Therefore, LID elements that conflict with codes are often simply omitted from development plans.



K. Philips, Tetra Tech

Local zoning code allows for curb cuts, Harrisonburg, Virginia

USEPA

Zoning code allows for LID practices and limited setback between homes, Seattle, Washington

Identifying LID Obstacles in Your Local Codes

Tools for Code Review

Once your community understands the need to revise the local codes to create a useful pathway to LID, the process may begin. Numerous tools, such as guidebooks and checklists from federal, state and local governments, are available to help you. EPA lists many resources on its Low Impact Development and Green Infrastructure webpages. Some communities complete the code review process on their own, and some seek outside assistance. Four free resources designed to help with code review are:

- **Tackling Barriers to Green Infrastructure: An Audit of Local Codes and Ordinances (2017).** Developed by Wisconsin's Sea Grant, this workbook is intended to help local governments identify and revise local codes and ordinances to allow for and support green infrastructure.
- **The Green Infrastructure Opportunities Checklist Tool.** This checklist can be used to evaluate local development codes and manuals to identify obstacles and opportunities for LID. It primarily focuses on the development site scale. The tool is designed to help users identify key provisions in codes that support or impede the use of LID.
- **Low Impact Development: Code Update and Integration Toolkit (July 2014).** This toolkit, developed by Washington Department of Ecology, provides worksheets and other resources to help jurisdictions integrate LID into local codes, rules, standards and other enforceable documents. It provides a step-by-step approach, addressing (1) who should be included in the effort, (2) what topics should be addressed, (3) where LID-related codes are usually found, (4) how to fill the gaps, (5) how to ensure review and adoption of codes, and (6) how to successfully implement the code.
- **EPA's Water Quality Scorecard (2009).** This scorecard is a tool for a local government to use to evaluate its water quality program. The evaluation is at three scales: site, neighborhood/district and whole community/watershed. It uses five topic areas to score the program: open space, compact development, green streets, green parking and LID development. The Scorecard covers more than 230 policies, code provisions and incentives.

Green Infrastructure Opportunities Checklist Tool: Phoenix Example

GOAL #1: MINIMIZE EFFECTIVE OR CONNECTED IMPERVIOUS AREA
Objective: Minimize impervious area associated with streets
Objective: Minimize impervious area associated with parking
Objective: Minimize impervious area associated with driveways and sidewalks
Objective: Clustering development
Objective: Incorporate sustainable hydrology practices into urban redevelopment

Key: Importance to City
● Essential
◗ Very important
Important
Not important

GOAL #1 KEY QUESTIONS	DEGREE OF IMPORTANCE	COMMENTS (INDICATE ORDINANCE FINDINGS "YES" OR "NO." WHEN "NO," NOTE SPECIFIC LOCATION OF BARRIER IN CODE)
Streets		
1. For residential development, are the street pavement widths allowed to be between 18 to 22 feet, with curb pullouts for passing of large vehicles?	●	**Code Findings: No** City of Phoenix Street Planning and Design Guidelines. Local Single Family Residential Streets: 28 to 32 feet of pavement width is required; Minor residential collector streets: 40 feet are required.
2. Are travel lanes allowed to be from 12 to 10 feet (or less), with curb pullouts for passing of large vehicles?	●	**Code Findings: No** City of Phoenix Street Planning and Design Guidelines. Local Single Family Residential Streets: 14 to 16 feet are required.
3. Are curb bumpouts/extensions allowed near intersections and mid-block for traffic-calming and bioretention opportunities?	◗	**Code Findings: Yes** City of Phoenix Street Planning and Design Guidelines. Traffic calming devices include several standard drawings of curb bumpout and planters that could accommodate bioretention.
4. Is pervious paving allowed for on-street parking and alleyways?		**Code Findings: No** City of Phoenix Street Planning and Design Guidelines. Alleys, on-street parking lanes and on-street bike lanes require asphalt.
5. Are grass swales or bioretention swales allowed instead of curb and gutter or with curb cuts (where slopes allow)?	◗	**Code Findings: Not expressly allowed or prohibited, but appears limited** City Code 32-289A. Urban density of 3 or more lots per gross area must have paved and curb streets. Note: There is no express allowance for bioretention or swales in those cases where curb is not required

The Green Infrastructure Opportunities Checklist helps localities identify elements of a development code that prevents the use of LID. Because the checklist is constantly being revised to reflect new information, the most up-to-date version is available to localities for free upon request by emailing gicodereviewchecklist@tetratech.com.

EPA's Water Quality Scorecard: Example Section

3. DESIGN COMPLETE, SMART STREETS THAT REDUCE OVERALL IMPERVIOUSNESS

3.B GREEN INFRASTRUCTURE ELEMENTS AND STREET DESIGN

3.B.2 QUESTION: Do regulations/policies promote use of pervious materials for all paving areas, including alleys, streets, sidewalks, crosswalks, driveways, and parking lots?

GOAL: Build and retrofit these surfaces with pervious materials to reduce stormwater runoff and its negative impacts. NOTE: While eliminating sidewalks or placing sidewalks on only one side of the road can reduce impervious cover, this strategy is typically most appropriate for rural areas. However, other effective strategies can achieve the same runoff reductions that will not limit residents' options for recreation and transportation.

WHY: Streets, sidewalks, and other hard surfaces contribute a large portion to a municipality's total imperviousness. Making these impervious surfaces more permeable protects water quality, reduces flooding, and can recharge groundwater.

Implementation Tools and Policies	[illegible]	[illegible]	Notes and Local References
ADOPT PLANS/EDUCATE:			
Sponsor/approve pilot programs to determine appropriate pervious materials for different paving areas (e.g., permeable concrete for sidewalks.), as well as process for installation and maintenance.	1	1	Taylor Mall, Helen Drake Senior Center, Manzanita Park, for example City does approve and sponsor such pilot programs on a case-by-case basis.
Pilot project results incorporated into standard practice for all new paved areas and retrofits of existing paved surfaces.	1	0	City has not incorporated into standard practice for all new paved areas and retrofits of existing paved surfaces; is currently evaluating the implementation of the City's Complete Streets Program with GI.
Adopt policy to replace impervious materials with pervious materials where practical.	1	0	City has not yet adopted a policy to replace impervious materials with pervious materials. O&M aspects still need to be evaluated.
REMOVE BARRIERS:			
Technical street specifications allow pervious paving materials in appropriate circumstances (e.g., not allowed over aquifer recharge areas).	1	0	City of Phoenix Street Planning and Design Guidelines do not allow pervious paving materials.
ADOPT INCENTIVES:			
Create formal program offering incentives (e.g., cost sharing, reduction in street widths/parking requirements, assistance with maintenance) to property owners who utilize pervious pavement elements.	1	0	Currently, the City doesn't have any such formal program that offers any incentives.
ENACT REGULATIONS:			
Adopt requirement that some percentage of parking lots, alleys, or roads in a development utilize pervious materials.	1	0	City of Phoenix Street Planning and Design Guidelines do not allow pervious paving materials.
Development approvals that allow/require use of pervious materials include requirements for ongoing maintenance/cleaning of pervious surfaces.	1	0	City of Phoenix Street Planning and Design Guidelines do not allow pervious paving materials.
		1	**Out of 7 possible points**

EPA's Water Quality Scorecard offers fill-in-the blank forms to help localities evaluate whether development codes are LID-friendly.

Removing Code-Related LID Obstacles

Once your community has identified the LID obstacles in its code, the process of removing them can begin. Some of the easier code fixes include revising text so it offers site design flexibility that explicitly allows or facilitates LID (see Easier Code Fixes, below). Some local governments take on more challenging code fixes, such as those involving negotiation between multiple parties (see More-Challenging Types of Code Revisions, next page). Finally, many local governments opt to include incentives in their code for LID (see Adding LID Incentives through Offsets or Credits, next page).

Easier Code Fixes

The following local code samples highlight improvements that are relatively easy to enact. These code fixes provide site design flexibility and explicitly favor LID; however, they do not include bonus incentives for the preferential use of LID (as show in the next section). [Note: Code samples are illustrative and do not indicate an EPA recommendation for any particular locality.]

Sample Code for Landscaping, Streetscape and Tree Preservation

To promote multifunctional LID practices and provide incentives for their use, bioretention areas, vegetated swales, planter boxes, rainwater harvesting systems, and other approved vegetated LID practices may be used to meet landscaping, buffering, streetscape, and tree preservation requirements in this chapter, and may be constructed in designated landscape, buffering, streetscape, and tree preservation areas if part of an approved stormwater management plan for the site. The dimensional and plant standards for landscaping areas and landscape strips in this chapter may accommodate LID features if they are part of an approved stormwater management plan for the site.

A. Goldstein

Landscaped detention area, Seattle, Wash.

Sample Code for Bufferyards

LID may be used to comply with bufferyard (i.e., vegetative screening of adjacent properties) requirements of section X. The city shall allow vegetated LID practices in buffer types A, B, and C. LID practices shall be allowed in the first ten (10) feet of bufferyards D, E, and F, as measured from the interior of the site. The minimum plant materials required in table X shall be met in the overall bufferyard area. The permanent irrigation requirements of this chapter shall not apply to LID practices that use native plants. Bufferyard areas with LID practices that use native plants and drought-tolerant vegetation and that do not install a permanent irrigation system shall provide a detailed alternative irrigation plan and schedule for the establishment and maintenance of the bufferyard.

Sample Code for Property Setback, Side Yard and Rear Yard

To accommodate LID practices and optimize LID site design, required setback, side yards, and rear yards in table X of this chapter may be reduced as long as such reductions meet fire code standards. The reductions may not compromise public safety such as the sight distance triangles defined in section X of this chapter.

J. Wright, Tetra Tech

Sidewalk retention area, Los Angeles, Calif.

Sample Code for Curb and Edge Treatment

Where a portion of a project or public improvement has been designed specifically as a LID stormwater management feature, curb only, saw tooth curb, and curb cut edge treatments are allowed and encouraged.

Sample Code for Parking Area Landscaping, Buffering and Shading

To promote multifunctional LID practices and provide incentives for their use, bioretention areas, vegetated swales, planter boxes, rainwater harvesting systems, natural channel design and other vegetated practices may be used to meet parking area landscaping areas required in this section. These may be constructed in designated landscape areas if part of an approved stormwater management plan.

More Challenging Types of Code Revisions

The following code revisions require more intensive negotiation between local government departments and with other local stakeholders and are more challenging to enact. Often, the departments have codes, policies, standards and enforceable documents that will need to be identified and updated to allow for LID. Because codes develop over time in response to needs of different departments (e.g., planning and inspections, stormwater, drinking water, wastewater, transportation/streets, fire safety, solid waste, recreation, economic development), crafting proposed code revisions requires input and agreement by all of them. LID practices that affect numerous departments and require coordination and negotiation during code revisions include:

M. Frey, Tetra Tech

Curb bump-out creates narrower streets and captures runoff, Gresham, Oregon

- Allowing narrower street pavement widths.
- Allowing LID practices in rights-of-way.
- Adding required retention or LID performance standards.
- Requiring wider stream buffers.
- Providing stormwater credit for LID practices installed in the privately maintained area of rights-of-way.

The documents highlighted in the Tools for Code Review section (page 5) offer approaches and advice for working through these issues.

A. Goldstein

A trail winds through neighborhood parkland, Lenexa, Kansas

Adding LID Incentives

Local governments might decide to further promote greater adoption of LID. To reward a developer for using LID practices, a locality could reduce the applicable stormwater fee, expedite necessary reviews, offer higher parkland or landscaping credits, or award development density and parking reduction bonuses. (For more ideas, see EPA's fact sheet on Encouraging LID.) Localities typically provide incentives f*or private development requirements* as shown in the following code text examples.

USEPA

Development includes open spaces and decentralized stormwater control, Wilsonville, Oregon

Sample Code for LID Landscaping Credit Incentive

Areas with LID practices will receive 1.5 credit acres for landscaping requirements of this section. Irrigation requirements of this chapter shall not apply to LID practices that use native or drought-tolerant plants. If an irrigation system is not installed, the landscape plan shall provide a detailed alternative irrigation plan and a schedule for the establishment and maintenance of the landscape.

Sample Code for LID Parkland Credit Incentives

LID practices will receive 1.5 credit acres towards parkland requirements for up to 20 percent of the site's parkland requirements. The parkland dimensional requirements may be reduced up to 10 percent to accommodate use of LID practices. Linear trails may receive 1.5 parkland credit acres for up to 50 percent of the site's required parkland area, if such trails are connected to a portion of the development's remaining parkland area via a pedestrian way. Such linear trails may deviate up to 10 percent from dimension requirements of this chapter.

Sample Code for LID Parking Incentive

Minimum parking may be reduced by one parking space for each tree 12 inches in diameter or larger that is preserved on-site. A maximum of two parking spaces, or 10 percent of the total number required, may be reduced, whichever is greater.

> A great way to increase the use of LID in your community is to revise your stormwater ordinance to include a retention requirement or volume control requirement; to meet the requirement, the developer would need to use some type of LID or hybrid LID plus traditional stormwater practices.

Additional Resources:
Zoning Codes and Smart Growth

- Codes That Support Smart Growth Development. EPA website providing examples of adopted zoning codes and guidelines that support smart growth and LID implementation.
- Essential Smart Growth Fixes for Urban and Suburban Zoning Codes (2009). EPA guidance document outlining zoning codes fixes to develop more environmentally responsible urban and suburban communities.
- Essential Smart Growth Fixes for Rural Planning, Zoning, and Development Codes (2012). EPA guidance document providing policy options to help rural communities strengthen their economies while preserving the area's rural character.


Tetra Tech

Visitors learn about a roadside rain garden from experts at the University of Maryland, College Park

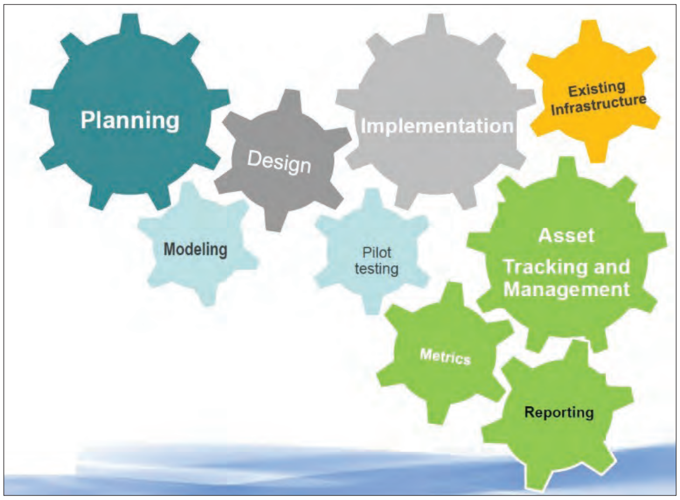
Next Steps: Build Local Capacity to Implement LID

Code change alone will not lead to LID implementation. Staff training and operational planning is necessary to ensure success.

Once you have identified and removed the most important obstacles to LID in your community's local development code, you might assume your new LID program will run smoothly on autopilot. It is important to note that, along with code revisions, your community also needs to build the operational capacity to implement the new code provisions. To equip your local government staff and the community with the tools they need, consider offering employee training for LID plan review and inspections, hosting developer/design community LID training, developing a LID design manual, and creating an operation and maintenance agreement template. It is also critical to establish a long-term funding mechanism for inspections, operations and maintenance, and to establish clear lines of departmental responsibility for these functions. These steps will ensure the staff can do its job and the development community understands the new provisions of the local development code—allowing LID to become a routine part of development in your community.

The good news is that you're not alone. Your biggest resource is the team of local staff that helped negotiate the new local code provisions. Key things they can do include:

- Develop an action plan for building operational capacity over a 5- to 10-year period.
- Reach out to neighboring jurisdictions or the state to see if they have already developed design manuals, plan review checklists, tracking systems for LID practices, etc., that you can build on.
- Ask your local college or university, state environmental agency or U.S. Environmental Protection Agency office if they have LID training or workshop materials available for local staff and the development community.



Building and maintaining a LID program requires cooperation and coordination between local government and community stakeholders

Urban Runoff: Model Ordinances to Prevent and Control Nonpoint Source Pollution

Many communities across the nation are facing challenges associated with natural resource degradation due to rapid growth and development. Local governments need to have legal authorities in place to shape development and to protect resources. This web site helps local governments by providing the necessary information needed to develop effective resource protection ordinances.

The ordinance types listed below include matters that are often forgotten in many local codes including aquatic buffers, erosion and sediment control, open space development, stormwater control operation and maintenance, illicit discharges and post construction controls.

- Aquatic Buffers
- Erosion & Sediment Control
- Open Space Development
- Stormwater Control Operation & Maintenance
- Illicit Discharges
- Post Construction Controls
- Source Water Protection
- Miscellaneous Ordinances
- Related Links

The sortable example ordinance table allows visitors to select the relevant topic to see a listing of related real-life examples of ordinances used by local and state governments around the nation. View the sortable ordinance table.

Aquatic Buffers

Aquatic buffers serve as natural boundaries between local waterways and existing development. They help protect water quality by filtering pollutants, sediment and nutrients from runoff. Other benefits of buffers include flood control, stream bank stabilization, stream temperature control and room for lateral movement of the stream channel.

Good aquatic buffer ordinances specify the size and management of the stream buffer and are a specific planning tool to protect stream quality and aquatic habitat. Effective buffer ordinances provide guidelines for buffer creation and maintenance and should require:

- buffer boundaries to be clearly marked on local planning maps
- maintenance language that restricts vegetation and soil disturbance
- tables that illustrate buffer width adjustment by percent slope and type of stream
- direction on allowable uses and public education

A strong buffer ordinance is only a first step to preserving stream buffers. In addition, communities will need an effective buffer program to manage buffers and enforce buffer regulations. During the construction phase, communities need to ensure that the clearing and grading permit is well integrated with the forest buffer application. After construction, programs that educate citizens about the importance of the buffer and how to manage the buffer can help preserve its integrity.

Erosion and Sediment Control

By most accounts, the most environmentally dangerous period of development is the initial construction phase when land is cleared of vegetation and graded to create a proper surface for construction. The removal of natural vegetation and topsoil makes the exposed area particularly susceptible to erosion, causing transformation of existing drainage areas and disturbance of sensitive areas.

Erosion and sediment control is widely accepted as a necessary practice, but there are certain ways to make even the most well-crafted ordinance more effective. First, communities need to have the staff and resources to enforce erosion and sediment control regulations; otherwise, the authority to inspect sites becomes useless. In addition, the technical manual referred to in the ordinance needs to provide useful guidance on selecting erosion and sediment control measures. Third, education of contractors, engineers, and designers regarding the importance and effective use of erosion and sediment controls is essential to implementing effective erosion and sediment controls.

Open space development

Also called "cluster development," is an alternative site planning technique that concentrates dwelling units in a compact area to reserve undeveloped space elsewhere on the site. In this technique, lot sizes, setbacks, and frontage distances are minimized to allow for open space. The typical open space development creates less impervious cover and reduces the need to clear and grade 35 percent to 60 percent of the site. Open space areas are often used for neighborhood recreation, stormwater management facilities, or conservation purposes. Open space preserved in a natural condition needs little maintenance and helps to reduce and sometimes to treat stormwater runoff from development.

Certain issues are not covered in this ordinance because many localities provide for them in other ordinances or they are too specific to each community. For example, language on road widths is not included because it is often a part of subdivision or other ordinances. Although most ordinances contain a section on the development review process, such language was not included because the review process varies widely by locality.

Although open space development is desirable, there are challenges to applying open space development criteria in every community. For open space development to be successful, the ordinance needs to be crafted in a way that fosters development that is both marketable and environmentally sensitive. The ordinance needs to effectively address issues such as maintenance, liability, and emergency vehicle access. In addition, the community needs to be prepared to manage the space or to dedicate open space to a responsible organization. Finally, decisions about when and where open space development is desired need to be made early.

Stormwater Control Operation and Maintenance

The expense of maintaining most stormwater best management practices (BMPs) is relatively small compared to the originale construction cost. Too frequently, however, BMP maintenance is not completed, particularly when the BMP is privately owned.e Improper maintenance decreases the efficiency of BMPs and can also detract from the aesthetic qualities of the practice. Thee operation and maintenance language within a stormwater ordinance can ensure that designs facilitate easy maintenance ande that regular maintenance activities are completed.

Some important elements of effective stormwater operation and maintenance ordinance language are the specification of ae specific entity responsible for long-term maintenance and reference to regular inspection visits. The ordinance should alsoe address design guidelines that can help ease the maintenance burden, such as the inclusion of maintenance easements.

Although language that legally requires operation and maintenance of stormwater BMPs is important, there might be a disjointe between the ordinance language and what happens "on the ground." In this section, the information provided in support of thee ordinance, such as maintenance agreements and inspection checklists, is as important as the ordinance to ensuring thate stormwater BMPs perform efficiently over time.

Illicit Discharge

is defined as any discharge to the municipal separate storm sewer system that is not composed entirely of storm water, excepte for discharges allowed under a NPDES permit or waters used for firefighting operations. These non-stormwater discharges occure due to illegal connections to the storm drain system from business or commercial establishments. As a result of these illicite connections, contaminated wastewater enter into storm drains or directly into local waters before receiving treatment from ae wastewater treatment plant. Illicit connections may be intentional or may be unknown to the business owner and often are duee to the connection of floor drains to the storm sewer system. Additional sources of illicit discharges can be failing septic systems,e illegal dumping practices, and the improper disposal of sewage from recreational practices such as boating or camping.

Illicit discharge detection and elimination programs are designed to prevent contamination of ground and surface watere supplies by monitoring, inspection and removal of these illegal non-stormwater discharges. An essential element of thesee programs is an ordinance granting the authority to inspect properties suspected of releasing contaminated discharges intoe storm drain systems. Another important factor is the establishment of enforcement actions for those properties found to be ine noncompliance or that refuse to allow access to their facilities.

Post Construction Controls

The management of stormwater runoff from sites after the construction phase is vital to controlling the impacts of developmente on urban water quality. The increase in impervious surfaces such as rooftops, roads, parking lots, and sidewalks due to lande development can have a detrimental effect on aquatic systems. Heightened levels of impervious cover have been associatede with stream warming and loss of aquatic biodiversity in urban areas. Runoff from impervious areas can also contain a variety ofe pollutants that are detrimental to water quality, including sediment, nutrients, road salts, heavy metals, pathogenic bacteria,e and petroleum hydrocarbons.

Source water protection

involves preventing the pollution of the groundwater, lakes, rivers, and streams that serve as sources of drinking water for local communities. Source water protection ordinances help safeguard community health and reduce the risk of contamination of water supplies. When drafting an ordinance aimed at protecting these sources, the drinking water supplies can be divided into two general sources; aquifers and wells (groundwater) and lak es and reservoirs (surface water). Wellhe ad Protection (WHP) Zones and Aquifer Protection Areas are two examples of source water protection ordinances that seek to protect groundwater sources. Water Supply Watershed Districts and Lake Watershed Overlay Districts are examples of local management tools that provide protection to surface water supplies by restricting land uses around a reservoir used for drinking water.

Communities may take for granted that a plentiful supply of high quality drinking water will be available. However, drinking water sources, whether they be from ground water, or surface water, or both, are a vulnerable natural resource that needs to be protected. To ensure that these drinking water sources are protected most effectively, an ordinance should contain several basic concepts. First, source water planning should be done on a scale that ensures protection of the whole recharge zones for that source water. For surface waters, communities may wish to create overlay zoning districts that have boundaries large enough to protect both the source water resource and the tributaries and streams that contribute to the resource. For groundwater, communities could consult with the USGS to be sure their overlay zoning district encompasses the entire area that recharges any aquifer. Second, an ordinance should have language specifying allowable and prohibited land uses within the source water protection zone. For example, many source water protection ordinances limit or forbid the storage of hazardous materials and place restrictions on the location of businesses that use these materials within the overlay district. An ordinance should also include procedures for review of proposed projects within a source water protection district to verify that the project is consistent with the ultimate goal of the ordinance. This might include requiring applicants to submit geotechnical and hydrological analyses to determine the potential impacts to water quality and the submission of spill control plans for businesses performing potentially contaminating activities. Finally, language explaining the mechanisms for enforcement of the requirements of the ordinance, including the civil and criminal penalties that may apply for failure to obey, should be included.

The source water protection ordinances are divided into two separate categories: a source water (groundwater) pr otection category and a surface water (reservoir) pr otection category. Each category contains a model ordinance and five example ordinances from around the country. The language for each of the models is borrowed from a number of ordinances and communities will need to assess what the appropriate requirements are for their area. In addition, some of the example ordinances have language addressing issues not dealt with in the model, and officials are encouraged to examine each of the ordinances for the best language to meet the specific needs of their community.

Helpful Resources

	Center for Watershed Protection <https://www.cwp.org/> CWP's resources include more than 250 Guidance manuals, articles and reports to assist with watershed and stormwater management needs.

	Local Government Environmental Assistance Network (LGEAN) <https://www.lgean.net/> LGEAN's goal is to provide a forum and clearinghouse of environmental information for local governments. This site contains areas to explore new federal and state regulatory requirements and post messages and a search engine to help navigate their extensive library.

Key Topic #4: Strategies to Evaluate NPS Sources, Issues, and Solutions

Learning Objectives

1. **Identify** tools and techniques used to assess non-point source pollution, including watershed mapping, stormwater flow tracing, and visual assessment methods.
2. **Explain** how monitoring data (e.g., water quality indicators such as turbidity, E. coli, nutrients) can be used to evaluate the presence and severity of NPS pollution.
3. **Describe** the challenges in monitoring, quantifying, and managing NPS pollution compared to point source pollution.
4. **Apply** simple field protocols to evaluate land use and physical features (e.g., slope, impervious cover, vegetative buffers) that influence runoff and pollutant transport.
5. **Interpret** basic maps, aerial imagery, or field data to locate potential sources of NPS pollution in a given watershed.
6. **Recommend** appropriate solutions based on identified issues in a mock or real-world NPS pollution scenario, drawing on field evidence or data interpretation.

Nonpoint Source Monitoring

(https://www.epa.gov/nps/nonpoint-source-monitoring-technotes)
See original document above for embedded references.

Through the National Nonpoint Source Monitoring Program (NNPSMP), states monitor and evaluate a subset of watershed projects funded by the Clean Water Act Section 319 Nonpoint Source Control Program. The program has two major objectives:

1. To scientifically evaluate the effectiveness of watershed technologies designed to control nonpoint source pollution
2. To improve our understanding of nonpoint source pollution

NNPSMP TechNOTES is a series of publications that EPA published between 2005 and 2014 that describes this unique research and monitoring effort. TechNOTES offer:

- guidance on data collection,
- implementation of pollution control technologies and monitoring design,
- case studies that illustrate principles in action.

Designing Water Quality Monitoring Programs for Watershed Projects
Excerpts

Designing Water Quality Monitoring Programs for Watershed Projects

(https://www.epa.gov/polluted-runononpoint-source-monitoring-technical-notes) See original document above for embedded references.

Define Goals

Monitoring is carried out to support watershed projects for a number of reasons, including the following (USEPA, 1997a):

- To identify water quality problems, use impairments, causes, and pollutant sources
- To assess permit compliance
- To assist program development and management
- To respond to emergencies
- To validate or calibrate models
- To conduct research
- To develop TMDLs and load/wasteload allocation
- To assess use support status
- To track trends
- To track management measure implementation
- To assess the effectiveness of watershed projects

Relevant monitoring goals are to track management measure implementation, look for trends, and assess watershed project effectiveness. Land treatment monitoring goals might include the following:

- To find out when and where management measures are implemented and operational
- To determine whether management measures are working as planned
- To determine the degree of pollution control achieved by the management measures
- To measure the pollutant contributions from areas where management measures are not implemented
- To discover unplanned activities that could affect project success

Trend analysis and watershed effectiveness monitoring goals might include the following:

- To document pre-implementation water quality conditions
- To measure changes in water quality due to implementation of management measures
- To develop information to guide changes in the implementation plan if water quality goals are not achieved
- To measure the pollutant removal efficiencies of specific management measures
- To measure water quality changes in subwatersheds
- To document changes in pollutant load at the watershed outlet

Review Available Information and Monitoring Efforts

A good watershed monitoring program must be based on a thorough understanding of the system(s) being monitored. Collecting and evaluating all available information and data from other monitoring efforts lays an important foundation for such an understanding. Currently available information should be reviewed before new data are collected to assess its potential use in characterizing the watershed and achieving monitoring goals.

Existing data can also be helpful in designing the management measure implementation plan. For example, stream data for relatively homogenous watersheds might be helpful in assessing pollutant delivery coefficients for current land uses. Comparing these coefficients with literature values might provide a crude indication of the extent to which management improvements could reduce pollutant delivery.

When reviewing historical data, it is important to explore any relationships that might exist between water quality data and land use or land management data. Abrupt changes in water quality parameter values could be related to the addition of or improvement to a point source discharge such as a wastewater treatment plant, changes in impervious surface percentage, increases or decreases in livestock herd sizes, changes in agricultural crop production or livestock types, hydromodification or bridge construction, urbanization, or other land use or land management changes.

Design the Monitoring Program

The specifics of a successful monitoring program depend on the monitoring goals, the availability of existing data and monitoring efforts, the time frame for yielding results, the variability of the system monitored, the types of variables tracked, funding, and the priorities of program managers.

A no-frills monitoring program that meets established goals should be the base, to which enhanced capabilities are added as resources and management allow. Even with generous budgets, no monitoring should be conducted without carefully considering the use of the data to be collected.

Statistical Design

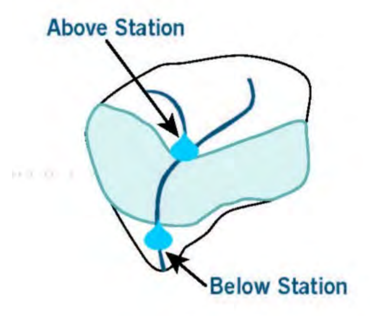
The statistical design must be chosen before other monitoring details (e.g., scale, number of sampling sites, monitoring station type, sampling frequency) can be determined. search sampling can be used to characterize a watershed and locate major pollutant sources; and probability sampling should be used to evaluate watershed projects. Types of probability sampling include simple random sampling, stratified random sampling, two-stage sampling, cluster sampling, systematic sampling, and double sampling

When evaluating the effectiveness of watershed projects, the emphasis should be on testing a hypothesis rather than estimating parameters. For example, the null hypothesis might be that phosphorus loads to the lake will not change between pre-implementation and post-implementation conditions. The goal for the monitoring design would be to test the null hypothesis and, if the null hypothesis is rejected, to conclude with some level of confidence that a change occurred.

The types of monitoring designs are as follows:

- Single-watershed before/after (not recommended)
- Above/below watersheds
- Side-by-side watersheds (not recommended)
- Paired watersheds (very good, but expensive)
- Trend monitoring (>10 years monitoring)

Above/Below Watersheds



In this design monitoring stations are placed above and below the area in which management measures are implemented. Also known as a nested design, this can be treated as a paired-watershed approach if monitoring is done before and after management measures are implemented (USDA, 1996). This design is not as vulnerable to year-to-year climate variations as is single watershed monitoring; it is fairly easy to find a situation where treatment can be implemented between stations; and it is possible to attribute changes in water quality to specific causes, as long as management measures and other land use variables are monitored in both watersheds.

One disadvantage is that the water quality at the above station and that at the below station are not independent because upstream concentrations usually affect downstream concentrations. This might confound statistical analysis of the data. If both pre-implementation and post-implementation monitoring are used, some of these problems can be addressed by a paired-watershed analysis. A paired t-test of the differences between paired above and below samples is appropriate for this design (USDA, 1996).

Watershed-level monitoring is the primary mechanism for evaluating the effectiveness of a watershed project because the projects are implemented at this scale. Watersheds can range in size from a few acres to several thousand acres depending on the project goals and setting. As a general rule, larger watersheds are slower to respond to treatment because of the pollutant transport mechanisms involved. This, however, might not be the case where biological monitoring is conducted, particularly in watersheds where habitat restoration is a key component of the implementation plan.

Variables

The basic monitoring program to assess watershed project effectiveness must focus on the pollutant sources identified in the watershed, the key pollutants from these sources, the water resources affected by these sources and pollutants, measures of designated use support in the affected water resources, and any biological and habitat issues of concern.

Logistical factors, including site access and conditions, personnel availability, and travel times, also influence the selection of water quality variables to monitor. Some water quality constituents, such as soluble reactive phosphorus, have short (24-hour) holding times and require refrigeration while waiting for pickup. In contrast, samples for total phosphorus analysis can be held for as long as 7 days under proper conditions. Samples for bacteria analysis can rarely be collected by automated sampling equipment because of sterility issues and have even shorter allowable holding times (6 hours) between collection and analysis. Trade-offs between the expense and personnel effort to accommodate such constraints and the value of the resulting information must be considered when selecting variables to monitor.

In the end, monitoring data will be used to make statements about the effectiveness of the watershed project. Precipitation, air temperature, and other weather variables are also typically tracked to aid in data analysis and interpretation.

Number of Samples

For many urban streams
it might be desirable to sample every storm event, whereas weekly sampling might be sufficient for rural streams. Storm event samples are often composited into weekly samples for laboratory analysis. Monthly or quarterly sampling could be adequate for some lakes, whereas reservoirs with short hydraulic residence times might require weekly sampling.

Monitoring of management measure effectiveness requires a greater sampling frequency than does trend monitoring. Trend monitoring, however, is typically carried out over a far longer period, bringing total sample counts near to those for effectiveness monitoring.

Trend Analysis

to support trend analysis, a sufficient number of samples must be collected to adequately represent seasonality or other sources of variability evident in the data. In general, a monthly sampling frequency (or taking more frequent samples that can be aggregated to monthly median values, for example) is generally the minimum frequency for sampling streams or rivers in nonpoint source situations. Sampling programs to support trend analysis should operate continuously for the entire project period, using consistent methods, locations, and schedules.

Timing

The sampling time chosen depends on the monitoring goals, the target population, and the anticipated relationship between management measure implementation and measured water quality. If seasonal impacts are expected, sampling should occur during the identified season(s). To determine the general conditions of the water resource, sampling should occur throughout the year, perhaps by weekly sampling.

For nonpoint source load estimation, sampling must occur during high-flow events because that is typically when the greatest pollutant loads occur. Some variables such as dissolved oxygen and temperature display diurnal patterns, and sampling time should be based on the portion of the pattern that is of interest. Biological monitoring is often done quarterly or on some other seasonal basis. In some climates summer sampling is impossible because there is no flow, while winter sampling might be precluded by freezing of the water resource.

Specific types of monitoring include:

- **Load Estimation**
- **Biological Monitoring**
- **Land Treatment**

Handling Noise in the Data

To cut through the noise to find the meaning or signal, a monitoring program to measure the effectiveness of a watershed project must be designed to include recognition of the variability described here. A number of obstacles and constraints must be overcome in most watershed monitoring programs, including the following:

- Lack of control over activities that affect water quality
- Hydrologic variation across seasons and between years
- Incremental change brought on by a land treatment program
- Lag time in the response of natural systems to change
- Surprises, disasters, and other unusual events

Keeping these issues in mind during the design and operation of a monitoring program will increase the probability of success.

Quality Assurance and Quality Control Plan

Quality assurance and quality control practices should be an integral part of the development, design, and implementation of a watershed evaluation project to minimize or eliminate problems associated with the methodologies, data quality, and coordination of sampling and analysis efforts (USEPA, 1997a).

Data Management, Analysis, and Reporting

While conducting a watershed evaluation project, it is important to document all data collected and used. All collected data should be validated with error checking, stored in a logically based and safe filing system with backups, and analyzed using proven approaches. Both hard and computerized copies of data should be maintained because each type of storage is susceptible to damage or loss. Both hard and computer copies should be housed separately from originals, and data should be backed up daily as long as new data are being acquired.

Exploring Your Data, The First Step

(https://www.epa.gov/polluted-runoffnonpoint-source-monitoring-technical-notes)
See original document above for embedded references.

Now that your monitoring program is up and running, it is time to evaluate the data. If you designed your monitoring program carefully (Tech Note #2), you will have the right kinds of data collected at appropriate times and locations to achieve your objectives. At the start, you should check your data for conformity with original plans and quality assurance/quality control (QA/QC) procedures. Use the Quality Assurance Project Plan (QAPP) you developed as a guide.

After you accept the dataset, you will still be faced with a challenge: What do I do with all these numbers? What do they mean? How do I start to make sense of them? The first step in answering such questions lies in exploratory data analysis (EDA). The purpose of EDA is to get the “feel” of your data, to begin to develop some ideas about what they can tell you and how you can draw some conclusions about them. Think of EDA as detective work—your job is to sift through all the facts, look for clues, and put the pieces together to find suggestions of meaning in the data.

Your specific objectives for data exploration might include the following:

- to describe the behavior of one or more variables
- to find extreme values and anomalies
- to test distribution and assumptions of independence and constant variance
- to see cycles and trends
- to find clusters or groupings
- to compare two or more locations or time periods and
- to examine relationships between variables

Data exploration is a necessary first step in analyzing monitoring data; unless initial exploration reveals indications of patterns and relationships, it is unlikely there there will be something for further analysis to confirm.

Decisions

If you are monitoring an erosion problem, you may want to see if there is a relationship between streamflow and suspended solids concentrations or look at how that relationship changed following land treatment. In most cases, you will want to look at the distribution of the data to determine whether the data satisfy statistical assumptions or whether a transformation is needed before further analysis.

There are two general approaches to EDA—quantitative (numerical) techniques and graphical approaches. The following sections identify some specific techniques for exploring your data.

Quantitative (Numerical) Techniques

Because these quantitative techniques are readily calculated by most spreadsheet programs and statistical software, this publication will not go into detail on the calculation of these statistics.

Evaluation of One Variable

Measures of Central Tendency

- The mean is computed as the sum of all values divided by the sample size.
- The median, or 50th percentile, is the central value of the distribution when the data are ranked in numerical order.

Measures of Spread

- The sample variance and its square root, the standard deviation, are the most common measures of the spread (dispersion) of a set of data.
- The coefficient of variation (CV), defined as the standard deviation divided by the mean, is a relative measure of the variability (spread) of the data.
- The interquartile range (IQR) is defined as the 75th percentile minus the 25th percentile

Evaluation of Two Variables

- In EDA, the simplest technique is correlation, which measures the strength of an association between two variables. The most common measure of correlation is Pearson's r, also called the linear correlation coefficient. If the data lie exactly on a straight line with positive slope, r.will equal 1; if the data are entirely random, r.will equal 0.

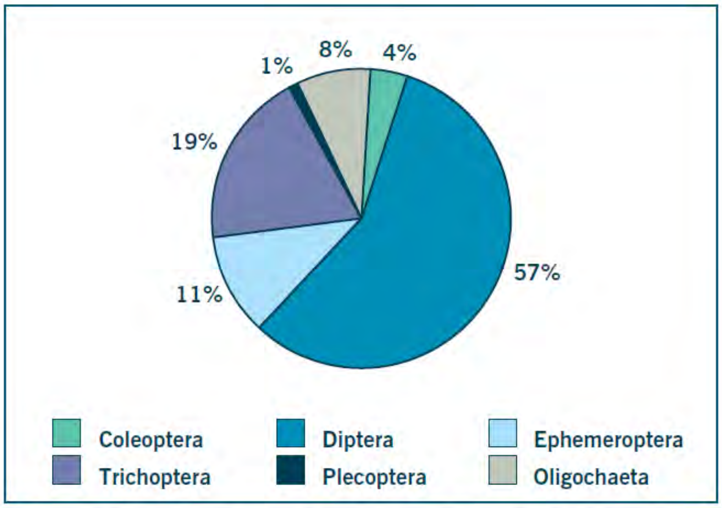
Graphical Approaches

Because graphs summarize data in ways that describe essential information more quickly and completely than do tables of numbers, graphics are important diagnostic tools for exploring your data. With the computers and software available today, there is simply no excuse for not graphing your data as part of EDA.

Graphical Evaluation of One Variable

Categorical Data

For categorical data such as the watershed area in different land uses or the number of aquatic macroinvertebrates in certain taxonomic groups, showing the data as frequencies in histograms or pie charts can effectively summarize data.



Pie Chart: Percent composition of the orders of macroinvertebrates, Godin Brook, 2000.

Other graphical methods include: histograms, quantile plots, box plots, time series, and autocorrelation.

Graphical Evaluation of Multiple Variables

Comparison of two or more variables is where EDA gets really interesting. This can mean comparing different datasets, such as stream nitrogen concentrations above and below a feedlot or phosphorus concentrations from a control and a treatment watershed, or comparing data from the same site over two different time periods, such as phosphorus loads from control versus treatment periods.

Graphical methods for multiple variables include: boxplots and scatterplots.

Next Steps

The results of your data exploration—knowledge of how your data are distributed, their characteristics, and their relationships—will help you formulate hypotheses that can be tested with more advanced statistical techniques. Procedures like the Student's t-Test, analysis of variance (ANOVA), analysis of covariance (ANCOVA), and regression can be used to draw conclusions about your data and its meaning (USEPA 1997).

Surface Water Flow Measurement for Water Quality Monitoring Projects

Excerpts Surface Water Flow Measurement for Water Quality Monitoring Projects
(*https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/nonpoint-source-monitoring-technical-notes*)
See original document above for embedded references.

Measurement of surface water flow is an important component of most water quality monitoring projects. Flooding, stream geomorphology, and aquatic life support are all directly influenced by streamflow, and runoff and streamflow drive the generation, transport, and delivery of many nonpoint source (NPS) pollutants. Calculation of pollutant loads requires knowledge of water flow.

Surface Flow Fundamentals

Surface water flow is simply the continuous movement of water in runoff or open channels. This flow is often quantified as discharge, defined as the rate of flow or the volume of water that passes through a channel cross section in a specific period of time. Discharge can be reported as total volume (e.g., acre-ft or millions of gallons) or as a rate such as cubic feet per second (ft3/s or cfs) or cubic meters per second (m3/s) (USGS, 2007). The terms flow and discharge are often used interchangeably, but they will be used only as defined here. Discharge data are essential for the estimation of loads of sediment or chemical pollutants exported from a river or stream

The depth of flow (m or ft) is most commonly measured as stage, the elevation of the water surface relative to an arbitrary fixed point. Stage is important because peak stage may exceed the capacity of stream channels, culverts, or other structures, while both very low and very high stage may stress aquatic life.

Purposes of Flow Measurement

Flow data can be used for a variety of purposes, including problem assessment, watershed project planning, assessment of treatment needs, targeting source areas, design of management measures, and project evaluation. Nonpoint source management projects generally focus on reducing either flow, availability of pollutants, or both. It is often easier and less expensive to document changes in flow than in pollutant levels as a measure of project effectiveness.

Peak flows are important to the stability of the stream channel, the size and quantity of bed material, and sediment transport rates, while low flows are important with regard to stream water temperature and fish habitat. Water yield is important in western states dependent upon hydropower.

Fundamental Measurements

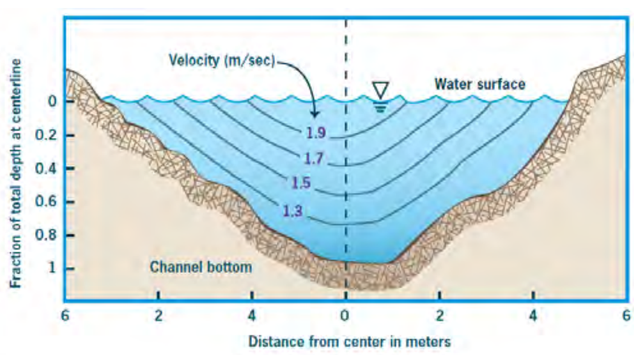
Basic Principles of Discharge Measurement

Discharge is typically calculated as the product of *velocity* and *cross-sectional area*. Surface water *velocity* is the direction and speed with which the water is moving, measured in feet per second (ft/s) or meters per second (m/s). The cross-sectional area of an open channel is the area (ft^2 or m^2) of a slice in the water column made perpendicular to the flow direction.

Determination of discharge (usually symbolized as Q) thus requires two measurements: the velocity of moving water (V, e.g., in m/s) and the cross-sectional area of the water in the channel (A, e.g, in m^2). The product of these two measurements gives discharge in volume per unit time:

$Q = V * A$ $1.25\ m/s \times 36\ m^2 = 45\ m^3/s$

It is important to recognize that the velocity of moving water varies both across a stream channel and from the surface to the bottom of the stream because of friction and irregularities in cross-section and alignment. Friction caused by the rough channel surfaces slows the water near the bottom and sides of a channel so that the fastest water is usually near the center of the channel and near the surface. On a river bend, the water on the outside of the bend moves faster than the water on the inside of the bend, as it has to cover more distance in the same time. The figure below shows a generalized schematic of the pattern of water velocity in a cross-section of a stream.



Water velocities in a typical stream cross-section
Source: L. L. Sanders. *A Manual of Field Hydrogeology*. Prentice Hall, Upper Saddle River, NJ, 1998. ISBN 0-13-227927-4.

For more details, refer to USGS "How Streamflow is Measured".

Lag Time in Water Quality Response to Land Treatment
Excerpt

Lag Time in Water Quality Response to Land Treatment
(https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_4_dec2013_lag.pdf)
See original document above for embedded references.

An important reason watershed projects may fail to meet our water quality expectations is *lag time*. Lag time is an inherent characteristic of the natural systems under study that may be generally defined as the amount of time between an action and the response to that action. In this case, we define lag time as the time elapsed between installation or adoption of land treatment at a level projected to reduce nonpoint source pollution and the first measurable improvement in water quality in the target water body. Installation refers to the completion of the construction phase for structural practices; some vegetative practices will still need to mature over time. Adoption refers to the full use of an installed physical practice or management practice such as nutrient management. Land treatment-water quality monitoring projects—even those designed to be "longterm"— may not show definitive results if the lag time exceeds the monitoring period.

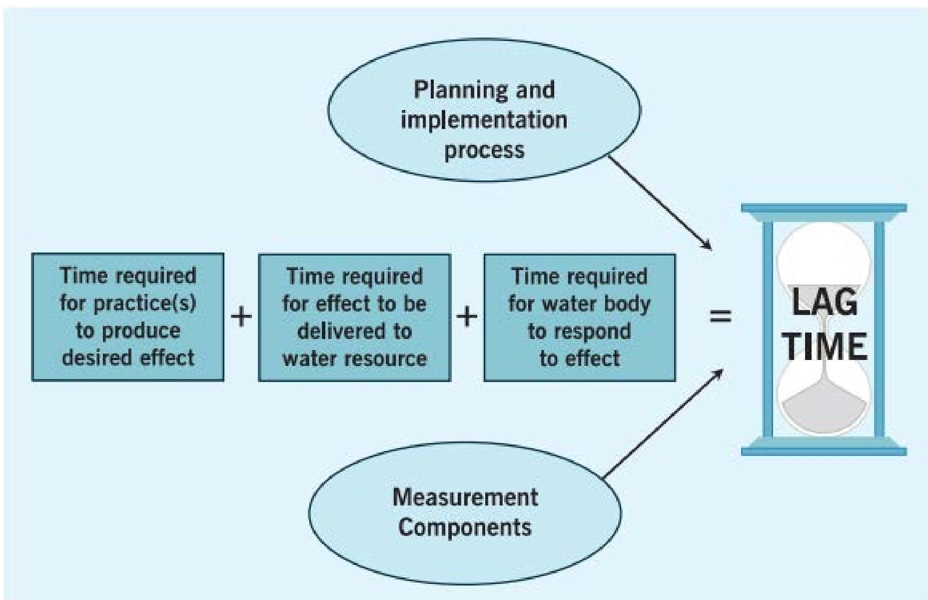


Figure 1. Components of lag time experienced in land treatment—water quality projects.

The time required to produce effects will vary depending upon the degree of impairment and the practices selected, as well as the nature of the effects themselves.

Figure 2. Fencing immediately excludes livestock from a stream (left, VT NNPSMP project), while a forested riparian buffer may take years to develop (right, PA NNPSMP project)

Time Required for Effect to Be Delivered to Water Resource

Practice effects initially occur at or near the practice location, yet usually watershed managers and stakeholders want and expect these effects to appear promptly in the water resource of interest in the watershed. The time required to deliver an effect to a water resource depends on a number of factors, including:

- The route for delivering the effect
    a. Directly in (e.g., streambed restoration) or adjacent to (e.g., shade) the water resource
    b. Overland flow (e.g., particulate pollutants)
    c. Overland and subsurface flow (e.g., dissolved pollutants)
    d. Infiltration to ground water (e.g., nitrate)
- The path distance
- The path travel rate
    a. Fast (e.g., ditches and artificial drainage outlets to surface waters)
    b. Moderate (e.g., overland and subsurface flow in porous soils)
    c. Slow (e.g., groundwater infiltration in absence of macropores)
    d. Very slow (e.g., transport in a regional aquifer)
- Precipitation patterns during the study period
    a. Wet periods generally increase volume and rate of transport
    b. Dry periods generally decrease volume and rate of transport

Time Required for Water Body to Respond to Effect

Another key factor is the speed with which the water resource responds to the effect produced by and delivered from the practice. For example, it may take a few years for algae production in a lake to decrease in response to reduced nutrient loading because of a lengthy flushing rate. If the response to be measured is fish populations rather than algae production, then even more time will be needed because fish need time to fill the newly improved habitat.

Example: Recent research in the **Chesapeake Bay Watershed** has confirmed that a substantial lag time between implementation of management practices and reductions in nitrogen loading to the Bay is very likely (Phillips and Lindsey 2003, STAC 2005). Ground water supplies a significant amount of water and nitrogen to streams in the watershed and about half of the nitrogen load in streams in the Bay watershed was transported through ground water. The age of ground water in shallow aquifers in the Chesapeake Bay watershed ranges from less than 1 year to more than 50 years.

The median age of all samples was 10 years, with 25 percent of the samples having an age of 7 years or less and 75 percent of the samples having an age of up to 13 years. Based on this age as representative of time of travel, scientists estimated that in a scenario of complete elimination of nitrogen applications in the watershed, a 50 percent reduction in base flow nitrate concentrations would take about five years, with equilibrium reached in about 2040.

Dealing with lag time *(summarized)*

- Adjust expectations
- Characterize the watershed
- Select and site BMPs
- Monitor small watersheds
- Select indicators carefully
- Design effective monitoring programs

Conclusions

Lag time between implementation of land treatment and water quality response is an unfortunate fact of life in many circumstances. Unless it is recognized and dealt with, the existence of lag time will frequently confound our ability to successfully document improved water quality resulting from treatment of nonpoint sources and may discourage vital restoration efforts. While ongoing and future research may provide us with better tools to predict and account for lag time, it is essential that watershed monitoring programs today recognize and grapple with this issue.

Using Biological and Habitat Monitoring Data to Plan Watershed Projects

Excerpts

Using Biological and Habitat Monitoring Data to Plan Watershed Projects

(https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_5_dec2013_biohab_planning.pdf)

See original document above for embedded references.

The status and condition of resident aquatic biota are important to water quality assessment programs and to the overall goals of protecting and restoring surface waters. This document is not intended to provide complete instruction in the process of biomonitoring but rather to provide a foundation for understanding the important roles that biological and habitat information can play in watershed planning and management.

2.0 Overview of Biological and Habitat Monitoring

The physical habitat represents the set of environmental conditions and constraints that supports or limits a biological community and includes such features as the geomorphology of the waterbody, the riparian zone, physical and chemical constituents dissolved or suspended in the water, and substrate and refugia for aquatic organisms. Measuring the components of the physical habitat is important to understanding and interpreting biological data because habitat is a major influence on what kind of organisms can inhabit the system.

Several questions can be addressed with comprehensive biological and physical habitat data:

1. What is the condition of the aquatic resource?
2. Is the resource impaired or degraded?
3. If there is a problem, what are the stressors?
4. What is the biological potential upon mitigation or restoration?

2.1 Relationship Among Biological, Physical, and Chemical Monitoring

The concept of ecological integrity embraces the combination of biological, physical, and chemical integrity. These three broad components of an ecosystem are inseparable in understanding the functioning of a healthy waterbody. The condition of the aquatic biological community reflects the exposure to, frequency, and duration of single or cumulative stressors in the ecosystem. In watershed planning, ecological attributes of the biological community can be considered response indicators of the multitude of stressors.

2.2 Elements of Survey Design for Bioassessment

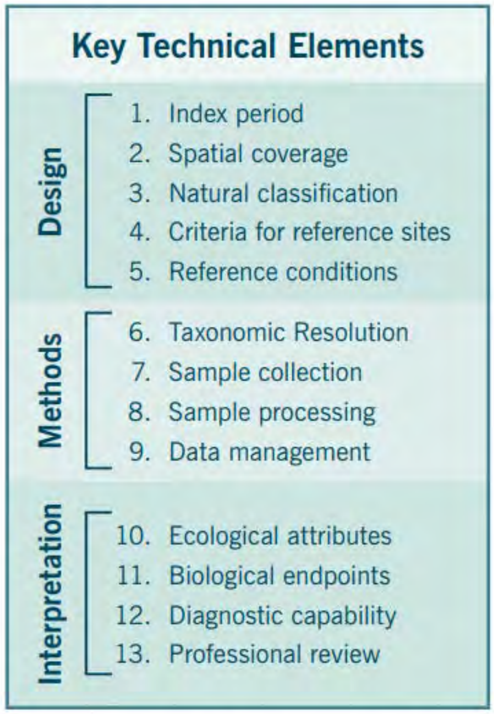


Figure 2. Critical elements of a bioassessment program.

3.0 Opportunities to Use Biological and Habitat Data in Watershed Project Planning

Biological and habitat data can be used effectively to build partnerships because they allow individuals to visualize problems better than can be done in many cases using chemical and physical data alone. While people may find it difficult to appreciate the significance of high nutrient levels, depressed dissolved oxygen concentrations, or elevated water temperatures, they can easily understand declining fishing success, depletion of prized fish species, fish advisories caused by mercury contamination, or outright fish kills.

3.2 Characterizing Watersheds

Use of biological indicators to understand resource condition.

The interpretation of biological data is grounded in the understanding of the condition of the resource that is expected under unperturbed or minimally disturbed scenarios—a condition termed as *reference condition*. Once a reference condition is established, a *best attainable condition* can be described. This condition reflects the balance between a regional reference condition that may be outside of a watershed of interest and the best attainable condition given the level and intensity of land use modification and effectiveness of implemented or proposed BMPs to offset the influence of stressors.

Use of biological and habitat measures to identify causes and sources of problems in the watershed.

Biosurvey techniques are best used for detecting aquatic life impairments and for assessing their relative severity.

4.0 What to Consider When Selecting and Implementing Biological/Habitat Data Collection

- Understand waterbody classification/types and take advantage of classification systems developed in your area (where available).
- Take advantage of reference condition work developed for your area.
- Make use of state-specific or eco-regionally refined indices whenever possible.
- Fully understand what the biological indicators you are using mean and what they do not mean, and, therefore, what they can and cannot do.
- Select and use methods that are appropriate to the biological indices you have chosen.
- Be sure to collect a core set of physical, chemical, and habitat data to complement your biological data.

Example 2: … habitat and biological data by themselves may not be enough to guide successful restoration if other factors play a role in causing the problem. The Waukegan River (Illinois) NNPSMP project documented biological impairment with fish, macroinvertebrate, and habitat surveys, as well as visual observations of eroding streambanks and high storm flows. The project sought to restore the fishery through a combination of biotechnical streambank stabilization measures and in-stream structures such as lunkers and improved pool and riffle sequences. Although habitat improvements were clearly documented and some small early improvements in fish numbers and several biological indices were noted, the project did not achieve the hoped-for improvements in the fish community (White et al. 2003). Project staff attributed this shortfall to a failure to address extremes in flow regime from the highly urbanized watershed or to other pollutants such as toxics that were not revealed in habitat and biological surveys. The project would have benefited from a more complete stressor identification process. This outcome illustrates the importance of combining both habitat/biological and physical/chemical data to develop a full understanding of the problem as the basis for designing a successful treatment plan.

Pollutant Load Estimation for Water Quality Monitoring Projects

Excerpts

Pollutant Load Estimation for Water Quality Monitoring Projects

(*https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_8_dec_2013_load.pdf*)

See original document above for embedded references.

Determination of pollutant load is a key objective for many nonpoint source (NPS) monitoring projects. The mass of nutrients delivered to a lake or estuary drives the productivity of the waterbody. The annual suspended sediment load transported by a river is usually a more meaningful indicator of soil loss in the watershed than is a suspended sediment concentration. The foundation of water resource management embodied in the TMDL (total maximum daily load) concept lies in assessment of the maximum pollutant load a waterbody can accept before becoming impaired and in the measurement of changes in pollutant loads in response to implementation of management measures.

Estimation of pollutant load through monitoring is a complex task that requires accurate measurement of both pollutant concentration and water flow and careful calculation, often based on a statistical approach. It is imperative that a NPS monitoring program be designed for good load estimation at the start.

Basic Terms

Flux – instantaneous loading rate (e.g., kg/sec)

Flow rate – instantaneous rate of water passage (e.g., L/sec)

Discharge – quantity of water passing a specified point (e.g., m^3)

Load – mass of substance passing a specified point (e.g., metric tons)

Issues of Variability

Both flow and concentration vary considerably over time, especially in NPS situations. Accurate load estimation becomes an exercise in both how many samples to take and when to take them to account for this variability.

The key point here is that many samples are typically needed to accurately and reliably capture the true load pattern. Quarterly observations are generally inadequate, monthly observations will probably not yield reliable load estimates, and even weekly observations may not be satisfactory, especially if very accurate load estimates are required to achieve project objectives.

Practical Load Estimation

Ideally, the most accurate approach to estimating pollutant load would be to sample very frequently and capture all the variability. Concentration is expensive to measure and in most cases impossible to measure continuously. It is therefore critically important to choose a sampling interval that will yield a suitable characterization of concentration.

There are three important considerations involved in sampling for good load estimation: sample type, sampling frequency, and sample distribution in time.

Planning Monitoring Programs for Effective Load Estimation

This leaves three basic choices for practical load estimation:

1. Find a way to estimate un-measured concentrations to go with the flows observed at times when chemical samples were not taken;
2. Throw out most of the flow data and calculate the load using the concentration data and just those flows observed at the same time the samples were taken;
3. Do something in between — find some way to use the more detailed knowledge of flow to adjust the load estimated from matched pairs of concentration and flow.

The second approach is usually unsatisfactory because the frequency of chemical observations is likely to be inadequate to give a reliable load estimate when simple summation is used. Thus almost all effective load estimation approaches are variants of approaches 1 or 3.

Summary and Recommendations

Estimation of pollutant load through monitoring is a complex task that requires accurate measurement of both pollutant concentration and water flow, as well as careful calculation, often based on a statistical approach. A NPS monitoring program must be designed for good load estimation at the start. In planning a watershed project, determine whether the project goals require knowledge of load, or if goals can be met using concentration data alone. In many cases, especially when trend detection is the goal, concentration data may be easier to work with and be more accurate than crudely estimated load data.

Good load estimates are usually derived from continuous flow data and intermittent data on pollutant concentration.

Land Use and BMP Tracking for NPS Watershed Projects
Excerpts

Land Use and BMP Tracking for NPS Watershed Projects
(https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_11_aug28_bmptrack.pdf)
See original document above for embedded references.

Nonpoint source (NPS) pollution is driven mainly by land use and land management activities, including best management practices (BMPs) that are implemented to reduce, prevent or treat such pollution. Accurate information about land use, land management, and the implementation and operation of BMPs is therefore of great interest to those who attempt to assess or solve NPS water quality problems. In a typical NPS watershed project, BMPs are implemented or adopted at various locations in the watershed to reduce the generation and delivery of NPS pollutants, while water quality monitoring is conducted to document the effects of implemented BMPs. Linking water quality response to land treatment requires monitoring of both water quality and land management.

General Considerations
Watershed projects often lack an up-front plan for collecting and using land use/BMP data to determine watershed condition, progress in BMP implementation, or whether implemented BMPs have improved water quality. These plans should be developed as part of the overall project planning process to ensure a clear understanding of the data needed to meet project objectives and how the data are to be obtained and used. Monitoring at the watershed scale can continue for multiple years or decades, so cost must be considered when making decisions about the scope, level of detail, and the frequency of land use/treatment monitoring that will be done. Knowing what is needed should help focus project efforts on ways to obtain the best dataset possible within cost constraints.

Project Objectives
BMPs are tracked for a variety of reasons, including:

- To determine whether the requirements of cost-sharing contracts or regulatory controls have been met
- To measure the impact of efforts designed to encourage voluntary adoption of BMPs
- To assess current or baseline watershed conditions
- To demonstrate progress in solving NPS pollution problems
- To determine the effectiveness of individual BMPs at reducing NPS pollution levels or impacts
- To assess the relationships between water quality monitoring data and pollution control status at a watershed or basin scale

Nonpoint source watershed projects often include an objective to relate indicators of water quality condition to indicators of land condition or management, either statistically or less rigorously. This relationship is captured conceptually with the following simplified equation:

Water Quality = ƒ (Pollutant Source Management)

The strength of the relationship in this equation is influenced by climate, type of water resource, local soils and topography, and other factors that are usually beyond the control of watershed projects. Water quality conditions on the left side of the equation are often represented by fairly well-recognized measures such as beneficial use support status, pollutant concentrations or loads, or biological/habitat condition. Pollutant source management, however, is often represented on the right side of the equation by basic land use variables (e.g., agriculture, mixed-use urban, forest) or broad indicators of land management (e.g., acres under conservation tillage or nutrient management, forest harvest acreage, nutrient application rates, BMPs applied) that are less well established or proven for this purpose.

Spatial Scale

Land use/treatment monitoring should address the entire area contributing to flow at the water quality sampling point(s). As a general rule, all land use and management activities that influence the generation and transport of pollutants in this area should be tracked or accounted for through experimental design.

Monitoring Design

The best way to isolate the impact of BMPs and land treatment programs on water quality conditions is to use a paired-watershed design or above/below-before/after (nested-pair) design.

Basic BMP Tracking Information

What – pollutant sources and source areas, and existence and/or operation of structural and management practices in place to reduce or prevent pollutant generation or delivery

Where – complete coverage or targeted locations within geographic area of interest

When – at important points of time during the project or during the lifespan of the BMP

How – using a variety of direct (e.g., visual observation) and indirect (e.g., third-party reports) approaches

Table 1. Selected pollutants and watershed source characteristics and activities to monitor.

Pollutant Type	Potential Source Characteristics and Activities to Monitor
Suspended sediment (upland erosion)	Cropland tillage, planting, harvesting, construction, logging, erosion control BMPs, precipitation
Suspended sediment (instream erosion)	Streamflow, stream morphometry, riparian zone management, precipitation
Phosphorus (P)	Manure applications, livestock populations, manure and fertilizer management, soil test P, wastewater treatment plant discharge
Nitrogen (N)	Fertilizer applications, legume cropping, manure and fertilizer management, groundwater movement, wastewater treatment plant discharge
Herbicides	Herbicide application rates and timing, precipitation
E. coli (rural)	Livestock populations, grazing practices, riparian zone management, pasture fencing, wildlife populations and seasonal patterns
E. coli (urban)	Pet populations, wildlife/waterfowl activity, septic system maintenance/failure, sewer maintenance, illicit discharge/connections, combined sewer overflow, wastewater treatment plant discharge
Heavy metals	Vehicle traffic, highway infrastructure, street sweeping, stormwater management structures and activities, wastewater treatment plant and industrial discharge
Stormwater flow	Impervious cover, stormwater management facilities, precipitation, combined sewer overflow discharge

Table 2. Relationship of water quality and land use/land treatment variables. "Weekly" and "Annual" variables represent different metrics to be assessed on different time scale.

Water Quality Monitoring Variable	Primary Source	~Weekly Land Use/Treatment Monitoring Variables	~Annual Land Use/Treatment Monitoring Variables
Suspended sediment	Cropland erosion	• Date of tillage operations • Form of tillage (e.g., no-till, mulch-till, reduced-till, and conventional tillage) • Crop canopy development (percentage of soil surface covered by plant foliage) • Cover crop density	• Acreage (and percentage) of land under reduced tillage • Acreage (and percentage) served by terrace systems • Acreage (and percentage) of land converted to permanent cover • Linear feet (and percentage of linear feet) of watercourse protected with riparian buffers (specify buffer width)
Total N	Agricultural cropland	• Manure and fertilizer application rates • Manure and fertilizer forms • Date of manure and/or fertilizer application • Manure and fertilizer application methods	• Number (and percentage) and acreage (and percentage) of farms implementing comprehensive nutrient management plans (CNMP) • Annual fertilizer and manure N applications per acre • Legume acreage • Crop N needs and basis
Stream flow	Urban	• Operation and maintenance of stormwater system • Functioning of stormwater diversions or treatment devices	• Percentage impervious cover • Acreage (and percentage) served by stormwater runoff collection system • Number and area of rain gardens or other infiltration practices • Annual inspection results

How: Data Collection Methods

Definitions

Tracking is following the course or trail of something, typically in order to find it or to note its location at various points in time.

Monitoring is observing and checking the progress or quality of something over a period of time.

Verification is proving that the information obtained by tracking or monitoring is true, accurate, or justified.

Validation is ensuring that the information obtained by tracking or monitoring will achieve the stated goals.

Specific methods

Direct observation

Personal observations may be the best way to track BMPs and land use for plot and field studies. At this smaller scale, sites are visited frequently to service monitoring equipment and collect samples, so a good record of source activities can be obtained. Today's mobile technology makes it possible to collect, transfer, and store information with multiple devices at virtually any location. Smartphones and smart GPS units are two of the options for performing these tasks.

Other types of direct observation include quantitative windshield surveys (systematic observations made from a moving vehicle). Photography can be an important tool in some situations. For example, an automated digital camera can be installed at an edge-of-field monitoring station to take periodic photographs looking up into the drainage area to record crop growth, agrichemical applications, or other visible information.

Landowner information

Land use and BMP information can often be collected directly from those owning or managing the source area and implementing the practices. This approach may be the only way to obtain good information on management activities such as manure or fertilizer application rates. Log books can be given to land owners and site managers to record activities relevant to the monitoring study. An advantage of this method is that the same individual who conducts the activity does the reporting. However, it is difficult to guarantee compliance or consistent reporting among different individuals.

Landowner self-assessment

Some jurisdictions require or provide incentives to induce landowners to conduct regular self-assessments of some or all of their installed/adopted BMPs. For those self-surveys to be useful, landowners must have a clear understanding of what each BMP is so that reporting is accurate and consistent across a watershed.

On-site assessment
The existence and condition of BMPs can be assessed by on-site inspections conducted by state or local personnel. It is essential that personnel performing the assessments be trained and certified appropriately so that information is collected in a consistent, reliable, and repeatable fashion.

Agency reporting
There are many state, county, and municipal programs that track, spot-check, and report BMP implementation, but the resolution, relevance, and availability of data from these programs is variable.

Surveys and statistical sampling
To conduct BMP verification in large, diverse watersheds, it may be appropriate to collect information on a sample of the total BMP population using surveys or statistical sampling procedures.

Remote sensing
Remote sensing can be used to track practices over large geographic areas, but it is only suited for recording information that can be detected visually (e.g., structural or land cover BMPs) rather than BMPs like nutrient management. Ground-truthing is needed to establish the relationship between the images and what is on the ground.

Remote sensing data may be collected on two basic platforms: aerial and space-based. Aerial imagery includes images and data collected from relatively low altitude and involves placing a sensor or camera on an aircraft. Space-based imagery includes images and data collected from satellites that orbit the earth. For large watershed projects, it may be feasible to fund a custom aerial photography effort or even engage in informal data collection by hiring a plane and pilot for a few hours and taking handheld photographs.

Hybrid approaches
Some BMPs can be detected and verified by some methods, but not by others.

Challenges
In many respects, collecting good data through land use/BMP tracking is more challenging than it is through water quality monitoring where procedures and practices are well-developed and based on decades of experience. Gaining access to suitable locations may be the biggest hurdle for water quality monitoring efforts, requiring permission from landowners. Sample collection for water quality monitoring, however, is generally unfettered once sites have been reached. On the other hand, efforts to collect suitable land use/BMP information can be much more complicated as illustrated by the challenges described below.

Confidentiality
A principal reason for the often haphazard nature of BMP data collection by watershed projects is the fact that privacy laws and policies often restrict the type and amount of information available to those involved in a watershed project, most notably information about agricultural enterprises.

Relating Land Use/Land Treatment Data to Water Quality Data
For a range of reasons, including budgets and programmatic constraints, watershed project monitoring efforts are almost never designed to establish true cause and effect relationships between land treatment and water quality. Rather, project effectiveness monitoring designs are generally intended to measure improvement in water quality and, ideally, relate the improvement to BMPs implemented in the watershed. A plausible argument that land treatment led to improved water quality is often the best that can be hoped for, and even that is usually not a simple task at the watershed level.

Recommendations

- Incorporate management and analysis of land use/treatment tracking data into project planning, including development of a QAPP.
- Before implementing new data collection efforts, consult with agencies and others managing cost-share or regulatory programs to see if they collect useful BMP data that can be shared with the project. Address issues of confidentiality of landowner BMP and management information at the beginning of the project.
- Track land use and BMPs to document progress in solving NPS pollution problems, to determine the effectiveness of individual BMPs, and to assess the relationships between water quality monitoring data and pollution control status at a watershed scale. Be sure to track land use change for long-term projects.
- Choose monitoring methods that are appropriate for the BMPs to be tracked.
- Select variables to monitor that reflect the pollutant types and sources important to water quality impairments and pollution control efforts.
- Ensure that observation frequency is appropriate both for the BMPs being tracked and for matching with water quality monitoring data in future, planned analyses.
- Track all land use and management activities that influence the generation and transport of pollutants in a project watershed. For BMPs this includes both cost shared and non-cost-shared practices. Assess both point and nonpoint sources at the beginning of watershed projects.
- When monitoring the effectiveness of individual BMPs or a watershed land treatment program, it is important to document compliance with design specifications, the spatial distribution and interrelationships of components in a BMP system, details of maintenance and operation, and situations where the BMP operated under conditions outside of the design range.

- In a diverse land treatment program, use hybrid approaches to BMP data collection that include different means of detecting structural and management practices because they are more likely than a single approach to give complete and reliable results.

Explanatory Variables: Improving the Ability to Detect Changes in Water Quality in Nonpoint Source Watershed Studies

Excerpts

Explanatory Variables: Improving the Ability to Detect Changes in Water Quality in Nonpoint Source Watershed Studies

(https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_12_aug2014_explan_var.pdf)

See original document above for embedded references.

An important objective of many nonpoint source (NPS) watershed projects is to document water quality changes and associate them with changes in land management. Accounting for major sources of variability in water quality and land treatment/land use data increases the likelihood of isolating water quality trends resulting from best management practices (BMPs). Correlation of water quality and land treatment changes alone is not sufficient to infer causal relationships. Factors not related to BMPs may be causing the water quality changes, such as changes in land use, climatic, or hydrologic conditions. These factors are often referred to as explanatory variables or covariates.

What are Explanatory Variables and Why are They Important in NPS Watershed Studies

<u>Definition of Explanatory Variable</u>

Categorical Variable: A variable that can take on one of a limited, and usually fixed, number of possible values (e.g., seasons).

Continuous Variable: A variable that can take on any value between its minimum and maximum value (e.g., flow rate).

Control: The absence of treatment with BMPs or other land treatment. Pertains to the control watershed in NPS monitoring studies.

Control Variable: A water quality variable (e.g., nitrate) measured in a control watershed at the same time it is also measured in the treatment watershed, resulting in a paired observation.

Covariate: Essentially equivalent to explanatory variable.

Dependent or Response Variable: The “Y” variable in an equation, typically the primary water quality variable of interest in NPS watershed studies.

Explanatory Variable: Variable that affects the relationship between the primary water quality variable of interest and the primary land treatment variable of interest (e.g., flow).

Factor: A variable that influences the value of the primary variable. Independent and explanatory variables are factors influencing the value of the primary water quality variable of interest in NPS watershed studies.

Independent Variable: Each “X” variable in an equation (e.g., trend variable, land treatment variable such as acres with cover crops, control watershed water quality variable, and other explanatory variables such as flow or season.

LS-Means: The mean values of Y for each time period that have been adjusted for explanatory variable values.

Primary Variable: The water quality variable of primary interest (e.g., total phosphorus).

Treatment: The application of BMPs or land treatment during a monitoring study. Occurs in the treatment watershed of a NPS monitoring study.

General Rules of Thumb

Both projects beginning with and without a rich dataset should apply some basic rules of thumb when selecting explanatory variables.

- The date should be associated with every variable value, thus allowing assignment of month or season to address seasonal considerations.
- The literature has many examples of relationships between flow measurements and pollutant concentrations and loads (Baker 1988, Foster 1980, Johnson et al. 1969, Lowrance and Leonard 1988, and Schilling and Spooner 2006), so flow or a flow surrogate (e.g., stage) should be measured whenever possible.
- Runoff begins with precipitation and a multitude of studies has shown the effects of rainfall intensity and amount on runoff quality and amount, so precipitation should be measured or weather data obtained from a nearby existing weather station.
- Information on land use and ground cover is essential to most projects, particularly given that BMPs are generally targeted on the basis of land use and management.
- Any sources that will be treated (e.g., cropland, streambanks, lawns) should be monitored using explanatory variables that relate to water quality and the BMPs being implemented (e.g., animal units with access to and excluded from streams, nutrient application rates and yield by crop type).
- Some variables of potential use are very inexpensive to track and can be dropped later if found to be useless. Examples include water and air temperature and salinity or conductivity.

Summary and Recommendations

The often extreme variability in NPS-related water quality data creates challenges in data interpretation that can only be met through sound design and execution of the monitoring plan coupled with defensible statistical analysis of the data. All NPS watershed projects designed to document water quality improvements and relate them to improved land management and treatment with BMPs should include explanatory variables in their monitoring programs. By collecting data on explanatory variables, projects strengthen their capabilities to detect true changes in water quality and isolate the likely causes of those changes.

How to Read a Topographic Map and Delineate a Watershed

USDA-NRCS Minnesota

Note: Websites and computer programs such as ArcGIS have tools that can be used to determine watershed boundaries and the area of the watershed. The procedure below is a manual method that teaches basic watershed determination skills and understanding.

Watersheds can be large (Mississippi River basin) or small (a portion of a roof or yard).

Interpreting Topographic Maps

In order to successfully delineate a watershed boundary, the evaluator will need to visualize the landscape as represented by a topographic map. This is not difficult once the following basic concepts of the topographic maps are understood.

Each contour line on a topographic map represents a ground elevation or vertical distance above a reference point such as sea level. A contour line is level with respect to the earth's surface just like the top of a building foundation. All points along any one contour line are at the same elevation.

The difference in elevation between two adjacent contours is called the contour interval. This is typically given in the map legend. It represents the vertical distance you would need to climb or descend from one contour elevation to the next.

The horizontal distance between contours, on the other hand, is determined by the steepness of the landscape and can vary greatly on a given map. On relatively flat ground, two 20 foot contours can be far apart horizontally.

On a steep cliff face two 20 foot contours might be directly above and below each other. In each case the vertical distance between the contour lines would still be twenty feet.

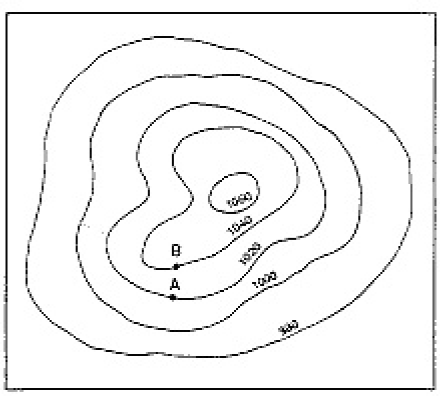


Figure E-1: Isolated Hill

One of the easiest landscapes to visualize on a topographic map is an isolated hill. If this hill is more or less circular the map will show it as a series of more or less concentric circles (Figure E-1). Imagine that a surveyor actually marks these contour lines onto the ground. If two people start walking in opposite directions on the same contour line, beginning at point A, they will eventually meet face to face.

If these same two people start out in opposite directions on different contours, beginning at points A and B respectively, they will pass each other somewhere on the hill and their vertical distance apart would remain 20 feet. Their horizontal distance apart could be great or small depending on the steepness of the hillside where they pass.

A rather more complicated situation is one where two hills are connected by a saddle (Figure E- 2). Here each hill is circled by contours but at some point toward the base of the hills, contours begin to circle both hills.

How do contours relate to water flow? A general rule of thumb is that water flow is perpendicular to contour lines. In the case of the isolated hill, water flows down on all sides of the hill. Water flows from the top of the saddle or ridge, down each side in the same way water flows down each side of a garden wall (See arrow on Figure E-2).

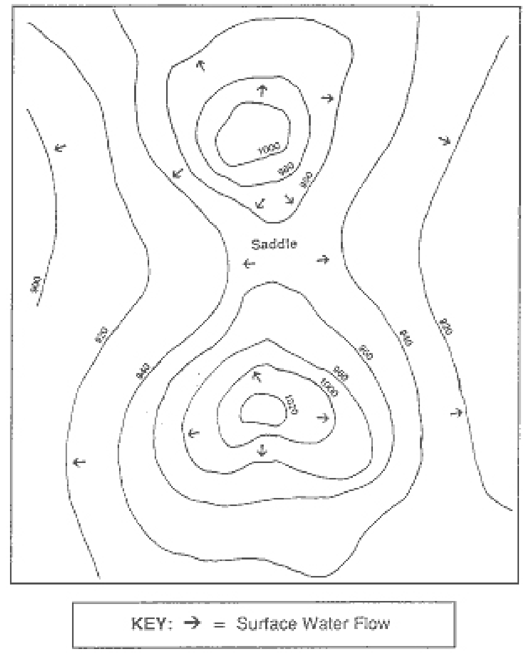


Figure E-2: Saddle

As the water continues downhill it flows into progressively larger watercourses and ultimately into the ocean. Any point on a watercourse can be used to define a watershed. That is, the entire drainage area of a major river like the Mississippi can be considered a watershed, but the drainage areas of each of its tributaries are also watersheds.

Each tributary in turn has tributaries, and each one of these tributaries has a watershed. This process of subdivision can continue until very small, local watersheds are defined which might only drain a few acres, and might not contain a defined watercourse.

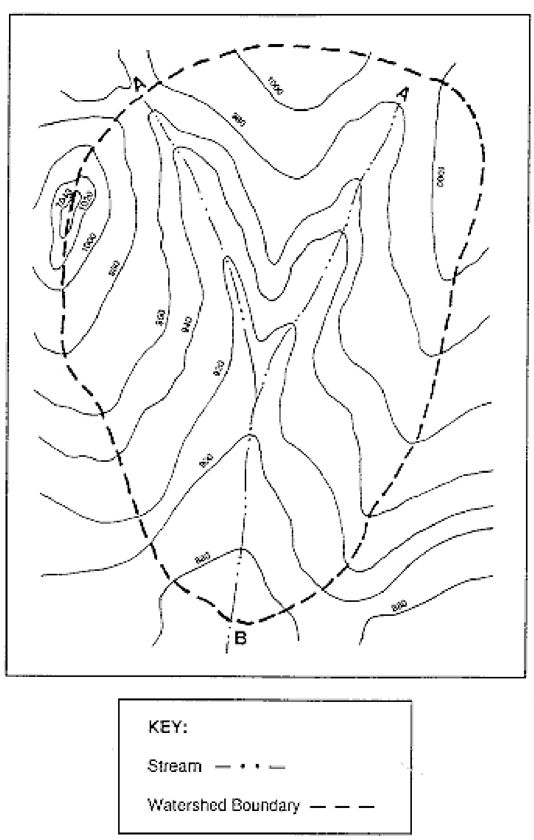


Figure E-3 shows an idealized watershed of a small stream. Water always flows downhill perpendicular to the contour lines. As one proceeds upstream, successively higher and higher contour lines first parallel then cross the stream. This is because the floor of a river valley rises as you go upstream. Like- wise the valley slopes upward on each side of the stream. A general rule of thumb is that topographic lines always point upstream. With that in mind, it is not difficult to make out drainage patterns and the direction of flow on the landscape even when there is no stream depicted on the map. In Figure E-3, for example, the direction of streamflow is from point A to point B.

Ultimately, you must reach the highest point upstream. This is the head of the watershed, beyond which the land slopes away into another watershed. At each point on the stream the land slopes up on each side to some high point then down into another watershed. If you were to join all of these high points around the stream you would have the watershed boundary. (High points are generally hill tops, ridge lines, or saddles).

Delineating a Watershed

The following procedure and example will help you locate and connect all of the high points around a watershed on a topographic map shown in Figure F-4 below. Visualizing the landscape represented by the topographic map will make the process much easier than simply trying to follow a method by rote.

1. Draw a circle at the outlet or downstream point of the wetland in question (the wetland is the hatched area shown in Figure E-4 to the right)
2. Put small "X's" at the high points along both sides of the watercourse, working your way upstream towards the headwaters of the watershed.
3. Starting at the circle that was made in step one, draw a line connecting the "X's" along one side of the watercourse (Figure E-5, below left). This line should always cross the contours at right angles (i.e. it should be perpendicular to each contour line it crosses).
4. Continue the line until it passes around the head of the watershed and down the opposite side of the watercourse. Eventually it will connect with the circle from which you started.

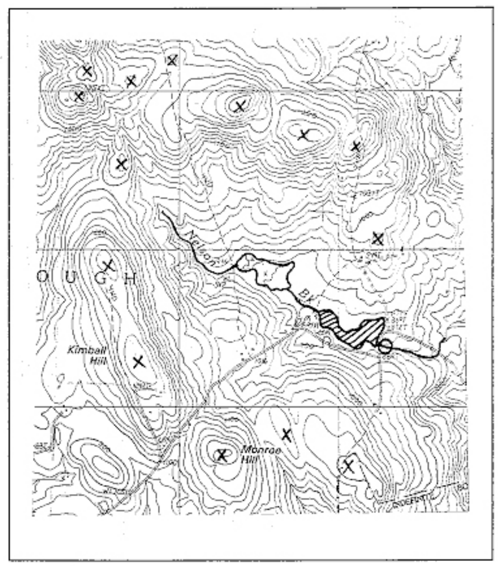


Figure E-4: Delineating a Watershed Boundary - Step 1

At this point you have delineated the watershed of the wetland being evaluated.

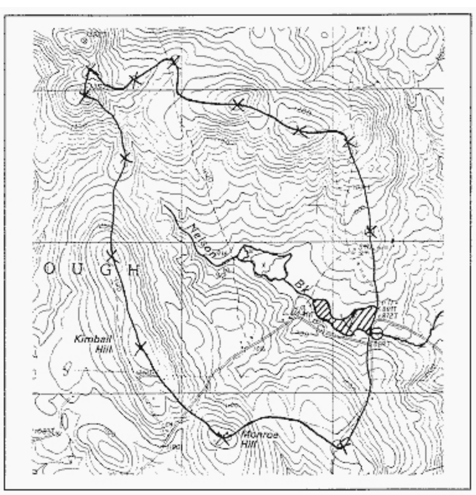


Figure E-5: Delineating a Watershed Boundary - Step 2

The delineation appears as a solid line around the watercourse. Generally, surface water runoff from rain falling anywhere in this area flows into and out of the wetland being evaluated. This means that the wetland has the potential to modify and attenuate sediment and nutrient loads from this watershed as well as to store runoff which might otherwise result in downstream flooding.

Measuring Watershed Areas

There are several available methods for measuring the area of a watershed:

a) Dot Grid Method,
b) Planimeter, and
c) Computer programs such as ArcGIS.

a) The dot grid method is a simple technique which does not require any expensive equipment. In this method the user places a sheet of acetate or mylar, which has a series of dots about the size of the period at the end of this sentence printed on it, over the map area to be measured. The user counts the dots which fall within the area to be measured and multiplies by a factor to determine the area. A hand held, mechanical counting device is available to speed up this procedure.

b) Another method involves using a planimeter, which is a small device having a hinged mechanical arm. One end of the arm is fixed to a weighted base while the other end has an attached magnifying lens with a cross hair or other pointer. The user spreads the map with the delineated area on a flat surface. After placing the base of the planimeter in a convenient location the user traces around the area to be measured with the pointer. A dial or other readout registers the area being measured.

c) Computer programs such as ArcGIS have measure tools that can be used to determine the area of the watershed.

For more information on Minnesota NRCS conservation planning and other technical references, visit https://www.nrcs.usda.gov/.

Key Topic #5: Legislation, Regulations, and Voluntary Measures

Learning Objectives

1. **Summarize** major U.S. policies and programs that address non-point source pollution, including the Clean Water Act (especially Sections 303 and 319) and Total Maximum Daily Loads (TMDLs).
2. **Differentiate** between regulatory and voluntary approaches to controlling NPS pollution and identify examples of each.
3. **Describe** how federal and state agencies support local communities in managing NPS pollution through funding, education, and technical assistance.
4. **Simulate** a decision-making process where students must select appropriate policy or program tools to manage a fictional watershed's NPS challenges.

Resource Title	Source	Located on
Nonpoint Source Program	*U.S. EPA*	Page 147-149
Overview of TMDLs	*U.S. EPA*	Page 150-153
Stormwater Runoff	*Chesapeake Bay Program*	Page 154-159
Mississippi River Gulf of Mexico Watershed Nutrient Task Force New Goal Framework	*U.S. EPA, December 3, 2014*	Page 160-163
Deepwater Horizon – BP Gulf of America Oil Spill	*U.S. EPA*	Page 164-166
How China is designing flood-resistant cities, *VIDEO*	*Vox, How China is Designing flood-resistant cities*	Page 167
Managing stormwater to improve Canadian cities' safety and resilience	*National Research Council, Government of Canada, 2022*	Page 168-170

Nonpoint Source Program

Available Assistance: Financial, Technical, Planning, Coordination, Facilitation

Statute: Clean Water Act and Safe Drinking Water Act

Program Type: Non-regulatory

EPA Contact(s):

- Robert Goo | Office of Wetlands, Oceans, and Watersheds | 202-566-1201 | goo.robert@epa.gov
- Ellie Flaherty | Office of Wetlands, Oceans, and Watersheds | 202-566-2456 | flahety.ellie@epa.gov

Main Website(s): Polluted Runoff: Nonpoint Source (NPS) Pollution

Helping states, territories, and tribes perform a wide variety of activities to prevent nonpoint source pollution from degrading water quality.

On this page:

About the Program

The 1987 amendments to the Clean Water Act established the Section 319 Nonpoint Source (NPS) Program to address NPS pollution. NPS pollution is caused when rainfall or snowmelt, moving over and through the ground, picks up and carries natural and human-made pollutants, depositing them into lakes, rivers, wetlands, coastal waters, and groundwaters. Increased precipitation from extreme weather will compound NPS pollution.

Types of Assistance

The NPS program provides grant money to states, territories, and tribes to support a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific NPS implementation projects. Receiving a NPS grant to implement projects for improving water quality first requires an EPA-approved watershed-based plan. More information about the NPS program is available in the National Nonpoint Source Program highlights report.

Program in Action

- Drinking Water Supplies: Restoration and Protection Activities in the Upper Branch of the Delaware River Protects New York City's Drinking Water Supply (pdf) (New York).
- Recreation: Urban and Rural Nonpoint Source BMPs Improve Water Quality in the Upper San Antonio River (pdf) (Texas).
- Fisheries: Sasco Brook Improves Due to Bacteria Source Reductions (pdf) (Connecticut).
- Wildlife: Community Partnerships Restore the Water Quality of Mill Creek (pdf) (Alabama).

How This Program Helps Build Resilience

NPS pollution is presently the dominant source of water quality pollution, causing harmful effects on drinking water supplies, recreation, fisheries, and wildlife. To address multiple pollutants and their risks, the NPS program promotes the use of watershed planning to protect and restore water resources (see Handbook for Developing Watershed Plans to Restore and Protect Our Waters). Watershed plans outline best management practices (BMPs) for implementation. BMPs can include bioretention systems, floodplain and stream restoration or stabilization, wetland creation, reforestation, and agricultural conservation approaches like cover crops and riparian buffers. In addition to improving water quality, nature-based practices can also create climate change adaptation and natural hazard mitigation co-benefits (e.g., resilience to droughts, floods, fires, urban heat islands, landslides, erosion, and harmful algal blooms). If plan priorities align, a partnership between hazard or risk reduction plans with watershed or water quality improvement plans could emerge. The annual number of projects implementing practices with climate/hazard mitigation co-benefits is reported as part of the Office of Water Climate Adaptation Implementation Plan. Over 300 Section 319 funded projects with potential climate co-benefits were reported in FY23.

The following success stories document specific examples of water quality improvements that remove stressors and therefore enhance the resilience of water bodies. More success stories about restoring water bodies impaired by NPS pollution can be found in an online database.

Connections to Other EPA, Federal, or Non-Governmental Efforts

The Federal Emergency Management Agency (FEMA) and the EPA have a Memorandum of Agreement that provides a collaborative framework for jointly working on activities related to both hazard mitigation and environmental management to create more resilient communities. The NPS program is currently working with FEMA's hazard mitigation assistance programs, which provide funding for eligible mitigation measures that help reduce disaster losses. Hazard mitigation actions or projects can also provide water quality improvements as a side benefit of reducing hazard risks. However, hazard mitigation projects are more likely to improve water quality if they are coordinated with other state or community water quality goals, strategies, or planned action items.

This information was pulled from EPAs website @ https://www.epa.gov/climate-change-water-sector/nonpoint-source-program.

Overview of Total Maximum Daily Loads (TMDLs)

On this page:

What is a TMDL?

A TMDL is the calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant. A TMDL determines a pollutant reduction target and allocates load reductions necessary to the source(s) of the pollutant.

Pollutant sources are characterized as either point sources that receive a wasteload allocation (WLA), or nonpoint sources that receive a load allocation (LA). For purposes of assigning WLAs, point sources include all sources subject to regulation under the National Pollutant Discharge Elimination System (NPDES) program, e.g. wastewater treatment facilities, some stormwater discharges and concentrated animal feeding operations (CAFOs). For purposes of assigning LAs, nonpoint sources include all remaining sources of the pollutant as well as natural background sources. TMDLs must also account for seasonal variations in water quality, and include a margin of safety (MOS) to account for uncertainty in predicting how well pollutant reductions will result in meeting water quality standards.

Expressed mathematically, the TMDL equation is:

$$\mathbf{TMDL = \Sigma WLA + \Sigma LA + MOS}$$

Where **WLA** is the sum of wasteload allocations (point sources), **LA** is the sum of load allocations (nonpoint sources and background) and **MOS** is the margin of safety.

Each pollutant causing a waterbody to be impaired or threatened is referred to as a waterbody/pollutant combination, and typically a TMDL is developed for each waterbody/pollutant combination. For example, if one waterbody is impaired or threatened by three pollutants, three TMDLs might be developed for the waterbody. However, in other cases, a single TMDL document may be developed to address several waterbody/pollutants combinations. Neither the CWA nor EPA's regulations define or limit the scale of TMDLs. Some states have been developing TMDLs on a watershed-scale basis. Such state TMDLs may also cover multiple watersheds.

What triggers the need for a TMDL?

According to the Clean Water Act, each state must develop TMDLs for all the waters identified on their Section 303(d) list of impaired waters, according to their priority ranking on that list.

Who is responsible for developing a TMDL?

As a general matter, states are responsible for developing TMDLs and submitting them to EPA for approval. Even if third parties assist in the development of the TMDL or its supporting analysis, such TMDLs must still be submitted to EPA by the states.

Under the CWA, the EPA reviews and either approves or disapproves the TMDL. If EPA disapproves a state TMDL, EPA must develop a replacement TMDL.

How are TMDLs developed?

The objective of a TMDL is to determine the loading capacity of the waterbody and to allocate that load among different pollutant sources so that the appropriate control actions can be taken and water quality standards achieved. The TMDL process is important for improving water quality because it serves as a link in the chain between water quality standards and implementation of control actions designed to attain those standards.

TMDLs are developed using a range of techniques, from simple mass balance calculations to complex water quality modeling approaches. The degree of analysis varies based on a variety of factors including the waterbody type, complexity of flow conditions and pollutant causing the impairment.

All contributing sources of the pollutants (point and nonpoint sources) are identified, and they are allocated a portion of the allowable load that usually contemplates a reduction in their pollution discharge in order to help solve the problem. Natural background sources, seasonal variations and a margin of safety are all taken into account in the allocations.

The approach normally used to develop a TMDL for a particular waterbody or watershed consists of five activities:

- Selection of the pollutant(s) to consider.
- Estimation of the waterbody's assimilative capacity (i.e., loading capacity).
- Estimation of the pollutant loading from all sources to the waterbody.
- Analysis of current pollutant load and determination of needed reductions to meet assimilative capacity.
- Allocation (with a margin of safety) of the allowable pollutant load among the different pollutant sources in a manner such that water quality standards are achieved.

TMDLs should clearly identify the links between the waterbody use impairment, the causes of impairment, and the pollutant load reductions needed to meet the applicable water quality standards.

Public participation in TMDL development

EPA’s regulations require public involvement in developing TMDLs, however, the level of citizen involvement in the TMDL process varies by state.

Local citizens sometimes know more about what is happening in their watersheds than state agencies, and this knowledge can be a valuable aspect of TMDL development. The public often contributes useful data and information about an impaired waterbody. The public can often offer insights about their community that may ensure the success of one pollutant reduction strategy over another. Citizen information and participation can improve the quality of TMDLs that are developed and can ultimately speed cleanup of impaired waters or secure protection of threatened waters. Public/stakeholder roles in the TMDL process can include:

- Providing data and information to the states.
- Reviewing and commenting on impaired water list.
- Reviewing and commenting on draft TMDLs.
- Assisting in the development of TMDLs.

What are the components of a TMDL document?

EPA issued review guidelines for TMDL submissions in *Guidelines for Reviewing TMDLs under Existing Regulations Issued in 1992*. Below is a TMDL Review Checklist with the minimum recommended elements that should be present in a TMDL document.

- Identification of Waterbody, Pollutant of Concern, Pollutant Sources and Priority Ranking.
- Applicable WQS and Numeric Water Quality Target.
- Loading Capacity.
- Load Allocations and Waste Load Allocations.*
- Margin of Safety.
- Consideration of Seasonal Variation.
- Reasonable Assurance for PS/NPS.
- Monitoring Plan to Track TMDL Effectiveness.
- Implementation Plan.
- Public Participation.

What happens after the TMDL is approved by EPA?

TMDL wasteload allocations (those pollutant allocations assigned to point sources) are generally implemented through EPA's National Pollutant Discharge Elimination System (NPDES) permits under CWA section 402. This section of the Act requires that point source discharges be controlled by including water quality-based effluent limits in permits issued to point source entities. Under EPA's permitting regulations, water quality-based discharge limits in NPDES permits must be "consistent with the assumptions and requirements" of wasteload allocations in EPA-approved TMDLs.

Non-point source load reduction actions are implemented through a wide variety of programs at the state, local and federal level. These programs may be regulatory, non-regulatory or incentive-based e.g., a cost-share program. In addition, waterbody restoration can be assisted by voluntary actions on the part of citizen and/or environmental groups. The EPA section 319 program provides grant money to the states to fund specific projects aimed at reducing the nonpoint source pollution.

Although states are not explicitly required under section 303(d) to develop TMDL implementation plans, many states include some type of implementation plan with the TMDL. When developed, TMDL implementation plans may provide additional information on what point and nonpoint sources contribute to the impairment and how those sources are being controlled, or should be controlled in the future.

This information was sourced from EPAs website @ https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls#1.

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Stormwater Runoff

When precipitation falls on roads, streets, rooftops and sidewalks, it can push harmful pollutants like fertilizer, pet waste, chemical contaminants and litter into the nearest waterway.

Mike Fritz from the Chesapeake Bay Program explains why stormwater runoff is a major source of pollution and what we can do to prevent it. (Produced by Matt Rath/Chesapeake Bay Program)

Overview

What happens to a drop of rain when it falls onto the ground? It may land on a tree and evaporate; it may land on a farm field and soak into the soil; or it may land on a rooftop, driveway or road and travel down the street into a storm drain or stream. Precipitation in an urban or suburban area that does not evaporate or soak into the ground but instead runs across the land and into the nearest waterway is considered stormwater runoff. Increased development across the watershed has made stormwater runoff (also called polluted runoff) the fastest growing source of pollution to the Chesapeake Bay.

How does stormwater runoff affect the Chesapeake Bay?

As stormwater flows across streets, sidewalks, lawns and golf courses, it can pick up harmful pollutants and push them into storm drains, rivers and streams. These pollutants can include lawn and garden fertilizers, pet waste, sand and sediment, chemical contaminants and litter.

Stormwater runoff can cause a number of environmental problems:

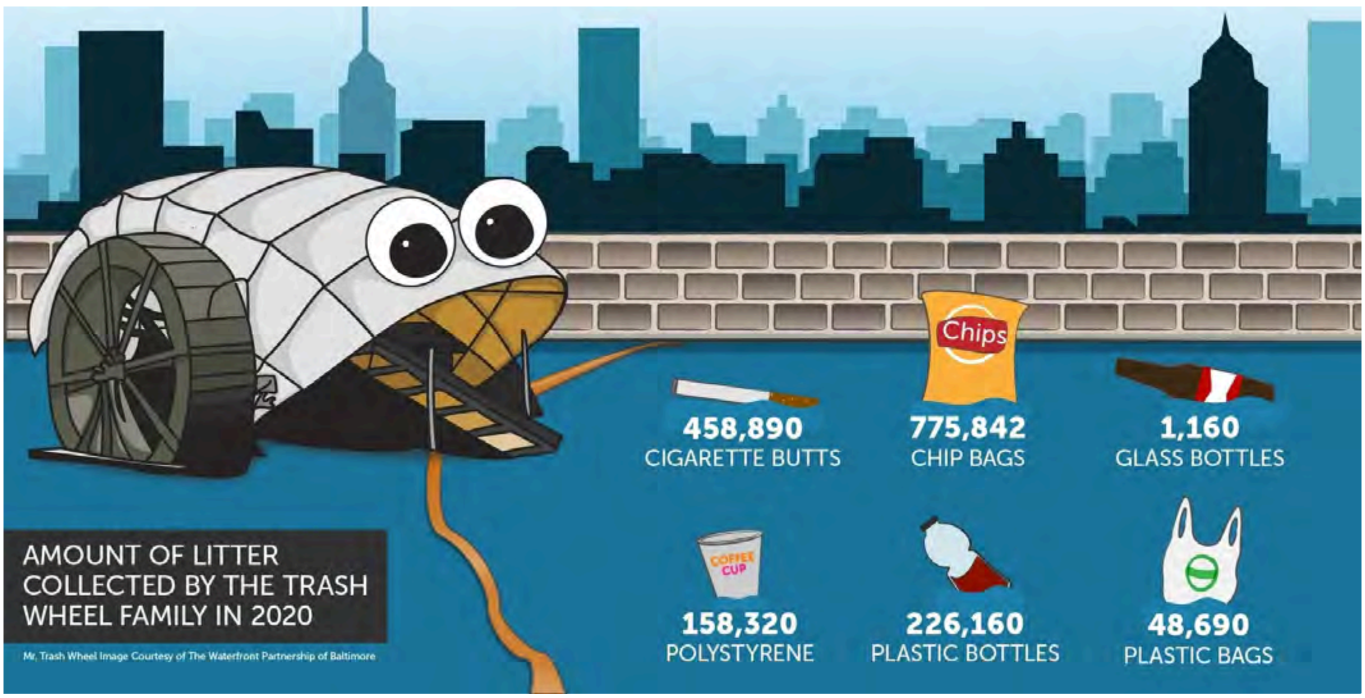
- Fast-moving stormwater runoff can erode stream banks, damaging hundreds of miles of aquatic habitat.
- Stormwater runoff can push excess nutrients (https://www.chesapeakebay.net/issues/threats-to-the-bay/nutrient-runoff) from fertilizers, pet waste and other sources into rivers and streams. Nutrients can fuel the growth of algae blooms that create low-oxygen dead zones (https://www.chesapeakebay.net/state/dead_zone) that suffocate marine life.
- Stormwater runoff can push excess sediment (https://www.chesapeakebay.net/issues/threats-to-the-bay/sediment-runoff) into rivers and streams. Sediment can block sunlight from reaching underwater grasses and suffocate shellfish.
- Stormwater runoff can push pesticides, leaking fuel or motor oil and other chemical contaminants (https://www.chesapeakebay.net/issues/chemical_contaminants) into rivers and streams. Chemical contaminants can harm the health of humans and wildlife.

Stormwater runoff can also lead to flooding in urban and suburban areas.

Forests, wetlands and other vegetated areas can trap water and pollutants, slowing the flow of stormwater runoff. But when urban and suburban development increases, builders often remove these natural buffers to make room for the impervious surfaces that encourage stormwater to flow freely into local waterways.

Litter from stormwater runoff

Litter such as plastic bags, cigarette butts and beverage bottles eventually get carried by stormwater into sewer systems or waterways. Litter detracts from an area's beauty, smothers aquatic plants and bottom-dwelling organisms, adds toxic contaminants to the water and makes animals sick. While nine in ten watershed residents never toss food wrappers, cups or cigarette butts onto the ground, about five percent of watershed residents sometimes, usually or always do.



Litter smothers aquatic plants and bottom-dwelling organisms, adds toxic contaminants to the water and makes animals sick. Trash traps like the water wheels in Baltimore capture and collect litter and debris. (Data provided by the Waterfront Partnership of Baltimore.)

▶ **Show image description**

Watershed organizations around the region rely on volunteers to remove litter from waterways, and many cities have installed trash traps to capture litter and debris. In Baltimore's Inner Harbor, a family of three water wheels (https://www.mrtrashwheel.com/meet-the-trash-wheels/) nicknamed "Mr. Trash Wheel", "Professor Trash Wheel" and "Captain Trash Wheel" collected 1,608 tons of trash between May 2014 and January of 2021. In 2021, the city's trash-collecting water wheel family will welcome it's fourth member: "Gwynnda the Good Wheel of the West". Gwynnda the Good Wheel is capable of collecting about 300 tons of trash and debris per year from the Gwynns Falls — more than the other three wheels combined.

What are impervious surfaces and why are they a problem?

Impervious surfaces are paved or hardened surfaces that do not allow water to pass through. Roads, rooftops, sidewalks, pools, patios and parking lots are all impervious surfaces.

Impervious surfaces can cause a number of environmental problems:

- Impervious surfaces can increase the amount and speed of stormwater runoff, which can alter natural stream flow and pollute aquatic habitats.
- Impervious surfaces limit the amount of precipitation that is able to soak into the soil and replenish groundwater (https://www.chesapeakebay.net/issues/groundwater) supplies, which are an important source of drinking water in some communities.
- Impervious surfaces that replace soil and plants remove the environment's natural ability to absorb and break down airborne pollutants (https://www.chesapeakebay.net/issues/air_pollution) .

According to the U.S. Environmental Protection Agency (EPA), the presence of roads, rooftops and other impervious surfaces in urban areas means a typical city block generates more than five times more runoff than a forested area of the same size.

Impervious surface data are used to measure the rate of development (https://www.chesapeakebay.net/issues/development) across the watershed and to identify high-growth areas and patterns of sprawling development. Between 1990 and 2007, impervious surfaces associated with growth in single-family homes are estimated to have increased about 34 percent, while the region's population (https://www.chesapeakebay.net/state/population) increased by 18 percent. This indicates that our personal footprint on the landscape is growing.

How much pollution does stormwater runoff send into the Chesapeake Bay?

Stormwater runoff is the fastest growing source of pollution to the Chesapeake Bay. According to data (http://www.chesapeakeprogress.com/clean-water/water-quality/watershed-implementation-plans) from the Chesapeake Bay Program's Watershed Model (https://www.chesapeakebay.net/what/programs/modeling) , stormwater currently contributes 17% of nitrogen (https://www.chesapeakebay.net/issues/threats-to-the-bay/nutrient-runoff) loads, 17 percent of phosphorus (https://www.chesapeakebay.net/issues/threats-to-the-bay/nutrient-runoff) loads and 9% percent of sediment (https://www.chesapeakebay.net/issues/threats-to-the-bay/sediment-runoff) loads to the Chesapeake Bay.

What you can do

To lessen the impacts of stormwater runoff on the Bay, consider reducing the amount of precipitation that can run off of your property. Install a green roof, rain garden or rain barrel to capture and absorb rainfall; use porous surfaces like gravel or pavers in place of asphalt or concrete; and redirect home downspouts onto grass or gravel rather than paved driveways or sidewalks.

Chesapeake Bay Program Goals

The Chesapeake Bay Program is committed to reducing the amount of sediment and nutrient pollution (https://www.chesapeakeprogress.com/clean-water/watershed-implementation-pla) from a number of sources, including stormwater, through its 2025 Watershed Implementation Plans (https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans) . In 2023, nitrogen, phosphorus and sediment pollution from developed areas (primarily stormwater runoff) accounted for 16%, 18% and 9% of the total pollution, respectively.

Track our work at ChesapeakeProgress.com › (https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans)

FAQ

▶ **What is stormwater runoff?**

▶ **What are impervious surfaces?**

▶ **What can be done to ease the effects of development?**

[More FAQ > (/discover/faq)]

Terms

▶ **Chemical contaminants**

▶ **Impervious**

▶ **Nutrients**

▶ **Precipitation**

▶ **Stormwater**

[All Terms > (/discover/glossary)]

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The Chesapeake Bay Program is a unique regional partnership that has led and directed the restoration of the Chesapeake Bay since 1983. The content on this website does not necessarily reflect the views or positions of the federal government.

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Mississippi River Gulf of Mexico Watershed Nutrient Task Force New Goal Framework

December 3, 2014

1. Updated Coastal Goal, Including Interim Target

For reference, the Hypoxia Task Force's (HTF) previous Coastal Goal is as follows:

> "Subject to the availability of additional resources, we strive to reduce or make significant progress toward reducing the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers by the year 2015 through implementation of specific, practical, and cost-effective voluntary actions by all Federal agencies, States, and Tribes, and address all categories of sources and removals within the Mississippi/Atchafalaya River Basin to reduce the annual discharge of nitrogen and phosphorus into the Gulf." - Gulf Hypoxia Action Plan 2008

The updated Coastal Goal, including an Interim Target, is as follows:

> We strive to reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers by the year 2035. Reaching this final goal will require a significant commitment of resources to greatly accelerate implementation of actions to reduce nutrient loading from all major sources of nitrogen and phosphorus in the Mississippi/Atchafalaya River Basin (MARB). An Interim Target of a 20% reduction[1] of nitrogen and phosphorus loading by 2025 is a milestone for immediate planning and implementation actions, while continuing to develop future action strategies to achieve the final goal through 2035. Federal agencies, States, Tribes and other partners will work collaboratively to plan and implement specific, practical and cost-effective actions to achieve both the Interim Target and the updated Coastal Goal.

[1] *The percent reduction is relative to the average MARB nutrient loading to the Gulf of Mexico during the 1980-1996 period.*

2. Commitment to Accelerated and New Actions to Reduce Nutrients Basinwide

Since 2001, the effort to reduce nutrient delivery to the Gulf of Mexico has seen progress at the local level in many locations within the MARB. However, the lack of overall progress to reduce the size of the Gulf of Mexico hypoxic zone illustrates the significant scaling up of action needed to reach the Interim Target within the next decade. Achieving meaningful progress will require well-targeted programs that expand existing and build new partnerships while supporting information and education programs to promote on-the-ground implementation. The HTF continues to follow the 2008 Action Plan, but since we have not seen a measurable reduction in nutrient loads delivered to the Gulf of Mexico between 2001 and the present time, the HTF is providing a set of initiatives to achieve the new Interim Target.

The following near-term actions were identified by the HTF based on their potential effectiveness in achieving progress toward the Interim Target. These actions focus on accelerating the implementation of existing programs and ongoing activities, as well as expanding the capacity of the HTF agencies and partners.

- **State Nutrient Reduction/ Strategies:** All states that are part of the HTF have submitted draft or completed State Nutrient Reduction Strategies (state strategies) for addressing nutrients within the respective state. The focus now can shift from planning to implementation of state strategies and updating of the strategies, as needed, to document, track, and report on nutrient activities or to quantify the nutrient load reductions that accrue from implementation of the state strategies so that their contribution to meeting the Interim Target in aggregate can be assessed. In addition to each state's own measures, the HTF commits to develop and report on a standard subset of measures applicable to all states that can improve quantification of progress.

- **Federal Programs:** At the federal level, integrate, strengthen and quantify the nutrient load reductions from programs scaled at the basin level, including, but not limited to, the USDA Regional Conservation Partnership Program, USDA Mississippi River Basin Healthy Watershed Initiative, US Fish & Wildlife Service (FWS) Mississippi River Habitat Initiative, FWS Landscape Conservation Cooperatives, Water Quality Standards development, and floodplain restoration and management by federal agencies and state and private partners.

- **Quantitative Measures:** Implementation of effective actions to reduce nutrient loadings must be verified with improved tracking mechanisms and watershed monitoring and modeling tools supported by the HTF and member agencies. These mechanisms and tools should be capable of being applied basin-wide to quantify and predict the ultimate nutrient reduction benefits of actions taken by HTF agencies and partners. Progress would also continue to be assessed by a coordinated basin-wide inland monitoring program, coupled to a coastal and offshore monitoring program.

- **Funding:** Recommit to the principle of the previous HTF Action Plans to identify funding needs and sources associated with specific and quantifiable nutrient reduction actions, pursue additional funding, and integrate this information in annual agency budget processes for the Interim Target and Coastal Goal since neither the Interim Target nor the Final Goal can be achieved without significant additional resources.

- **Partnerships:** Continue to expand existing and new HTF partnerships and alliances to carry out ecosystem and watershed restoration actions that result in nutrient load reductions. Where possible, strategically coordinate these partnerships to help the HTF reach the 2025 Interim Target, as well as work with partners to quantify and account for the load reduction benefits of these partner efforts. Five key sets of partners will be necessary for success:

Universities – The Land Grant Universities (LGUs) within the Basin provide both support for critical research needs and outreach to many communities throughout the Basin, including in particular the agricultural community. LGUs are already partnering with individual states to address the diversity of nutrient sources and geographic, climatic and hydrologic variability of the MARB. In addition to these individual state partnerships, the LGUs are working collaboratively across the MARB to improve the consistency of communications and collectively advance technologies and knowledge needed to reach the HTF goals. LGUs across the HTF states have played a critical role in assisting with the development of state nutrient strategies, and they will continue to play an integral role in implementing these strategies as recognized by the Non-Funded Cooperative Agreement developed between the HTF and these universities. This agreement provides a partnership framework between the LGUs and HTF that will serve to focus efforts of mutual interest specific to the MARB and HTF efforts.

Farmers and Agricultural Organizations – Farmers are recognized for their long tradition of commitment to soil and water stewardship and have been a critical part of the development and implementation of state strategies in every state. Farm innovations and the examples set by early adopters help improve solutions and provide needed demonstration, accelerating the rate of adoption of actions that improve agricultural productivity and water quality. The members of the HTF will seek to promote and stimulate markets for farmer led actions that improve water quality and enhance ecological benefits and services. Reducing the loss of nutrients, while simultaneously providing economic, agronomic, and soil health benefits, will be a win-win, benefiting farm sustainability, as well as downstream waters.

Businesses – The ability of business to create products and services to meet the needs of the American people is unprecedented. Nitrogen inhibitors and other products already play key roles in keeping nutrients in the soil and getting those nutrients to plants. Additionally, many businesses are actively working to reduce their environmental impacts and have lessons to share that will enable other businesses to implement similar actions. For example, those industries that discharge significant nutrients can provide leadership in identifying and piloting cost effective process optimization or control technologies.

Cities and Communities – Municipal wastewater agencies and the communities they serve will be relied upon to improve performance of sewage treatment facilities as a component of state nutrient strategies. Groups such as the Mississippi River Cities and Towns Initiative illustrate the number of ways these cities rely on the river and its tributaries. Achieving the Coastal Goal will require reductions from all sources of nutrients and will benefit those who depend on the river for water, recreation and many other uses.

Other Non-governmental Organizations – Many non-governmental organizations have goals and missions that overlap and are consistent with those of the HTF and are working on initiatives related to water quality and nutrients in the MARB.

- **Research:** Research is a core need for creating and improving effective actions and reducing uncertainties. We will also need to develop new technologies and shifts in practices over the period of the Interim Target, the Final Goal, and beyond. The 2008 Action Plan highlights a number of relevant research areas. In addition, the effects of extreme weather events on the Gulf of Mexico hypoxic zone and on the actions taken to lessen nutrient inputs in the Basin must be studied. The need for science is complemented by a need for a greater inclusion of the social sciences, especially the emerging field of behavioral economics, to determine how to best promote sound practices and understanding of the importance of the health of the MARB and Gulf of Mexico to this nation.

- **Reporting to Congress:** In the Biennial Report to Congress commencing June 30, 2015, report on the progress made by the HTF federal agencies and states toward nutrient load reductions, lessons learned and appropriate actions. Present to Congress a clear view of the priority needs to meet those load reduction goals and how adaptive management will be used to track and, if necessary, revise the strategies set forth in the Gulf Hypoxia Action Plan.

https://www.epa.gov/sites/default/files/2015-07/documents/htf-goals-framework-2015.pdf

Deepwater Horizon – BP Gulf of America Oil Spill

On April 20, 2010, the oil drilling rig *Deepwater Horizon*, operating in the Macondo Prospect in the Gulf of America, exploded and sank resulting in the death of 11 workers on the Deepwater Horizon and the largest spill of oil in the history of marine oil drilling operations. Four million barrels of oil flowed from the damaged Macondo well over an 87-day period, before it was finally capped on July 15, 2010. On December 15, 2010, the United States filed a complaint in District Court against BP Exploration & Production and several other defendants alleged to be responsible for the spill.

This webpage provides information and materials on EPA's enforcement response to the Deepwater Horizon Oil Spill, settlements with several of the defendants, including the record-setting settlement with BP Exploration & Production for an unprecedented $5.5 billion Clean Water Act penalty and up to $8.8 billion in natural resource damages.

The information provided below is limited to EPA's enforcement-related activities only, and does not cover all legal or other actions against BP Exploration & Production and other parties for the spill, such as private party/class action settlements for medical claims and economic damages, or other actions against those responsible for the spill. The U.S. District Court for the Eastern District of Louisiana has established the Deepwater Horizon Oil Spill <https://www.laed.uscourts.gov/oilspill/oilspill.htm> website for this purpose. In addition, links for additional information on the spill, cleanup activities and other responses are provided below.

On this page:

- Case and Settlement Information
- Additional Information

Case and Settlement Information

- December 15, 2010: Civil complaint of the United States <https://epa.gov/enforcement/complaint-and-summary-judgment-deepwater-horizon-bp-gulf-mexico-oil-spill>
- February 17, 2012: $90 million civil settlement with MOEX Offshore 2007 LLC <https://epa.gov/enforcement/moex-offshore-2007-llc-settlement>
- February 22, 2012: Court order granting partial summary judgment of liability for the spill <https://epa.gov/enforcement/complaint-and-summary-judgment-deepwater-horizon-bp-gulf-mexico-oil-spill>
    - June 4, 2014: 5th Circuit decision affirming ruling on summary judgment - 5th Circuit Decision June 4, 2014 <https://epa.gov/enforcement/5th-circuit-decision-june-4-2014>
    - November 5, 2014: 5th Circuit decision denying panel reconsideration and affirming summary judgment ruling - Nondispositive Panel Opinion <https://epa.gov/enforcement/5th-circuit-decision-denying-panel-reconsideration-and-affirming-summary-judgment-ruling>
    - January 9, 2015: 5th Circuit order denying petition for rehearing en banc - Deepwater Horizon order denying petition for rehearing en banc <https://epa.gov/enforcement/deepwater-horizon-order-denying-petition-rehearing-en-banc>
- November 15, 2012: $4 billion criminal plea agreement with BP Exploration & Production <http://www.justice.gov/criminal/vns/docs/2012/11/2012-11-15-bp-guilty-plea-agreement.pdf>
- January 3, 2013: $1 billion civil settlement with Transocean Offshore Deepwater Drilling Inc., Transocean Deepwater Inc., Transocean Holdings LLC, and Triton Asset Leasing GmbH ("Transocean") <https://epa.gov/enforcement/transocean-settlement>
- January 3, 2013: $400 million criminal plea agreement with Transocean <https://www.justice.gov/sites/default/files/criminal-vns/legacy/2013/01/18/2013-01-03-transocean-plea-agreement.pdf>
- September 4, 2014: Phase One Trial: Findings of Fact and Conclusions of Law on Gross Negligence and Willful Misconduct <https://epa.gov/enforcement/phase-one-trial-findings-fact-and-conclusions-law-gross-negligence-and-willful>

- January 15, 2015: Phase Two Trial: Findings of Fact on Source Control and the Amount of Oil Spilled <https://epa.gov/enforcement/phase-two-trial-findings-fact-source-control-and-amount-oil-spilled>
- February 19, 2015: Ruling on Maximum Dollars-Per-Barrel Penalty Amount, as Adjusted by the Penalty Inflation Act <https://epa.gov/enforcement/ruling-maximum-dollars-barrel-penalty-amount-adjusted-penalty-inflation-act>
- October 5, 2015: $14.9 billion civil settlement with BP Exploration & Production <https://epa.gov/enforcement/consent-decree-deepwater-horizon-bp-gulf-mexico-oil-spill>
- November 30, 2015: $159.5 million Civil Penalty Ruling Against Anadarko Petroleum Co. <https://epa.gov/enforcement/civil-penalty-ruling-against-anadarko-petroleum-co>

Additional Information on the Deepwater Horizon Oil Spill

- Restoring the Gulf of America After the Deepwater Horizon Oil Spill <https://epa.gov/deepwaterhorizon>
- 2010 National Coastal Condition Assessment Results and Report <https://epa.gov/national-aquatic-resource-surveys/ncca>
- RestoreTheGulf: official federal government site for spill response and recovery <http://www.restorethegulf.gov/>
- Final Report <https://www.gpo.gov/fdsys/pkg/gpo-oilcommission/pdf/gpo-oilcommission.pdf> of the National Commission on the BP Deepwater Horizon Oil Spill
- Deepwater Horizon Joint Investigation Team <https://www.bsee.gov/site-page/deepwater-horizon-joint-investigation-team-releases-final-report>

Last updated on April 23, 2025

How China is designing flood-resistant cities

YouTube Video

https://youtu.be/nf-Yy3EuZi0?si=-zpo-pYbEwl-oc8d

Managing stormwater to improve Canadian cities' safety and resilience

Government of Canada Gouvernement du Canada

February 18, 2022 - Ottawa, Ontario

Adapting to new realities, in a changing climate

The population density in Canadian cities has continued to increase over time. Combined with rising sea levels and unpredictable precipitation, the pressure on municipal infrastructure to manage excess water has been increasing. Stormwater infrastructure plays a critical role in helping to prevent urban flooding. By studying how it performs during extreme storms, engineers can provide advice to help local authorities adapt their infrastructure and mitigate losses from flooding.

In this context, the City of Toronto worked with researchers from the National Research Council of Canada (NRC) who have technical expertise in infrastructure resilience supported by well-known, unique testing facilities. The objective of the project was to study how increased rainfall behaves on Toronto streets and how efficiently the existing infrastructure diverts water into the storm drainage system.

Recreating roads inside the testing facilities

Researchers from the NRC's Ocean, Coastal and River Engineering and Construction Research Centres worked together on this project as part of the Climate-Resilient Buildings and Core Public Infrastructure (CRBCPI) Initiative, and with funding support from Infrastructure Canada and the City of Toronto. Since 2016, the NRC has been working to develop decision-support tools such as national model codes, guides, standards and climate design data to help ensure buildings and core public infrastructure are designed and built to withstand the effects of climate change in Canada. In fact, the idea for the project arose from a workshop that the NRC organized with municipalities to identify research needs.

With expertise in adaptive and sustainable engineering solutions, and in structural and coastal resilience, the NRC has been supporting the development of technologies to mitigate the impacts of weather extremes and climate change, including flooding from coastal and inland sources.

The building of a road infrastructure physical model, using wood and tar paper.

At the NRC's [Coastal wave basin research facility] in Ottawa, NRC experts built a physical model of the City of Toronto's road infrastructure, using wood and tar paper. With a water pump and a flow straightener, they recreated several scenarios from typical light rain conditions to heavy rains and even extreme flood conditions. Through testing, researchers evaluated the infrastructure's ability to capture the water under various flooding conditions.

"It's always rewarding to help our clients answer important questions that allow them to make key decisions. It's also interesting to "play" in the lab and see what it's like to throw 1 ton of water on a roadway every 2.5 seconds. It's like having a waterfall running through your office," says research council officer and project manager, Louis Poirier.

Choosing the right grates for the best results

Various grates used as entrance points to the underground catch basins.

To manage this water and prevent overland flooding that can lead to basement flooding, surface grates and catch basins on the street play a crucial role. As the only visible part of a much larger infrastructure system, surface grates and catch basins collect stormwater (rain or melted snow) from streets and move it through a complex underground storm sewer system. The stormwater eventually flows into the environment—normally a river, stream or lake. Although all surface grates and catch basins serve the same purpose, which is to move stormwater off the roadway, each surface grate model offers unique advantages, suited for different results. Some of the common catch basin grate patterns residents may see while walking in their neighbourhood include the herringbone pattern, a square grid, or parallel rectangular bars. To aid drainage, the grates are often placed near intersections and along low points in the roads. Residents can help reduce flooding by keeping them clear of leaves, debris, and snow.

Using wave gauges to calculate the amount of water on the model road surface, the research team determined how much water was removed from the roadway for each catch basin in various conditions. Data was collected for numerous scenarios, including various surface grates pattern styles and different incident water depths. The results gathered from the testing phase will help the City of Toronto and other Canadian municipalities improve the numerical models of their storm drainage system, to better meet the challenges of managing extreme rainfall events.

Close-up picture of a large grate under water.

"We're looking forward to reviewing the data from this research and applying it to the City of Toronto's ongoing planning and future stormwater management and basement flooding-prevention projects. Thank you to the team at the National Research Council of Canada for your scientific and technical expertise, and for working with us on this exciting and innovative project," says Jennifer Spence, Project Manager with Toronto Water who, together with Senior Engineer Tom Dole, led this study for the City of Toronto.

Working together to make cities more resilient for all Canadians

With a changing climate and increasing urbanization, municipal authorities will need to continue to adapt to new realities. A better understanding of their existing infrastructure's performance will support informed funding decisions when it comes to expanding, upgrading or replacing existing systems. Planning for severe weather events and using prediction tools and physical testing of novel infrastructure will lead to improved flooding preparedness and resilience.

With infrastructure being the backbone of modern society, the federal government is investing to modernize Canada's infrastructure to ensure that it is sustainable, inclusive and resilient for future generations. As part of its Departmental Sustainable Development Strategy 2020 to 2023, the NRC is committed to supporting the federal sustainable development goals through research towards modern and resilient infrastructure. This project realized with the City of Toronto and the NRC will help Canada create safer and more sustainable environments for all Canadians.

From: National Research Council Canada

Date modified: 2022-02-18

Key Topic #6: Your Best Management Practices for NPS

Learning Objectives

1. **Identify** common BMPs used to reduce NPS pollution in urban, suburban, and agricultural environments (e.g., rain gardens, cover crops, buffer strips, pervious pavement).
2. **Explain** how selected BMPs reduce pollutant loads or improve stormwater infiltration, using diagrams or real-world examples.
3. **Compare** the costs, benefits, and feasibility of different BMPs in various land use contexts (e.g., a schoolyard vs. a farm vs. a residential street).
4. **Demonstrate** how to plan or assess a BMP using a field checklist, photo documentation, or a site sketch (e.g., rain garden layout or runoff path).
5. **Recommend** appropriate BMPs for a hypothetical site based on land use, soil conditions, and observed pollution risks.

Resource Title	Source	Located on
BMPs used to reduce NPS pollution in urban environment, *excerpts*	*National Management Measures to Control Nonpoint Source Pollution from Urban Areas, US EPA, 2005*	Page 172-184
Agricultural Nonpoint Source Pollution, Hydromodification, *excerpts*	*U.S. EPA, 2005*	Page 185-186
Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice, *Abstract excerpt*	*Ribaudo et al, Resource Economics Division, Economic Research Service, U.S.D.A. Agricultural Economic Report No. 782, 1999*	Page 187
Estimating Benefits and Costs of Stormwater Management: *chart and graphic*	*Environmental Finance Center, Sacramento State, 2019*	Page 188-189
Case Study-Burnsville rain gardens	*Minnesota Stormwater Manual, 2005*	Page 190-193
Case studies for stormwater and rainwater harvest and use/reuse	*Minnesota Stormwater Manual, 2012*	Page 194-200
Home NPS BMPs: Reducing Nonpoint Source Pollution at Home, *summary*	*Rodrigue, Paul, USDA NRCS and U.S. EPA*	Page 201-202
Steps to Help Control NPS Pollution, *excerpts*	*Mississippi Department of Environmental Quality*	Page 203

BMPs used to reduce NPS pollution in urban environment

From "National Management Measures to Control Nonpoint Source Pollution from Urban Areas", United States Environmental Protection Agency, 2005

The *National Water Quality Inventory: 2000 Report to Congress* identified urban runoff as one of the leading sources of water quality impairment in surface waters (USEPA, 2002b). Of the 11 pollution source categories listed in the report, "urban runoff/storm sewers" was ranked as the fourth leading source of impairment in rivers, third in lakes, and second in estuaries.

Management practices to control urban runoff can be classified in seven categories. The following practices are described for illustrative purposes only. EPA has found these practices to be representative of the types of practices that can be applied successfully to achieve the new development runoff treatment management measure. As a practical matter, EPA anticipates thatthe management measure can be achieved by applying one or more management practices appropriate to the source(s), location, and climate. Thus, practices that by themselves do not achieve 80 percent TSS removal can be combined with other practices to achieve 80 percent removal (such that x + y + z = 80 percent). This is the "treatment train" approach, in which several types of practices are used together and integrated into a comprehensive runoff management system (WMI, 1997b). The seven categories include:

— Infiltration practices;
— Vegetated open channel practices;
— Filtering practices;
— Detention ponds or vaults;
— Retention ponds;
— Wetlands; and
— Other practices such as water quality inlets.

Infiltration Practices

These practices capture and temporarily store runoff before allowing it to infiltrate into the soil over several days. Design variants include:
— Infiltration basins;
— Infiltration trenches; and
— Pervious or porous pavements.
To prevent premature clogging, these practices must not receive drainage from a construction activity or site. Infiltration practices can be placed in service after the construction activity is complete or the site is stabilized.

Infiltration basins

Infiltration basins (Figure 5.1) are impoundments created by excavation or creation of berms or small dams. They are typically flat-bottomed with no outlet and are designed to temporarily store runoff generated from adjacent drainage areas (from 2 to 50 acres, depending on local conditions). Runoff gradually infiltrates through the bed and sides of the basin, ideally within 72 hours, to maintain aerobic conditions and ensure that the basin is ready to receive runoff from the next storm. Infiltration basins are often used as an off-line system for treating the first flush of runoff flows or the peak discharges of the two-year storm.

The key to successful operation is keeping the soils on the floor and side slopes of the basin unclogged to maintain the rate of percolation. This is usually much easier said than done. For example, Schueler (1992) reported infiltration basin failure rates ranging from 60 to 100 percent in the mid-Atlantic region. To help keep sediment out of the basin, incoming runoff should be pretreated using vegetated filter strips, a settling forebay, or other techniques. Grasses or other vegetation should also be planted and maintained in the basin. If soil pores become clogged, the basin bottom should be roughened or replaced to restore percolation rates.

Infiltration trenches

Infiltration trenches (Figure 5.2) are shallow (2- to 10-feet deep) excavated ditches with relatively permeable soils that have been backfilled with stone to form an underground reservoir. The trench surface can be covered with a grating or can consist of stone, gabion, sand, or a grasscovered
area with a surface inlet. Runoff diverted into the trench gradually infiltrates into the subsoil and, eventually, into the ground water. Trenches can be used on small, individual sites or for multi-site runoff treatment. Pretreatment controls such as vegetated filter strips should be incorporated into the design to remove sediment and reduce clogging of soil pores. More expensive than pond systems in terms of cost per volume of runoff treated, infiltration trenches are best-suited for drainage areas of less than 5 to 10 acres, or where ponds cannot be used. Variations in the design of infiltration trenches include dry wells, which are pits designed to control small volumes of runoff (such as rooftop runoff) and exfiltration trenches. A typical dry well design includes a perforated pipe 3 to 4 feet in diameter that is installed vertically in deposits of gravely/sandy soil. Rock is then backfilled around the base of the well. An exfiltration trench is an infiltration trench that stores runoff water in a perforated or slotted pipe and percolates it out into a surrounding gravel envelope and filter fabric. Dry wells and other infiltration practices that involve subsurface drainage may be regulated by EPA's Underground Injection Control Program. See the EPA's Underground Injection Control Program Web site at http://www.epa.gov/safewater/uic.html for more information.

Pervious or porous pavements

Pervious pavement has the approximate strength characteristics of traditional pavement but allows rainfall and runoff to percolate through it. The key to the design of these pavements is the elimination of most of the fine aggregate found in conventional paving materials. There are two types of pervious pavement, porous asphalt and pervious concrete (WMI, 1997b). Porous asphalt has coarse aggregate held together in the asphalt with sufficient interconnected voids to yield high permeability. Pervious concrete, in contrast, is a discontinuous mixture of Portland cement, coarse aggregate, admixtures, and water that also yields interconnected voids for the passage of air and water. Underlying the pervious pavement are a filter layer, a stone reservoir, and a filter fabric. Stored runoff gradually drains out of the stone reservoir into the subsoil. Figure 5.3 shows several types of porous pavement. More information about pervious pavement can be found at http://www.gcpa.org/pervious_concrete_pavement.htm (Georgia Concrete & Products Association, 2003).

(https://stormwater.pca.state.mn.us/index.php?title=File:Picture_of_porous_asphalt_1.jpg)

Modular pavement consists of individual blocks made of pervious material such as sand, gravel, or sod interspersed with strong structural material such as concrete. The blocks are typically placed on a sand or gravel base and designed to provide a load-bearing surface that is adequate to support personal vehicles, while allowing infiltration of surface water into the underlying soils. They usually are used in low-volume traffic areas such as overflow parking lots and lightly used access roads. An alternative to pervious and modular pavement for parking areas is a geotextile material installed as a framework to provide structural strength. Filled with sand and sodded, it provides a completely grassed parking area. More information about concrete pavers can be found at http://www.concretenetwork.com/concrete/porous_concrete_pavers/ (Concretenetwork.com, 2003).


(https://stormwater.pca.state.mn.us/index.php?title=File:Univ_of_MN_PICP_Photograph.jpg)

Vegetated Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff through infiltration, filtration, or temporary storage.

A vegetated swale is an infiltration practice that usually functions as a runoff conveyance channel and a filtration practice. It is lined with grass or another erosion-resistant plant species that serves to reduce flow velocity and allow runoff to infiltrate into ground water. The vegetation or turf also prevents erosion, filters sediment, and provides some nutrient uptake benefits. These practices are also known as biofiltration swales. Check dams are often used to reduce flow velocity. When used, sediment that collects behind check dams should be removed regularly.

Two types of channels are typically used in residential landscapes:

— *Grass channels*. These have dense vegetation, a wide bottom, and gentle slopes (Figure 5.4). Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

— *Dry swales*. As with grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation (Figure 5.5). From there, runoff moves downward through a bed of sandy loam soil and is collected by an underdrain pipe system. The treated water is delivered to a receiving water or another structural control. Dry swales are used in large-lot, single-family developments and on campus-type office or industrial sites. They are applicable in all areas where dense vegetative cover can be maintained. Because of a limited ability to control runoff from large storms, they are often combined with other structural practices. They should not be used in areas where flow rates exceed 1.5 feet per second unless additional erosion control measures, such as turf reinforcement mats, are used.


(Photo of a dry swale. Courtesy of Limnotech.)

Filtering Practices

Filtering practices capture and temporarily store runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include:
— Surface sand filter;
— Underground sand filter;
— Organic filter;
— Pocket sand filter; and
— Bioretention areas.

Filtration basins and sand filters

Filtration basins are impoundments lined with a filter medium such as sand or gravel. Runoff drains through the filter medium and through perforated pipes into the subsoil. Detention time is typically four to six hours. Sediment-trapping structures are often used to prevent premature clogging of the filter medium (NVPDC, 1980; Schueler et al., 1992).

Sand filters are usually two-chambered practices: the first is a settling chamber and the second is a filter bed filled with sand or another filtering medium. As runoff flows into the first chamber, large particles settle out and finer particles and other pollutants are removed as runoff flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chambered treatment train (Robertson et al., 1995). All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging site designs (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

Media filtration units
Similar to wastewater treatment technology, passive filtration units can be used to capture pollutants from runoff. Media filtration practices commonly use trenches filled with sand or peat. Other media, including types of crushed rock and composted leaves, can also be used. A basin collects the runoff and gradually routes discharge through cartridges filled with filter media. An emergency bypass prevents system flooding during large rainstorms. According to the Unified Sewerage Agency of Washington County in Oregon (WEF, 1998), composted leaf media trap particulates, adsorb organic chemicals, and remove 90 percent of solids, 85 percent of oil and grease, and 82 to 98 percent of heavy metals through cation exchange from leaf decomposition. Similar types of systems with various filter media are available commercially.

Bioretention systems
Bioretention systems are suitable to treat runoff on sites where
there is adequate soil infiltration capacity and where the runoff volumes that are not infiltrated do not present a safety or flooding hazard. Typical applications for bioretention include parking areas with or without curbs, traffic islands, and swales or depressed areas that receive runoff from impervious areas.

Bioretention system designs are very flexible, can be adapted to a wide range of commercial, industrial, and residential settings, and can be linked in series or combined with structural devices to provide the necessary level of treatment depending on expected runoff volumes and pollutant loading. A common technique is to use bioretention areas to pre-treat sheet flow before it is channelized or collected in an inlet structure.

Bioretention practices are commonly called rain gardens.

Bioretention is a terrestrial-based (up-land as opposed to wetland) water quality and water quantity control process. Bioretention employs a simplistic, site-integrated design that provides opportunity for runoff infiltration, filtration, storage, and water uptake by vegetation.

Bioretention areas are suitable stormwater treatment practices for all land uses, as long as the contributing drainage area is appropriate for the size of the facility. Common bioretention opportunities include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage and street-scapes (i.e., between the curb and sidewalk). Bioretention, when designed with an underdrain and liner, is also a good design option for treating stormwater hotspots (PSHs). Bioretention is extremely versatile because of its ability to be incorporated into landscaped areas. The versatility of the practice also allows for bioretention areas to be frequently employed as stormwater retrofits.

(https://stormwater.pca.state.mn.us/index.php?title=Bioretention)

Detention and Retention Practices

Detention ponds and vaults

These practices temporarily detain runoff to ensure that the post development peak discharge rate is equal to the predevelopment rate for the desired design storm (e.g. two-, 10-, or 25-year).

These practices may also be used to provide temporary extended detention to protect downstream channels from erosion (e.g., 24-hour extended detention for a one-year storm). Extended detention (ED) ponds are an example of this type of facility. ED ponds temporarily detain a portion of urban runoff for up to 24 hours after a storm, using a fixed orifice to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. ED ponds are normally dry between storm events and do not have any permanent standing water. These basins are typically composed of two stages: an upper stage, which remains dry except after larger storms, and a lower stage, which is designed for typical storms. Enhanced ED ponds are equipped with plunge pools or forebays near the inlet, a micropool at the outlet, and an adjustable reverse-sloped pipe as the ED control device (NVPDC, 1980; Schueler et al., 1992). Most ED ponds use a riser with an anti-vortex trash rack on top to control large floating solids.

(https://stormwater.pca.state.mn.us/index.php?title=File:Picture_of_a_dry_pond_1.jpg)

Detention tanks and vaults are underground structures used to control peak runoff flows. They are usually constructed out of concrete (vaults) or corrugated metal pipe (tanks). Underground detention can also be achieved by retrofitting the over-capacity storm drain pipes with baffles. The baffles allow water to be stored in the pipes so it can be released at a slower rate. Pretreatment structures such as water quality inlets and sand filters can be used to treat runoff and remove trash and debris.

These systems are primarily applicable where space is limited and there are no other practical alternatives. Concrete vaults are relatively expensive and are often used to control small flows where system replacement costs are high. Corrugated metal pipe systems are less expensive and are often used to control larger volumes of runoff in parking lots, adjacent to rights-of-way, and in medians. These systems should be located where maintenance can be conducted with minimal disturbance.

Underground detention structures provide runoff quantity control but do not provide significant water quality control without modifications. Corrugated metal pipe systems can work in conjunction with infiltration to provide additional runoff treatment. This is accomplished by adding perforations to the pipe to allow it to store the water until it can be released into the soil (FHWA, no date).

Retention ponds

These practices use a permanent pool, extended detention basin, or shallow marsh to remove pollutants and can include:

— Micropool extended detention ponds;
— Wet ponds;
— Wet extended detention ponds; and
— Multiple pond systems.

Ponds are basins designed to maintain a permanent pool of water and temporarily store runoff (ED wet pond), which is released at a controlled rate. Ponds allow particulates to settle and can provide biological uptake of pollutants such as nitrogen or phosphorus. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed.

(https://stormwater.pca.state.mn.us/index.php?title=File:Picture_of_a_wet_pond_2.jpg)

Constructed wetlands

Constructed wetlands are engineered systems designed to treat runoff. They are typically designed to provide some of the functions of natural wetlands, e.g., wildlife habitat, in addition to controlling runoff volumes and pollutant loadings. There are many variations of constructed wetlands, such as shallow wetlands, extended detention wetlands, pond/wetland systems, and small isolated "pocket" wetlands. Constructed wetlands may contain some or all of the following elements: shallow vegetated areas, permanent pools, sediment forebays, transition areas, and weirs. Designs are intended to slow flow through the wetlands and provide maximum contact with wetland vegetation.

Other Practices

Other practices used to control urban runoff have not been studied as extensively as those above

but have been used with varying degrees of success. They include:
— Water quality inlets;
— Hydrodynamic devices;
— “Baffle boxes;”
— Catch basin inserts;
— Vegetated filter strips;
— Street surface storage;
— On-lot storage; and
— Microbial disinfection.

In some cases, these practices are used for pretreatment or are part of an overall runoff management system, which is sometimes referred to as a “treatment train.” For example, water quality inlets, catch basin inserts, and vegetated filter strips installed upslope of a wet pond or filtration practice will help remove a portion of the pollutants present in runoff before it enters the pond or filtration practice. These other practices in the treatment train improve runoff quality and can help extend the longevity of the filtration practice and wet pond.

Pollution Prevention

Implement pollution prevention and education programs to reduce nonpoint source pollutants generated from the following activities:
— The improper storage, use, and disposal of household chemicals, including automobile fluids, pesticides, paints, solvents, etc.;
— Lawn and garden activities, including the improper application and disposal of lawn and garden care products, and the disposal of leaves and yard trimmings;
— Turf management on golf courses, parks, and recreational areas;
— Commercial activities, including parking lots and gas stations;
— Improper disposal of pet wastes; and
— Activities that generate trash.

The four main avenues for household chemicals to become problem pollutants are through leaks and spills, improper use, improper storage, and improper disposal.
(1) *Leaks and spills*. Chemicals leaking from improperly maintained automobiles and lawn equipment or faulty containers can accumulate on roads, driveways, and lawns and be carried by runoff to receiving water bodies.
(2) *Improper use*. Failure to follow label instructions properly may result in over-application of fertilizers or pesticides and can lead to chemical accumulation in the soil and grass. These chemicals can leach to ground water or be carried by runoff to surface waters.
(3) *Improper storage*. Improper storage of chemicals can lead to spills that can contaminate runoff and ground water or result in dangerous chemical reactions.
(4) *Improper disposal*. It is a common practice for citizens to pour unwanted chemicals, such as detergents, cleansers, or automotive fluids, onto their lawns or driveways or directly down storm drains. Contrary to popular belief, most storm sewers do not connect to wastewater treatment plants—chemicals disposed of this way could be discharged directly to receiving water bodies. Additionally, when chemicals are poured down drains connected to a

wastewater treatment plant or septic system, they could interfere with treatment systems by killing the bacteria that metabolize pollutants, causing water discharged from the plants to be contaminated. Ground water is also at risk because runoff can carry these chemicals through the soil to the water table. Product labels describe requirements for proper disposal and should be followed carefully.

(5) *Outdoor car washing*. This activity can result in high loads of nutrients, metals, and hydrocarbons being carried to receiving waters during dry weather conditions when the wash water flows into the storm drain system. According to surveys, 50 to 75 percent of households wash their own cars and 60 percent of those households wash their cars at least once a month (Schueler and Swann, 2000b).

Failing septic systems

Approximately one in four American households relies on a septic system to dispose of their wastewater. Septic systems have a failure rate of 5 to 35 percent, depending on soil conditions and other factors. When septic systems fail, the untreated or partially treated wastewater discharges to surface and ground waters. A survey conducted in the Chesapeake Bay watershed found that the average age of septic systems in the area was about 27 years, which is seven years beyond the design life of an unmaintained system. About half the owners indicated that they had not inspected or cleaned out their system in the previous three years. (Schueler and Swann, 2000b).

Lawn and garden activities

Lawn care practices are often targeted by watershed managers as contributors of pesticides and nutrients to runoff. A nationwide study by the U.S. Geological Survey (USGS) in 1999 found a high incidence of insecticides and herbicides in urban streams. Insecticides commonly used in homes, gardens, and commercial areas were found more frequently and in higher concentrations in urban streams than in agricultural streams. These concentrations often exceeded guidelines for the protection of aquatic life. Herbicides, such as those used for weed control, were found in 99 percent of sampled streams, but rarely at levels that exceeded guidelines.

Maintaining a healthy lawn might require fertilizers, pesticides, and heavy watering in some areas. Overuse of fertilizers, pesticides, and water can lead to excessive growth, increased pest problems, and environmental damage. In terms of fertilizer inputs, nutrients typically are applied to lawns at about the same rates as for row crops.

Commercial activities

Runoff from commercial land uses, such as shopping centers, office parks, and parking lots or garages may contain high hydrocarbon loadings and metal concentrations that are twice those found in the average urban area. These loadings can be attributed to heavy traffic volumes and large areas of impervious surface on which automotive-related pollutants concentrate.

Other commercial uses, such as vehicle maintenance, liquids storage, and equipment storage and maintenance, can also introduce pollutants to runoff.

Lawn, Garden, and Landscape Activities

Lawns are a significant feature of urban landscapes. This large area of managed landscape has

the potential to contribute to urban runoff pollution due to over-fertilization, overwatering, overapplication
of pesticides, and direct disposal of lawn clippings, leaves, and trimmings. Also,
erosion from bare patches of poorly managed lawns contributes sediment to watercourses, and disposal of lawn clippings in landfills can reduce the capacity of these facilities to handle other types of waste. Public education for citizens and municipal crews with respect to pest tolerance and proper handling of fertilizers, pesticides, water, and yard waste can greatly reduce the potential for adverse impacts to waters receiving runoff from lawns. Municipalities and watershed managers should develop an outreach campaign that targets citizens, lawn care businesses, landscapers, and municipal crews. Materials should highlight the following steps to help citizens and lawn care professionals maintain healthy, attractive lawns with less maintenance and fewer chemical inputs:

— Lawn conversion
— Soil building
— Grass selection
— Mowing and thatch management
— Minimal fertilization
— Weed control and tolerance
— Pest management
— Sensible irrigation

Lawn conversion
Grasses are very water-hungry and labor-intensive landscaping plants when compared to ground cover, flowers, shrubs, and trees. Therefore, to reduce the maintenance requirements of a lawn and address problem areas where turf is difficult to grow, property owners could identify areas where turf grass can be replaced with other types of plantings.

EXISTING DEVELOPMENT

The purpose of this management measure is to protect or improve surface water quality by developing and implementing watershed management programs that pursue the following objectives:

— Reduce surface water runoff pollution loadings from areas where development has already occurred.
— Reduce the volume and peak runoff rates of surface water runoff to reduce runoff flow, increase infiltration, and minimize habitat degradation and sediment loadings from erosion of streambanks and other natural conveyance systems.
— Preserve, enhance, or establish buffers that provide water quality benefits along water bodies and their tributaries.

Maintaining water quality becomes increasingly difficult as urbanization occurs and areas of impervious surface increase. Increased peak runoff volumes from impervious surfaces result in alteration of stream channels, natural drainageways, and riparian habitat. This alteration, in turn, results in elimination or reduction of predevelopment aquatic flora and fauna and degradation of predevelopment water quality. Other effects include increased bank cutting, streambed scouring, embedded cobbles, siltation, increases in instream water temperature, decreases in dissolved oxygen, and changes to the natural structure and flow of the stream or river.

Agricultural Nonpoint Source Pollution

The primary agricultural NPS pollutants are nutrients, sediment, animal wastes, salts, and pesticides. Agricultural activities also have the potential to directly impact the habitat of aquatic species through physical disturbances caused by livestock or equipment. Although agricultural NPS pollution is a serious problem nationally, a great deal has been accomplished over the past several decades in terms of sediment and nutrient reduction from privately-owned agricultural lands. Much has been learned in the recent past about more effective ways to prevent and reduce NPS pollution from agricultural activities.

NRCS maintains a National Handbook of Conservation Practices (USDA–NRCS, 1977), updated continuously, which details nationally accepted management practices. These practices can be viewed at the USDA-NRCS web site at https://www.nrcs.usda.gov/resources/guides-and-instructions/field-office-technical-guides. In addition to the NRCS standards, many States use locally determined management practices that are not reflected in the NRCS handbook.

WATER QUALITY ANDFORESTRY ACTIVITIES

The effects of forestry activities on surface waters are of concern to EPA and state and local authorities because healthy, clean waters are important for aquatic life, drinking water, and recreational use. Surface waters and their ecology can be affected by inputs of sediment, nutrients, and chemicals, and by alterations to stream flow that can result from forestry activities. The purpose of implementing management measures and best management practices (BMPs) to protect surface waters during and after forestry activities is to protect important ecological conditions and characteristics of the surface waters in roaded and logged forested areas.

Management Measures

- Road System Planning
- STREAMSIDE MANAGEMENT AREAS
- REVEGETATION OF DISTURBED AREAS
- FOREST CHEMICAL MANAGEMENT

Hydromodification

USEPA (1993) defines hydromodification as the "alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources." Examples of hydromodification in streams include dredging, straightening, and, in some cases, complete stream relocation. Other examples include construction in or along streams, construction and operation of dams and impoundments, channelization in streams, dredging, and land reclamation activities. Hydromodification can also include activities in streams that are being done to maintain the stream's integrity such as removing snags.2 Some indirect forms of hydromodification, such as erosion along streambanks or shorelines, are caused by the introduction or maintenance of structures in or adjacent to a waterbody and other activities, including many upland activities, that change the natural physical properties of the waterbody. EPA has grouped hydromodification activities into three categories: (1) channelization and channel modification, (2) dams, and (3) streambank and shoreline erosion.

Hydromodification is one of the leading sources of impairment in our nation's waters. According to the *National Water Quality Inventory: 2000 Report to Congress* (USEPA, 2002a), there are almost 3.7 million miles of rivers and streams[4] in the United States. Approximately 280,000 miles of assessed rivers and streams in the United States are impaired for one or more designated uses, which include aquatic life support, fish consumption, primary and contact recreation, drinking water supply, and agriculture. Many of the pollutants causing impairment are delivered to surface and ground waters from diffuse sources, such as agricultural runoff, urban runoff, hydrologic modification, and atmospheric deposition of contaminants. The leading causes of beneficial use impairment (partially or not supporting one or more uses) are nutrients, sediment, pathogens (bacteria), metals, pesticides, oxygen-depleting materials, and habitat alterations (USEPA, 2002a).

Economics of Water Quality Protection From Nonpoint Sources: Theory and Practice

(Economic Research ServiceU.S. DEPARTMENT OF AGRICULTURE)

Water quality is a major environmental issue. Pollution from nonpoint sources is the single largest remaining source of water quality impairments in the United States. Agriculture is a major source of several nonpoint-source pollutants, including nutrients, sediment, pesticides, and salts. Agricultural nonpoint pollution reduction policies can be designed to induce producers to change their production practices in ways that improve the environmental and related economic consequences of production. The information necessary to design economically efficient pollution control policies is almost always lacking. Instead, policies can be designed to achieve specific environmental or other similarly-related goals at least cost, given transaction costs and any other political, legal, or informational constraints that may exist.

Estimating Benefits and Costs of Stormwater Management

Chart and Graphic from:
https://www.efc.csus.edu/reports/efc-cost-project-part-1.pdf

Table 6: Some potential benefits for stormwater management as described in Stormwater Resource Plans through CA State Water Resources Control Board guidelines.

Benefit Category	Benefits	Non-Monetary Metric
Water quality	Prevent or reduce pollutant discharges	Load of total suspended solids (TSS) reduced
	Prevent or reduce hydromodification	Volume of runoff reduced
Water supply	Augment water supply	Volume captured and infiltrated into groundwater basins
	Reduce water demands	Volume captured that results in reduced demand on other sources
Flood management	Prevent or reduce localized flooding	Peak flow reduction for design storm
	Prevent or reduce regional flooding	Size of area with flood mitigation
Climate change adaptation and resilience	Support water supply reliability	Additional volume of water available for supply
	Address increased precipitation volumes and intensities	Rate of peak flow reduced for the identified design storm
	Provide infrastructure redundancy	Volume of new redundant capacity
	Provide infrastructure longevity	Months or years of expected additional component life
Environmental	Protect or restore habitat	Size of area of wetland, riparian zone, or habitat
	Support biodiversity	Number of additional habitat acres for sensitive species
	Improve instream flow rates	Rate of instream flowrate improved
	Improve instream flow temperatures	Water temperature (°F or °C) improved or percent canopy cover increased
	Reduce urban heat island effects	Reduced air surface temperatures
	Reduce greenhouse gas emissions and air pollutants	Mass of greenhouse gas emissions sequestered or reduced
Community	Support permit compliance	Achieved permit needs with regulator
	Create jobs	Number of new jobs
	Provide recreational opportunities	Size of space created/enhanced
	Improve mental and physical health	Quantified improvement in community health, such as reduced hospital visits
	Provide educational opportunities	Number of outreach materials provided, events conducted, or participants
	Increase property values	Dollar value increase in property values
	Improve aesthetics	Size of public space created
	Improve community involvement	Number of hours volunteered or participants

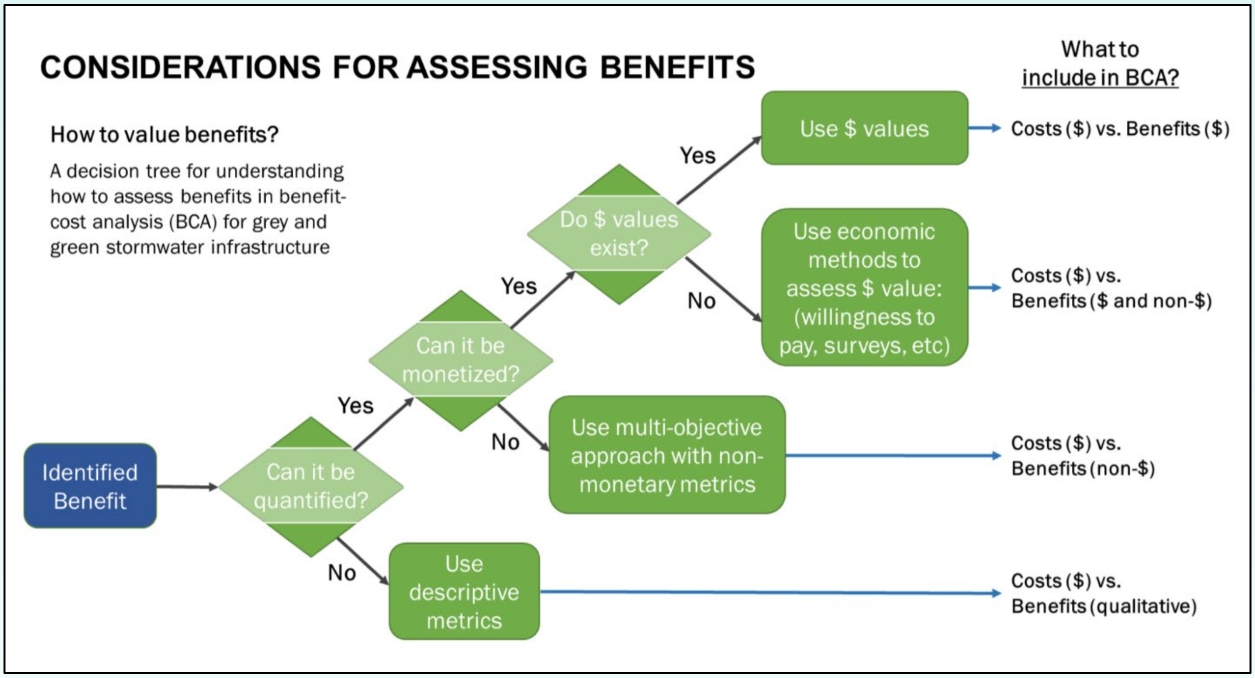


Figure 7: A decision tree for applying methods to assess benefits in benefit-cost analysis

Case Study:

Burnsville rain gardens - retrofitting for water quality

Over the past decades, Burnsville's Crystal Lake had seen a marked decrease in water clarity, due in part to algae bloom resulting from increased phosphorus entering the lake. Water quality typically decreased from spring to late summer, which impacted recreational use of the lake.

Contents

Photo showing one of the rain gardens installed as part of the Burnsville rain garden project.

Project summary

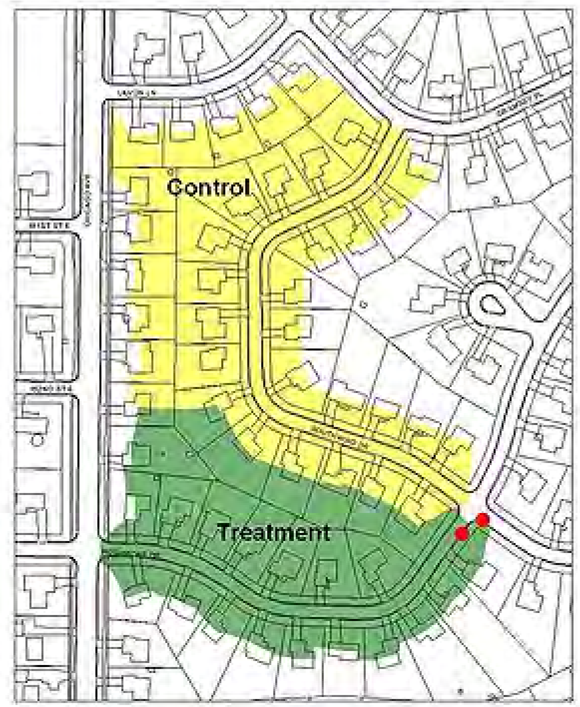
- Location: Burnsville
- Landscape setting: suburban residential
- Drainage area: 5.3 acres, 25 houses (17 with rain gardens)
- Project timeline: 2001 to 2006
- Project cost: $147,000
- Project contact: Barr Engineering (https://www.barr.com/)

Background

Recognizing that incoming stormwater from surrounding residential neighborhoods was an important factor in lake health, the City of Burnsville sought an alternative treatment method to reduce that runoff. However, curb and gutter was already in place in the 20-year-old neighborhoods near the lake, and there was insufficient room for traditional stormwater ponds.

Rain gardens—shallow, vegetated depressions that capture runoff and allow it to soak into the ground—emerged as the best solution. In addition to suiting the space and budget constraints in this fully built residential area, rain gardens offer visual amenity that tend to increase residents' commitment to help implement and maintain them.

With the help of two grants—$30,000 from the city and $117,000 from the Metropolitan Council—Burnsville was not only able to design and build the gardens, but to implement a study to gauge their effectiveness. A paired watershed study—monitoring one 5.3 acre neighborhood with 17 rain gardens and a similar, no-rain-garden neighborhood nearby—allowed the city and its partners to see how the BMPs performed during actual storm events.



Schematic illustrating the location of control and treatment watersheds. Control watersheds, shaded yellow, contained no rain gardens, while the treatment area, shaded green, contained rain gardens.

Implementation

To get baseline data, gauges were installed in each neighborhood to measure runoff for two summers prior to rain garden installation.

Since the greatest concentration of pollutants is washed off impervious surfaces during the first inch of precipitation, rain gardens are designed to accommodate that "first flush" from a given watershed. The Burnsville gardens were designed to accommodate 0.9 inches and drain rapidly, within 24 to 48 hours. Rain gardens can be planted with many types of vegetation, including native perennials and shrubs or cultivated varieties. The Burnsville participants were given the choice of three basic garden styles: native wildflower, cultivated perennials and/or shrubs.

Following evaluations of soil and topography, city staff and consultants sought to educate area residents about efforts to improve Crystal Lake water clarity and how rain gardens fit into the picture. The Rushmore Drive neighborhood, characterized by gentle topography and sandy soils, was selected, with hopes of getting at least 30 percent of the 25 residents to participate. As it happened, 85 percent of households signed on, resulting in 17 gardens—13 in front yards, 4 in back. All but one selected a scheme using low-maintenance cultivated perennials and shrubs, which tend to look neater than an all-native garden.

Grading plans, created by engineer Kurt Leuthold, in consultation with landscape architect Fred Rozumalski, incorporated stone retaining walls and gradual slopes from street to basin. During the design phase, Gopher One marked underground utilities so they could be accurately surveyed. The project engineer stresses the importance of this step to help minimize pre-construction surprises and changes.

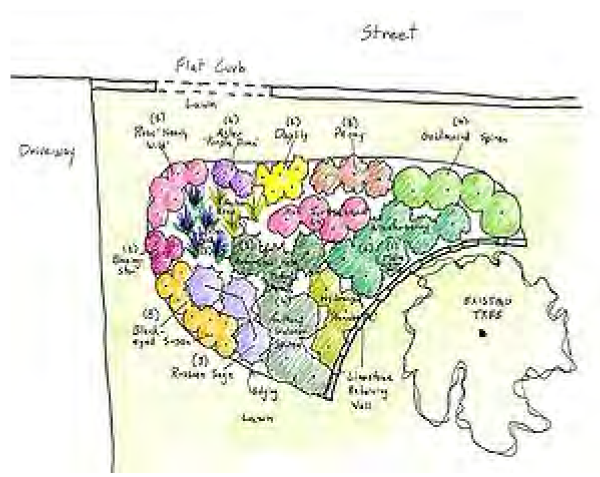
The landscape architect met with homeowners and drew up planting plans that considered individual resident preferences. Each garden is separated from the street and curb cut by a mow strip, which serves two purposes: to lend a neat, intentional edge to the garden and to trap sediment traveling with the rainwater. The planting designs emphasize showy groupings of tidy-looking plants, which enhance the appearance of the front yards. Construction began in fall 2003. In order to avoid hitting utilities and to ensure proper flow, precise grading of the gardens was critical, as was close adherence to soil specifications and avoiding compaction. Native sandy topsoil was stockpiled and mixed with compost, then installed at a depth of 12 inches following grading. To ensure quality, the city relied on the engineering consultant to do extensive construction observation, and Gopher One marked utilities two additional times—before sod stripping and soil removal and also prior to grading.

Photos illustrating a private residence before and after installation of a rain garden. Notice the curb cut from the street into the rain garden.

Small construction companies were more responsive to the request for bids on this relatively small project (the grading budget was $50,000); city staff indicated that in the future they would not solicit bids from large companies for a project of this scale.

Instead of having planting completed by the contractor, the Burnsville project utilized resident-volunteers to plant their own gardens, with the help of the landscape architect and city staff. This not only helped keep the budget down, but gave homeowners a hands-on investment in their gardens, and familiarized them with the plants.

In order to let plants become established before being inundated, curb cuts were not made until spring 2004. It is important to design curb cuts sufficiently wide so stormwater actually reaches the gardens; a too-narrow cut can allow water to wash on by. At Burnsville, the typical curb opening was 6 feet, with 2 feet tapering sections on each side.



Schematic showing the design for a rain garden. Note the placement of plants within different locations in the rain garden.

Costs

Cost per garden was approximately $7500, with about $500 of this going toward plants.

Results

Resident reviews have been favorable (an important factor in ongoing success of the gardens), and the monitoring data indicates excellent results.

2004 monitoring data showed that the rain gardens achieved an 80 percent reduction in runoff volume in 49 rain events. Most basins drained dry within 3 to 4 hours. During winter, some ice build-up was evident, but as the melt infiltrated, ice collapsed and disappeared with no adverse effects.

Future actions

Photo illustrating a completed rain garden.

The Dakota County Soil and Water Conservation District conducted runoff audits on each lot in the study neighborhood to provide homeowners with additional suggestions on reducing runoff from their properties, such as redirecting downspouts, installing rain barrels to capture roof runoff and aerating lawns to enhance infiltration.

Another effort to benefit Crystal Lake, a single infiltration basin in West Buck Hill Park, was installed in fall 2004. It accepts runoff from a 25-acre sub-watershed.

The Burnsville rain garden project area and control neighborhood are being monitored through 2005. While the success of the project recommends installing more rain gardens elsewhere in the city, the project coordinator has departed, so it is unclear whether additional gardens will be built in the near future.

Links

- Barr report (http://www.ci.burnsville.mn.us/DocumentCenter/Home/View/449)
- Fact sheet (http://www.burnsville.org/DocumentCenter/Home/View/450)
- City of Burnsville (http://www.burnsville.org/index.aspx?NID=594)
- [1] (http://www.landandwater.com/features/vol48no5/vol48no5_2.html)

Case studies for stormwater and rainwater harvest and use/reuse

This page provides general information

Green Infrastructure: Stormwater and rainwater harvest and use systems can improve or maintain watershed hydrology, reduce pollutant loading to receiving waters, increase water conservation, reduce stress on existing infrastructure, and reduce energy consumption

Cottage Grove City Hall

- **Location:** Cottage Grove, MN
- **Owner:** City of Cottage Grove
- **Designer**: Wold Architects (City Hall), SkyHarvester (reuse system)
- **Year of Completion**: 2012
- **Total Drainage Area**: 0.9 acres of rooftop
- **Total Construction Cost**: $120,000
- **Pretreatment/Methods of Filtration**: Rainwater filter (screen to remove large particles leaves, debris, and sediment), Fine filter (filter fine particles, down to 5 microns), UV Treatment (provides microbial disinfection)
- **Documented Maintenance Practices**: Replacement of filter media and UV bulbs as needed, general winterization of irrigation system
- **Pollutant Removal**: Runoff volume control approximately 1.8 acre-feet (570,000 gallons) per year. MIDS calculator estimates pollutant reductions of approximately 1.5 pounds of phosphorus (0.85 pounds particulate phosphorus and 0.70 pounds dissolved phosphorus), and 282 pounds total suspended solids per year.
- **Is the site publicly accessible**: Yes, an interpretive sign is on the rear patio of City Hall for public viewing.
- **Special Design Features**: Rainwater Harvester Control Panel to regulate operation of systems, Irrigate planting beds on 7-acre site, education signage about system

In 2012 the City of Cottage Grove completed construction of the new City Hall and Public Safety complex, designed by Wold Architects. The building is situated in a growing part of the community, directly adjacent to Cottage Grove Ravine Regional Park, a natural resource and recreation amenity area which features unique habitat and a beloved fishing lake. In an effort to reduce water use and impacts on stormwater runoff, the building design incorporates a stormwater harvester system. The harvester reuses stormwater collected from the building's roof for irrigation of the green space around the building and the Veterans Memorial fountain located at the building entrance. This system collects runoff from the 0.9 acre roof and stores it in an underground storage tank. From the storage tank, the water is filtered and treated with ultraviolet light then pumped through the irrigation system for use on the 7-acre City Hall grounds, and at the fountain. The purpose of the system is to provide the dual benefits of reducing the use of groundwater for landscape irrigation and minimizing stormwater runoff to Ravine Lake.

Click on an image for enlarged view.

Photo of Cottage Grove City Hall building. Image courtesy Emmons and Olivier Resources.

Photo of signage at Cottage Grove harvest and use system. Image courtesy Emmons and Olivier Resources.

Photo of tank for harvest and use system. Image courtesy City of Cottage Grove.

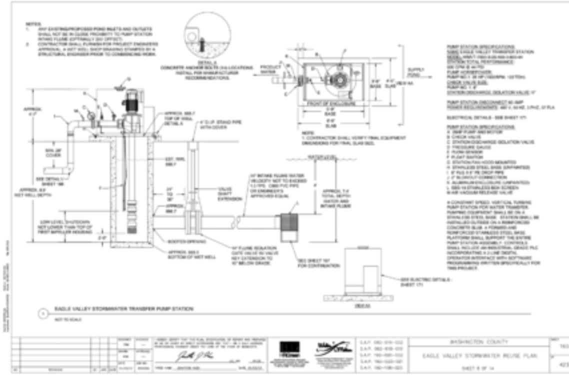
Photo of tank for harvest and use system. Image courtesy City of Cottage Grove.

Eagle Valley and Prestwick Golf Club, Woodbury

- **Location**: Woodbury, MN
- **Owner**: City of Woodbury/Prestwick Golf Club Inc
- **Designer**: HR Green, Water in Motion
- **Year of Completion**: 2014
- **Design Features**:
    - Eagle Valley - large storage pond and babbling brook landscape feature for holding and moving stormwater runoff and reuse
    - Prestwick – creation of one large storage pond from two smaller ponds for holding and moving stormwater runoff for irrigation reuse
- **Total Drainage Area**: 430 acres (Eagle Valley), 130 acres (Prestwick)
- **Total Construction Cost**: $700,000.00 (funding from South Washington Watershed District/Clean Water Fund)
- **Pretreatment**: screen filter on intake pump
- **Documented Maintenance Practices**: winterize irrigation system each year, clean pump screen if it gets clogged (has not been needed during first three years of operation)
- **Pollutant Removal**: 99 lbs phosphorus per year, and 9.6 Acre/ft per event volume reduction
- **Is the site publicly accessible**: Yes

Plan for the harvest system showing storage and transport components. Image courtesy Emmons and Olivier Resources, HR Green and Water in Motion.

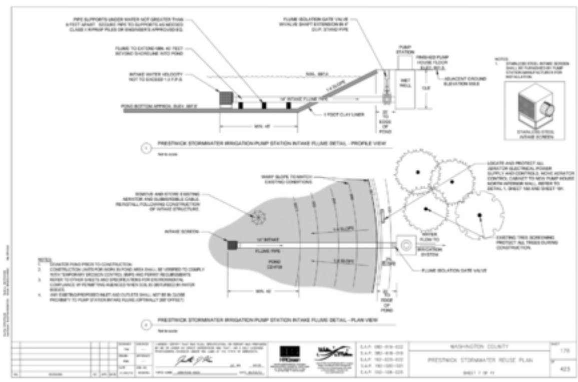
Project Background



Eagle Valley Stormwater Transfer Pump Station detail. Image courtesy HR Green and Water in Motion.

In 2014, the City of Woodbury, with funding from the South Washington Watershed District, constructed stormwater reuse for irrigation systems at Eagle Valley and Prestwick golf clubs. Each system collects runoff from a large drainage area containing roads, housing developments, and a golf course and stores it in a centralized pond. A pump then draws water from the pond for use in golf course irrigation. The total cost of both projects was $700,000.00. The catalyst for the projects was the planned reconstruction of CSAH 19 (Woodbury Drive), changing it from a rural 2-lane road to an urban 4-lane road. The goals for the project were to have no measurable downstream stormwater impacts from the road reconstruction project, and to help achieve Colby Lake's target TMDL standard to reduce phosphorus (TP) inputs by 30 lbs per year.

Eagle Valley Golf Course



Irrigation pump station intake flume detail. Image courtesy HR Green and Water in Motion.

Prior to the reuse for irrigation project Eagle Valley Golf Course pumped 30 million gallons of well water annually to irrigate approximately 60 acres of golf course turf and landscaping. This project collects stormwater runoff from a 430 acre drainage area covering the golf course, surrounding neighborhoods, and Woodbury Drive into a storage pond on the course. The drainage area is 33.8% impervious. The reuse system can pump approximately 22.5 million gallons of stormwater for irrigation from the pond annually. The remainder of irrigation water that is needed will be supplied by the existing well. Stored water can also be routed through a babbling brook landscape feature on the golf course. The P8 modeled water quality benefits of the project at Eagle Valley were reductions in TP to Colby Lake of 56 lbs per year, and a volume reduction of 6.1 acre/ft per event.

Prestwick Golf Club

Prestwick golf club regularly irrigates up to 75 acres of turf and landscaping. Previously, course managers pumped 35 million gallons of water annually from a course well to accomplish this. The stormwater reuse system which was installed in 2014 can now supply approximately 17.5 million gallons of water from the storage pond annually. The 130 acre drainage area for the pond is 27% impervious. The remainder of irrigation water that is needed will be supplied by the existing well. The P8 modeled water quality benefits of the project at Prestwick were reductions in TP of 43 lbs per year, and a volume reduction of 3.5 acre/ft per event.

Conclusion

The City of Woodbury far exceeded their goals for water quality and volume reduction with the implementation of these two reuse projects at Prestwick and Eagle Valley. In total the projects reduce TP loading to local lakes by almost 100 lbs per year, and also reduces volume by 9.6 acre/ft for each event. The goals were 35 lbs of TP per year, and 1.84 acre/feet per event. In addition, both projects combine to reduce pumping from local aquifers by 40 million gallons annually by utilizing surface storage features (ponds) that add beauty and challenge to both golf courses.

Click on an image for enlarged view.

Photo of creek used to move stored water within the irrigation system. Image courtesy Emmons and Olivier Resources.

Photo of storage pond used for irrigation. Image courtesy Emmons and Olivier Resources.

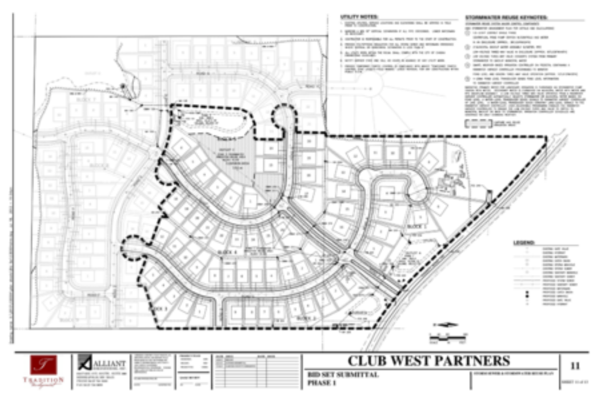
Sign for Eagle Valley Golf Course, with storage pond in the background. Image courtesy Emmons and Olivier Resources.

Photo of pump box for harvest and use system. Image courtesy City of Woodbury.

Photo of pump for harvest and use system. Image courtesy City of Woodbury.

Carver County Club West Development

- **Location**: Harvest Estates, Chaska, MN
- **Project Owner**: Club West Partners LLC
- **Project Designer**: Alliant Engineering
- **Year of Completion**: 2015
- **Design Features**:
  - Gallons used for irrigation annually: Permitted for 22.2 million gallons
  - Use for water: Irrigation of Lawn in Park, Boulevard Plantings and Flower Beds
  - Rainwater Harvester Control Panel: Regulates operation of irrigation systems
- **Total Drainage Area**:
  - Pond 1 = 28 acres
  - Pond 3 = 25 acres
- **Drainage Area Surface Type**: Residential (roads, driveways, turf, etc.)
- **Pond Size**:
  - Pond 1 = 18,600 sq ft
  - Pond 3 = 22,413 sq ft Irrigated area
  - Pond 1: 30,807 square feet



Carver County Club West storm sewer reuse plan. Image courtesy Alliant Engineering.

    - Pond 3: 42,267 square feet
- **Cost Savings Per Year**: $3,000 on irrigation water (compared to City potable water rates)
- **Pretreatment**: NURP pond and screen filter in intake pump
- **Methods of Filtration**: Filter Screens
- **Documented Maintenance Practices**: winterize irrigation system each year, clean clogged pump screen (annual startups and blow outs)
- **Pollutant Removal**: 4.37 lb TP and 1,503 lb TSS per year
- **Is the site publicly accessible**? Yes - Park and boulevards are central features to the neighborhood. With the systems in close proximity to the neighborhood and park entrances, awareness of the system is heightened.

Rainwater harvest components. Images courtesy Alliant Engineering.

Club West Partners, the developer of Harvest Estates, worked with the Carver County Watershed Management Organization (CCWMO) to implement a stormwater harvest and use system that would meet stormwater, TP, and TSS reduction requirements (90% TSS and TP reduction, per CCWMO rules) for that subwatershed. Designed by Alliant Engineering, the harvest and use project utilizes stormwater runoff draining from a new development, Harvest Estates, for irrigation of common areas within the development. The site is located in southwest Chaska, MN, in close proximity to the Minnesota River, where population growth trends continue to encroach on undeveloped areas of the watershed. This project is one of five sites in Carver County where stormwater is being used to irrigate green space in order to mitigate the impacts of population growth on groundwater withdrawals.

At Harvest Estates, stormwater is collected into three stormwater ponds. Two intake pumps draw the stormwater from two of the three ponds to irrigate a central park and boulevard at the entrance of the development. By incorporating the harvest and use system into the construction of the new development, overall stormwater runoff impacts are partially mitigated and use of potable water for irrigation is reduced. Up to 22.2 million gallons of harvested stormwater can be used to irrigate the park and boulevards. The project goal is to harvest and use up to 12,500 cubic feet of stormwater per week, or equivalent to a depth of ½”of stormwater over the surface area of the new impervious paving in the development (18.8 acres total). The harvest and use system uses a 1.5-2.0 HP centrifugal stormwater pump, which is then transferred and managed through irrigation controller pedestals that allow for the efficient harvest and use of stormwater. The system reduces the need to pump irrigation water from conventional sources, with a bypass switch for municipal water only in cases of decreased rainfall. Harvested stormwater pumped from the two ponds goes through a filter system to remove sediment prior to irrigation uses. The modeled water quality benefits of the project are TP reductions up to 4.37 lb per year and TSS reductions up to 1,503 lb per year. To date, roughly 1.5 million gallons of stormwater have irrigated the site through the harvest and use system, with an overall cost savings of $3,000 each year due to the decreased use of potable water.

Click on an image for enlarged view.

Photo of Carver County site. Image courtesy DR Horton Homes.

Photo of irrigated area. Image courtesy Emmons and Olivier Resources.

Photo of irrigated area. Image courtesy City of Cottage Grove.

Mississippi Watershed Management Organization (MWMO)

Cistern located at Mississippi Watershed Management Organization. Photo by MWMO Staff. To enlarge, click on image.

Name of Project: Mississippi Watershed Management Organization (MWMO)
Type of Reuse System: Cistern
Overview: The cistern, located at the MWMO, utilizes rooftop runoff from the main office area roof to water trees in a trench system.
Location: Mississippi Watershed Management Organization, 2522 Marshall Street NE, Minneapolis 55418
Owners: Mississippi Watershed Management Organization
Contractors: Meisinger Construction-general contractor for facility construction
Operators: Mississippi Watershed Management Organization
Cost (*additional plumbing would be needed if plumbed into the building to be used as grey water*):

- Concrete Slab - $5,200
- Cistern (including piping) – $23,700
- Rain Leader- $8,400

Type and size of system: 4,000 gallon capacity CorGal Water Tank, volume annual dependent on rainfall, filled by roof runoff only
Year of Completion: 2012
Drivers/Stormwater Goals: To water trees, reduce stormwater runoff that reaches the river, infiltrate rainwater. Future use as grey water in facility.

Funding sources: Public – MWMO funding
Monitoring: Total Suspended Solids, VSS, bacteria, once every 3 months
Web links: http://mwmo.org/
Lessons Learned: Design flaws – the plumbing was not correct and all the water drained out, the rain leader diverter operation was not intuitive. Additionally plumbing code hindered process of connecting to facility to be used as grey water. Staff opted to do this at a later time once plumbing codes were updated and other projects set precedence.
For more information contact:

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Cistern located at Mississippi Watershed Management Organization. Photo by MWMO Staff. To enlarge,click on image.

Home NPS BMPs: Reducing Nonpoint Source Pollution at Home

Nonpoint source (NPS) pollution is the leading cause of water quality problems in the U.S.. It's caused by pollutants carried by rainfall or irrigation runoff, which can come from various sources like agricultural runoff, urban streets, and construction sites.

Homeowners can significantly contribute to preventing NPS pollution by implementing Best Management Practices (BMPs) around their homes.

Here are some key NPS BMPs homeowners can use:

1. Managing Runoff:
    - Direct downspouts: Divert roof runoff onto grassed areas or into rain barrels instead of paved surfaces or storm sewers.
    - Install rain gardens or permeable pavement: These features help infiltrate stormwater into the ground, reducing runoff and promoting groundwater recharge.
    - Reduce impervious surfaces: Limit concrete and asphalt walkways and driveways. Consider using alternatives like gravel, stone, or permeable pavers.
    - Plant trees and native vegetation: Trees and native plants help slow down runoff, absorb excess water, and filter pollutants.

2. Smart Lawn and Garden Care:
    - Fertilize and apply pesticides sparingly: Use these chemicals only when necessary and follow recommended application rates. Avoid applying them before rain events.
    - Choose drought-resistant and native plants: These plants require less water, fertilizer, and pesticides, reducing environmental impact.
    - Compost yard waste: Recycling grass clippings and leaves through composting reduces fertilizer needs and keeps waste out of storm drains.
    - Mow properly: Follow recommended mowing heights and avoid excessive watering.
    - Control soil erosion: Plant ground cover and stabilize erosion-prone areas to prevent soil runoff.

3. Responsible Waste Management:
    - Dispose of hazardous materials properly: Never pour oil, antifreeze, paint, or other household chemicals down storm drains or into the trash. Utilize local hazardous waste collection programs.
    - Clean up spills: Absorb spills of fluids like oil and grease with absorbent material and dispose of it properly.
    - Manage pet waste: Promptly clean up pet waste to prevent it from washing into storm drains and contaminating waterways.
    - Maintain septic systems: If you have a septic system, have it inspected and pumped regularly to ensure proper function and prevent pollution.

4. Vehicle Care:
    - Wash cars on pervious surfaces: Use a commercial car wash or wash your car on a lawn to prevent soapy water from entering storm drains.

- Address leaks promptly: Repair any leaks from your vehicle to prevent fluids from entering the storm drain system.
- Recycle used automotive fluids: Dispose of used oil and other fluids at designated recycling stations.

By implementing these simple BMPs, homeowners can make a significant difference in protecting water quality and reducing NPS pollution.

Steps to help control NPS pollution

Summarized from: https://www.mdeq.ms.gov/water/surface-water/nonpoint-source-pollution-program/steps-tohelp-control-nps-pollution/

• Collect litter and animal waste before they wash into storm drains.

• Apply fertilizer at the recommended rate when heavy rain isn't likely to wash it away.

• Recycle grass clippings and leaves by mulching or composting. If you can't compost, collect and dispose of yard waste according to local provisions. Do not put in storm drain.

• If you change your own oil, take the used oil to a recycling station. Check with your local service stations for such facilities. Never dump oil into a storm drain.

• Home septic tanks should be located, constructed and installed according to regulations. Maintenance and prompt correction of problems are important.

• Direct roof runoff onto a grassed area. Roof drains should not be connected to a sanitary or storm sewer system.

• Watch for soil erosion around your home. Seed, install sod or plant ground cover to protect the site.

• Use porous surfaces such as flagstone, gravel, stone, and interlocking pavers rather than concrete and asphalt.

• If you're concerned about the effects of runoff leaving a nearby construction site, contact the local governing body responsible for erosion and sediment control in your area.

• Be active! Join a civic or environmental group and participate in stream cleanup activities. Give talks, man booths, join the Adopt-A-Stream Program… spread the word.

You couldn't live long without clean water. Nothing can. Do your part to protect our waters.