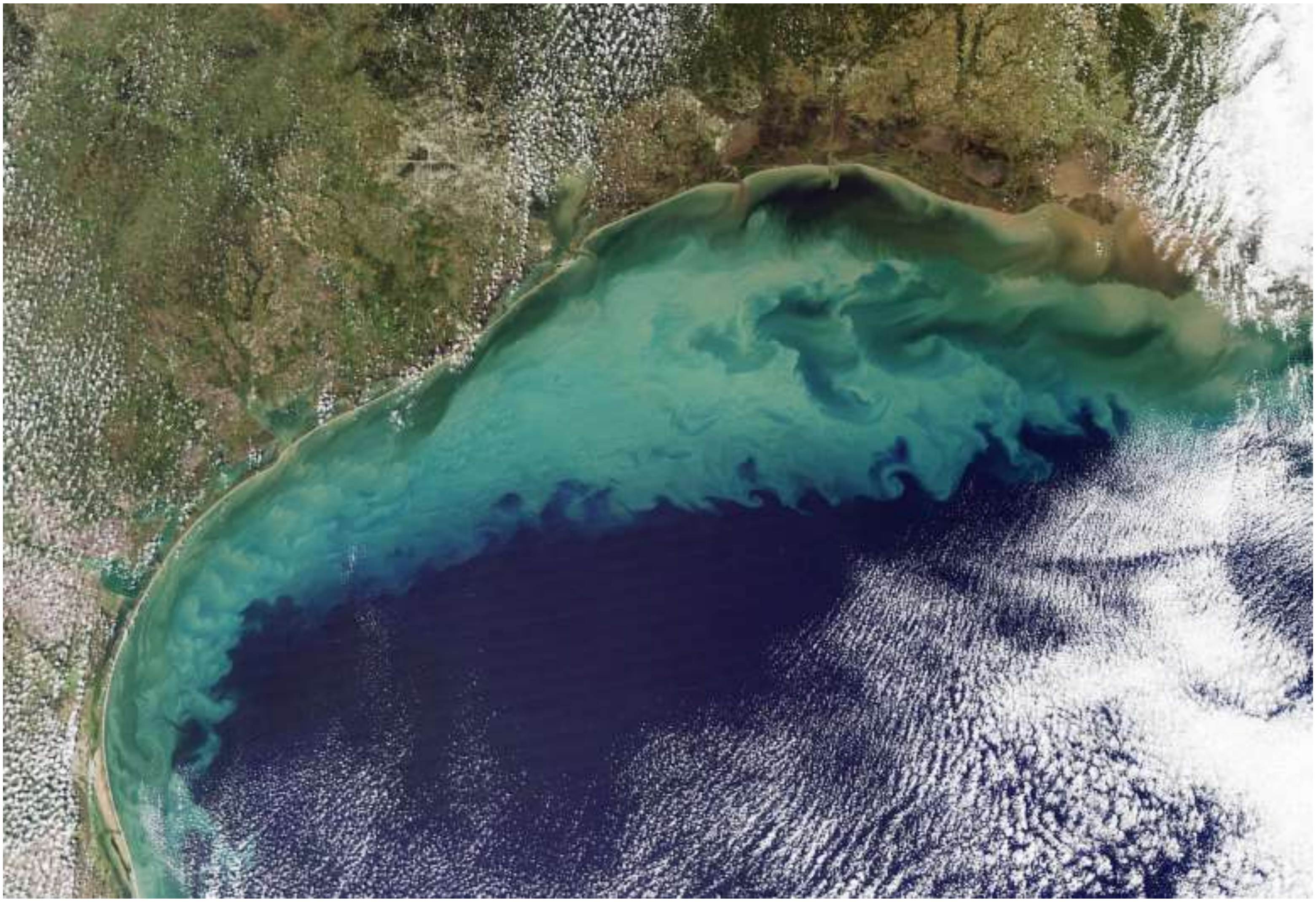

NONPOINT SOURCE WATER CONTAMINATION

From the *Technology and Environmental Decision-Making* Series

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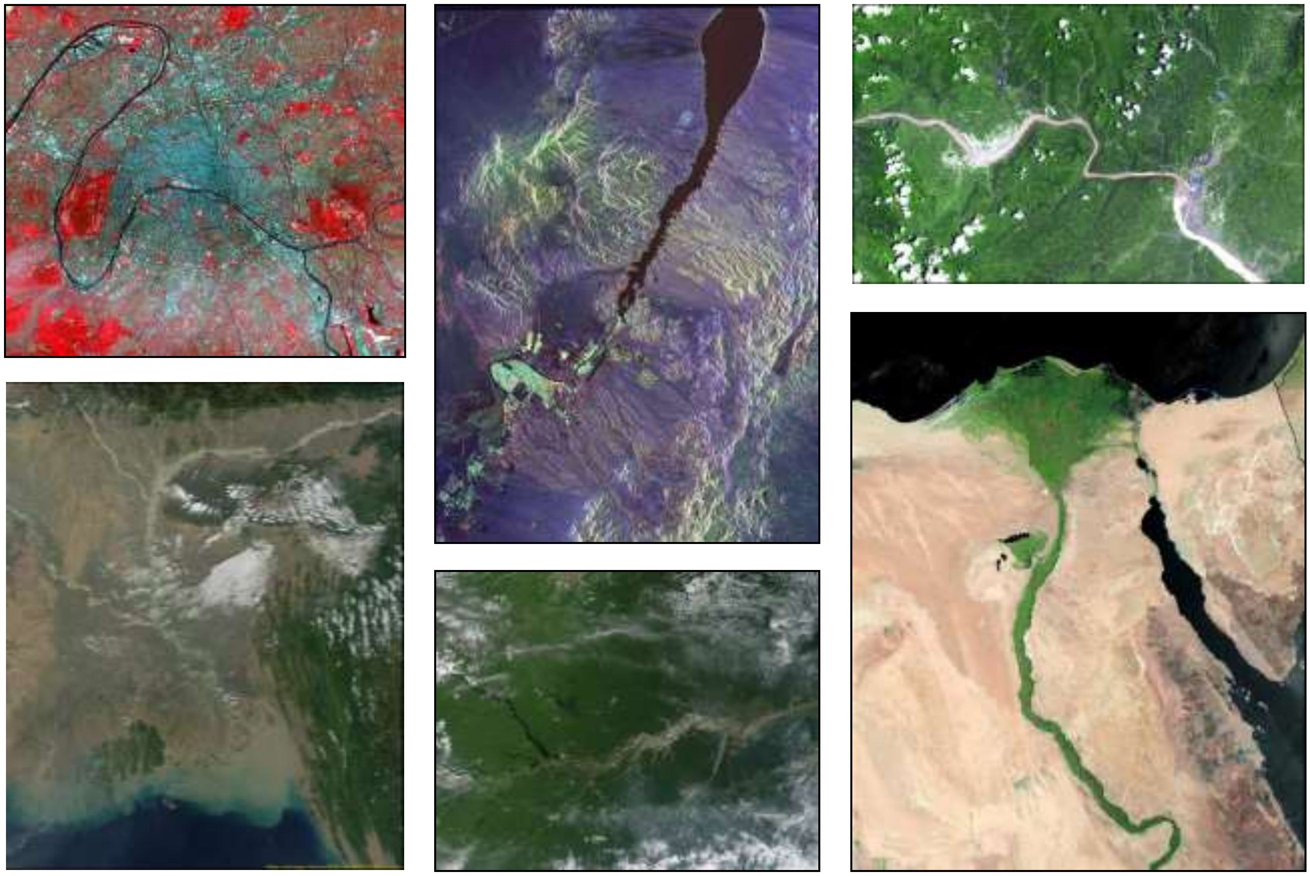
Nonpoint Source Water Contamination



Rivers of the world (clockwise from top left): Seine, Colorado, Yangtze, Ganges, Amazon, and Nile.
Credit: NASA

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Introduction

Credit: NASA

> "Aldo Leopold, a great environmentalist and an eloquent writer, borrowed a metaphor from one of the tall tales about the mythical lumberjack, Paul Bunyan. This was the "**Round River**" of early Wisconsin, the river that flowed around, ceaselessly, into itself.
>
> "Aldo Leopold extended the meaning of the Round River to the "never-ending circuit" of energy through life and the environment.
>
> "That imaginative notion is evocative today, because it neatly conveys the central thesis of **how we need to view water on a planetary scale**."
>
> Dr. Rita R. Colwell, former Director of the National Science Foundation in *Abel Wolman Distinguished Lecture speech*

Thirsty? Turn on a faucet or twist the lid from a bottle nearly anywhere in the United States. Most of us take it for granted that water is there when we need it or want it. But will it always be? And will it be clean? What is clean? How clean is clean enough? If it's not clean enough, then what?

If we accomplish the monumental task of answering these questions to our own satisfaction, then we will have necessarily learned that the quality of our local water supplies is inextricably linked to the quality of regional and even global water supply systems—that we're all living next to Aldo Leopold's "Round River."

Particularly in industrialized societies, we are constantly exposed to the evidence of the interconnectedness of our ***human*** systems—evidence that is manifested daily through information technology, politics, and economic activity. And more than ever before, the global interaction and interdependence of ***natural*** systems are being studied and recognized in the scientific community.

For example, the past few decades have seen an increase in worldwide concern and research activity on long-term climate change. Scientific consensus is overwhelming that human activity has had and continues to have negative impacts on the global environment. The *Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report* concludes, with 95 percent certainty, that **"the human influence on the climate system is clear and is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system."**[1] (For more in-depth discussion of climate change, see "Climate Change" in this *Technology and Environmental Decision-Making* series of modules.)

"If you're ever stuck out in the wilderness, remember what survival experts call 'the Rule of Threes.' You can live 3 minutes without air.... In a harsh environment...you have 3 hours to survive without shelter. You can make it 3 weeks without food. **After 3 days, you need water or you'll perish.**

How Long Can a Person Survive Without Water? at LiveScience.com

The United Nations' "Climate Change 2014: Impacts, Adaptation, and Vulnerability" report addresses the potentially serious ramifications of climate change and socioeconomic processes. It emphasizes to us all the interconnectedness of the world's natural systems. Although technological advances allow much of the world to concentrate more and more on quality of life, rather than mere subsistence, addressing a decline in food and water resources will soon become an immediate global priority. And due to current energy concerns, the interdependence of energy and water systems is a priority now.

Cities spend up to 20 percent of their electricity just to pump, purify, and recycle their water. **That means wasting water is pouring energy down the drain.**

Switch Energy Film and Education Project

Demands on Freshwater Systems

Credit: Dan Macy

The energy-water nexus is one way to view the growing demand on freshwater systems and its interconnection with other natural and human systems. A specific example of water demand and its direct effects on climate change is reflected in the operation of the Navajo Generating Station in Arizona and its withdrawals from the Colorado River.

"The power generated enables a modern wonder. It drives a set of pumps 325 miles down the Colorado River that heave trillions of gallons of water out of the river and send it shooting over mountains and through canals. That water—lifted 3,000 vertical feet and carried 336 miles—has enabled the cities of Phoenix and Tucson to rapidly expand.

"This achievement in moving water, however, is gained at an enormous cost. Every hour the Navajo's generators spin, the plant spews more climate-warming gases into the atmosphere than almost any other single facility in the United States. Alone, it accounts for 29 percent of Arizona's emissions from energy generation. The Navajo station's infernos gobble 15 tons of coal each minute, 24 hours each day, every day."

Abrahm Lustgarten,
Scientific American/ProPublica

The World Health Organization provides some critical key facts about drinking water on a global scale.

- In 2015, 91 percent of the world's population had access to an improved drinking-water source, compared with 76 percent in 1990.
- 2.6 billion people have gained access to an improved drinking-water source since 1990.
- 4.2 billion people now get water through a piped connection; 2.4 billion access water through other improved sources including public taps, protected wells, and boreholes.
- 663 million people rely on unimproved sources, including 159 million dependent on surface water.
- Globally, at least 1.8 billion people use a drinking-water source contaminated with feces.
- Contaminated water can transmit diseases such diarrhea, cholera, dysentery, typhoid, and polio. Contaminated drinking-water is estimated to cause 502 000 diarrheal deaths each year.
- By 2025, half of the world's population will be living in water-stressed areas.
- In low- and middle-income countries, 38 percent of health care facilities lack any water source, 19 percent do not have improved sanitation, and 35 percent lack water and soap for handwashing.[2]

Decisions must be made to ensure healthy water, but few people understand fully the ramifications of polluted water. No one will argue with the fact that humans need clean drinking water to survive. But beyond drinking water, what other effect does polluted water have in our lives?

> "Water is your body's principal chemical component and makes up about 60 percent of your body weight. Every system in your body depends on water. For example, water flushes toxins out of vital organs, carries nutrients to your cells, and provides a moist environment for ear, nose and throat tissues."
>
> MayoClinic.com

To better analyze this issue, we must first understand that there are two overarching sources of water contamination—point and nonpoint sources. Point sources (PS) are generally considered to be fairly localized, identifiable sources of contamination, whereas nonpoint source (NPS) contamination is dispersed from a very broad area or combination of areas, and often from a combination of sources. In this series of modules, "Point Source Water Contamination" discusses PS pollution in detail.

Leading Sources of Impairment to Freshwater Quality			
Rank	**Rivers**	**Lakes**	**Wetlands**
1	Agriculture	Atmospheric deposition	Agriculture
2	Atmospheric deposition	Agriculture	Atmospheric deposition
3	Hydromodification (stream/habitat changes)	Natural/wildlife	Industrial

Source: U.S. EPA, National Summary of Probable Sources of Impairments in Assessed Rivers and Streams

As noted in the above table, agriculture has been identified as one of the leading sources of impairment to the quality of the nation's freshwater. This module explores the interconnectivity of surface water systems and the resulting relationship specific to a human system of agriculture and NPS contamination. This module presents a case study illustrating the NPS contamination of the northern Gulf of Mexico, also known as the "Dead Zone." This area has been afflicted with hypoxia, which is believed to have been greatly exacerbated by surface runoff of chemicals into the Mississippi River and eventually into the Gulf.

Credit: U.S. EPA

Each section in the module provides the instructor with a brief summary of the different issues that affect the module topic, with links throughout to the case study and other modules in this series. At the end of each issue discussion is a link to this module's Aids to Understanding section, which provides in-depth resources on that issue.

Contaminant Formation and Environmental Impact

This section provides the instructor with a brief review of the facts—the basic science—involved in agricultural nonpoint source (NPS) contamination of surface waters.

Overview

A variety of human activities (stemming from agricultural, industrial, community, and residential needs), as well as natural processes, can contaminate water. Sources of contamination are referred to as point or nonpoint sources. Point sources are generally considered to be fairly localized, identifiable sources of contamination, whereas nonpoint source (NPS) contamination is dispersed from a very broad area or combination of areas, and often from a combination of sources. To learn more about point source water contamination, refer to "Point Source Water Contamination" in this *Technology and Environmental Decision-Making* series of modules.

Nonpoint sources of agricultural contamination include the use and storage of fertilizers and pesticides, and the disposal of animal and agricultural waste. Contaminants enter the water from improper processes for the storage, handling, and transporting of materials, and from the improper use of surface impoundments to store, treat, and dispose of wastewater and liquid wastes. Mining operations, leaking underground storage tanks (LUSTs), and improperly managed hazardous waste sites are also significant sources of water contamination.[3]

Community and residential waste disposal, including septic systems and improper storage and disposal of chemicals in our homes, also contributes to water contamination. A major cause of ground water contamination comes from residential effluent, or outflow from septic tanks and cesspools. Finally, natural substances found in rocks or soils (such as arsenic, iron, manganese, chloride, fluoride, and sulfate) can become dissolved in and contaminate water.[4]

For details on water quality-based assessment and integrated analysis of point and nonpoint sources, refer to "Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)."

Nonpoint Source Contamination

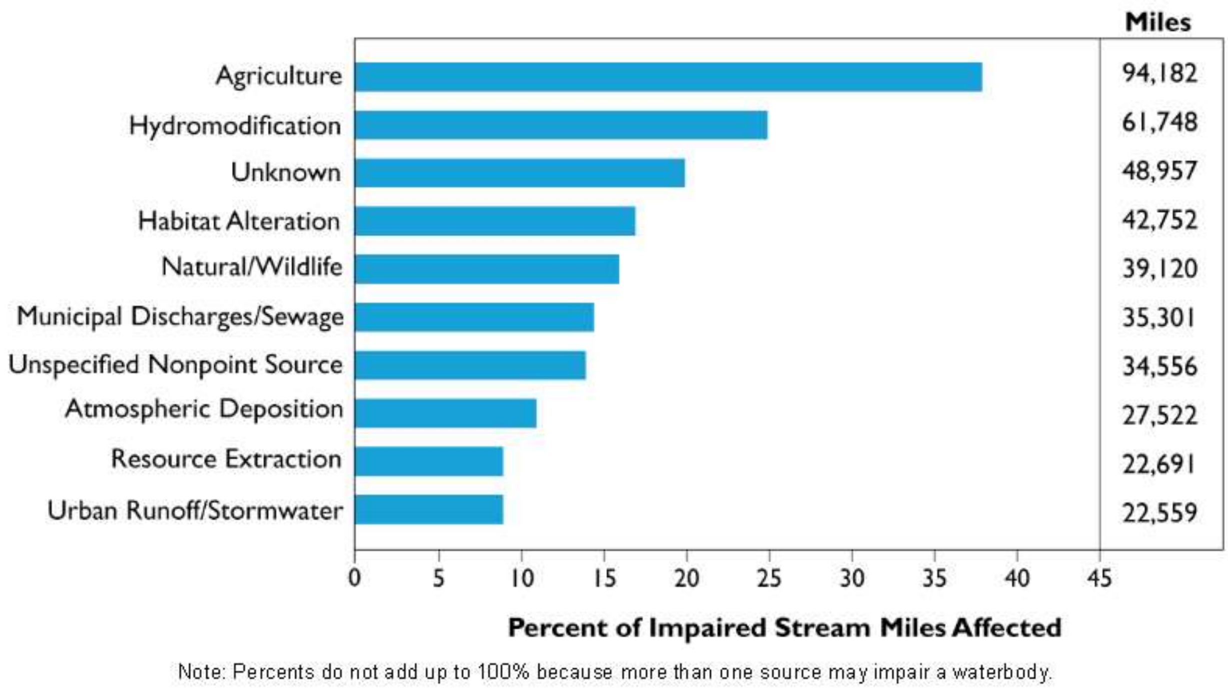
The United States has made advances in the past 40 years to clean up the aquatic environment by controlling contamination from industries and sewage treatment plants (point sources). Unfortunately, not enough has been done to control contamination from diffuse, or nonpoint, sources. Today, NPS contamination remains the nation's largest source of water quality problems. It is the main reason that **approximately 40 percent of surveyed U.S. rivers, lakes, and estuaries are not clean enough to meet basic uses such as fishing or swimming**.[5]

NPS contamination of water occurs when rainfall, snowmelt, or irrigation runs over land or through the ground, picks up contaminants, and deposits them into rivers, lakes, and coastal waters or introduces them into ground water. Imagine the path taken by a drop of rain from the time it hits the ground to when it reaches a river, ground water, or the ocean. Any contaminant it picks up on its journey can become part of the NPS problem (e.g., motor oil from a parking lot or the pesticide from a tomato plant). NPS contamination also causes adverse changes to the vegetation, shape, and flow of streams and other aquatic systems.[6]

NPS contamination is widespread because it can occur whenever any activity disturbs the land or water. Agriculture, forestry, grazing, septic systems, recreational boating, urban runoff, construction, physical changes to stream channels, and habitat degradation are all potential sources of NPS contamination. Careless or uninformed household management also contributes to NPS contamination problems.[7]

Credit: NOAA

The National Water Quality Assessment shows that agricultural NPS contamination is the leading source of water quality impacts on surveyed rivers, streams, and wetlands, and the second largest source of impairments to lakes.[8] (See table below.)



Source: U.S. EPA, National Summary of Probable Sources of Impairments in Assessed Rivers and Streams

The National Water Quality Inventory Report to Congress (305(b) report) and the Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) database are the primary vehicles for informing Congress and the public about general water quality conditions in the United States. Together, this report and database characterize our water quality and identify widespread water quality problems of national significance. The most current, regularly updated state water quality information is available in the ATTAINS database.

The most common NPS contaminants are sediment and nutrients. These wash into water bodies from agricultural land, small and medium-sized animal feeding operations, construction sites, and other areas of disturbance. Nitrogen and phosphorus are the nutrients of greatest concern. Other NPS contaminants of note include:

- pesticides.
- pathogens (bacteria and viruses).
- salts.
- oil.
- grease.
- toxic chemicals.
- heavy metals.
- dissolved oxygen and lack of oxygen.
- Pharmaceuticals.

For examples of an urban problem with excess phosphorus, refer to the USGS' Phosphorus and Water.

For an example of a major NPS contamination problem, refer to the case study on the Gulf of Mexico's dead zone in this module.

For more information on:

- nitrogen and phosphorus in U.S. waters, refer to Nutrients in the Nation's Waters—Too Much of a Good Thing? from the USGS.
- the use of nutrients in agriculture, refer to Iowa Nutrient Reduction Strategy at Iowa State University and Nutrient Recovery Technologies from USDA.
- types of NPS contamination, refer to NPS Categories from the U.S. EPA.

Nutrients in Agriculture

Readily available nutrients are essential for plant growth in crop production. The proper management of all nutrient sources (including commercial fertilizer, compost, and manure) within the constraints of farm production systems and operational goals is prerequisite for both profitable crop production and environmental sustainability.[9]

> In a statewide survey of producers conducted in Iowa, 75 percent of farmers reported that they consult with professional advisers to some degree for fertilizer program development.
>
> *2014 Iowa Farm and Rural Life Poll, Iowa State University Extension*

Inappropriate management, however, can lead to reduced economic return and potential environmental degradation of surface and ground water. The environmental consequences are especially pertinent to nitrogen (N) and phosphorus (P). Nitrogen is of particular concern in agriculture, while phosphorus is usually more of a problem near urban areas.[10]

When applied in excess of plant needs, nutrients can wash into aquatic ecosystems where they can cause excessive plant growth. This can reduce swimming and boating opportunities, create a bad taste and odor in drinking water, and kill fish. In drinking water, high concentrations of nitrate can cause methemoglobinemia, a potentially fatal disease in infants also known as blue baby syndrome. Nutrient management plans and precision farming can be implemented to help maintain high crop yields and save money on the use of fertilizers while reducing NPS pollution.[11]

Nitrogen

Nitrogen is a nutrient needed for plant growth in the forms of nitrate, nitrite, or ammonium. Agricultural runoff contributes excess nitrogen to contamination of water in streams, lakes, and estuaries. This excess nitrogen from fertilizers is rapidly converted to nitrate (NO_3^-) in the soil, where it can run off directly into surface waters. Nitrate can also leach into ground water and reappear in the water that feeds lakes and streams.[12]

All forms of nitrogen rapidly convert to nitrate in soil. Nitrogen may also volatilize directly into the atmosphere as ammonia (NH_3). The ammonia is then deposited into the surface waters through precipitation. Nitrogen can also be denitrified to atmospheric gas (N_2).[13]

Denitrification is the conversion of nitrates (NO_3^-), to nitrites (NO_2^-), to nitrous oxide (N_2O), and finally to nitrogen gas (N_2), which is lost to the atmosphere. This nitrogen gas itself is not a pollutant, but the byproducts of denitrification (e.g., the nitrous oxide, which is also a greenhouse gas) negatively affect the ozone layer.[14]

Denitrification:

Nitrogen (N) → Nitrate (NO_3^-) → Nitrite (NO_2^-) →

Nitrous oxide (N_2O) → Nitrogen gas (N_2) → atmosphere

In animal production systems, the surface runoff contains nitrogen in the forms of ammonium (NH_4^+) and nitrate; and phosphorus as phosphate (PO_4^{3-}); in addition to bacteria.[15]

Excess nitrogen can cause overstimulation of growth of aquatic plants and algae. Excessive growth of these organisms, in turn, can clog water intakes, use up dissolved oxygen during decomposition, and block light to deeper waters. This process can fatally affect the respiration of fish and aquatic invertebrates, leading to a decrease in animal and plant diversity, and affects human use of the water for fishing, swimming, and boating. Too much nitrate in drinking water can be harmful to infants or young livestock.[16]

For more information on the health effects of nitrate and nitrite in drinking water, refer to EPA's Contaminants and Standards.

For details on the effects of excess nitrogen in an aquatic environment, refer to the Gulf of Mexico's dead zone case study in this module.

Animal Waste

By confining animals to areas or lots, farmers and ranchers can more efficiently feed and maintain livestock. But these confined areas become major sources of animal waste. Runoff from poorly managed facilities can carry pathogens (bacteria and viruses), nutrients, and oxygen-demanding substances that contaminate shellfishing areas and create other major water quality problems. Ground water can also be contaminated by seepage. Discharges can be limited by storing and managing facility wastewater and runoff with an appropriate waste management system.[17]

Sediment

Sedimentation occurs when wind or water runoff carries soil particles from an area, such as a farm field, and transports them to a water body, such as a stream or lake. Excessive sedimentation clouds the water, which reduces the amount of sunlight reaching aquatic plants, covers fish spawning areas and food supplies, and clogs the gills of fish. In addition, other pollutants such as nitrogen, phosphorus, pathogens, and heavy metals are often attached to the soil particles and wind up in the water bodies with the sediment.[18]

Pesticides

Pesticides, herbicides, and fungicides are used to kill pests and control the growth of weeds and fungi. These chemicals can enter and contaminate water through direct application, runoff, wind transport, and atmospheric deposition. They can kill fish and wildlife, poison food sources, and destroy the habitat that animals use for protective cover.[19]

The USDA has more information on:

- Animal Waste Management.
- Erosion.
- Nutrient and Pest Management.

Aids to Understanding provides resources and activities.

Fate and Transport

Introduction

The phrase "fate and transport" is often used in the multidisciplinary fields of earth and environmental science. The study of fate and transport involves math (usually calculus), geology, hydrology, chemistry, engineering, and biology. The phrase usually refers to chemicals in the environment and, in particular, to contaminants. The properties of the chemical, and the media (air, water, and/or soil) in which the chemical exists, are studied.[20]

Contaminant fate and transport are relatively easy to observe and study in surface waters, as opposed to ground water or air. Nonpoint source (NPS) contaminants, however, can be difficult to trace since they often derive from multiple sources in disparate locations.

Human activities on land can add excess nutrients to surface waters or can compromise the ability of ecosystems to remove nutrients either from the landscape or from the waterways themselves. Nutrient over-enrichment from human activities, particularly agriculture, is one of the major stresses impacting coastal ecosystems.[21]

The transport and delivery of these nutrients is a complex process controlled by a range of factors, including the chemistry of the nutrient (e.g., chemical compounds can be reactive and subject to chemical transformation) and the ecology, hydrology, and geomorphology of the various portions of a watershed and the receiving system.[22]

Generally, excess nutrients in a receiving water body lead to increased algae production and increased availability of organic carbon within an ecosystem, a process known as eutrophication. In marine and estuarine ecosystems, depending on conditions, this algae population explosion can be followed by increased production of the oxygen-depleting bacteria that naturally consume dead

Water quality patterns in agricultural areas

Transport of a chemical compound depends on its mobility. Some compounds, such as nitrate and atrazine, readily dissolve and move with water in both streams and ground water. Many forms of phosphorus, however, attach to soil particles rather than dissolve; a large proportion of such compounds is transported to streams with eroded soil, particularly during times of high runoff from precipitation or irrigation. Ground water typically is not vulnerable to contamination by compounds that attach to soils.

The transport of a chemical compound in the environment also depends on its persistence. Some pesticides are not readily broken down by microorganisms or other processes in the natural environment. For example, DDT and chlordane can persist in soil, water, sediment, and animal tissue for years and even decades. Other pesticides, such as carbaryl, are relatively unstable in water and break down to other compounds in days or weeks. Chemical compounds that persist for a long time are likely to be transported farther than compounds that are short-lived.

"The Quality of Our Nation's Waters–Nutrients and Pesticides," USGS

algae. The low oxygen environment causes slow-moving shellfish to suffocate and faster-moving fish to relocate, creating a hypoxic zone.

For further details on fate and transport of chemicals in the environment, refer to:

- "Point Source Water Contamination" in this *Technology and Environmental Decision-Making* series of modules.
- "Chemicals in the Environment: Fate and Transport" from MITOpenCourseWare.
- *Chemical Fate and Transport in the Environment* by Harold Hechner and Elizabeth Fechner-Levy.
- Using Predictive Methods to Assess Exposure and Fate under TSCA from the U.S. EPA, including software for fate and transport modeling.

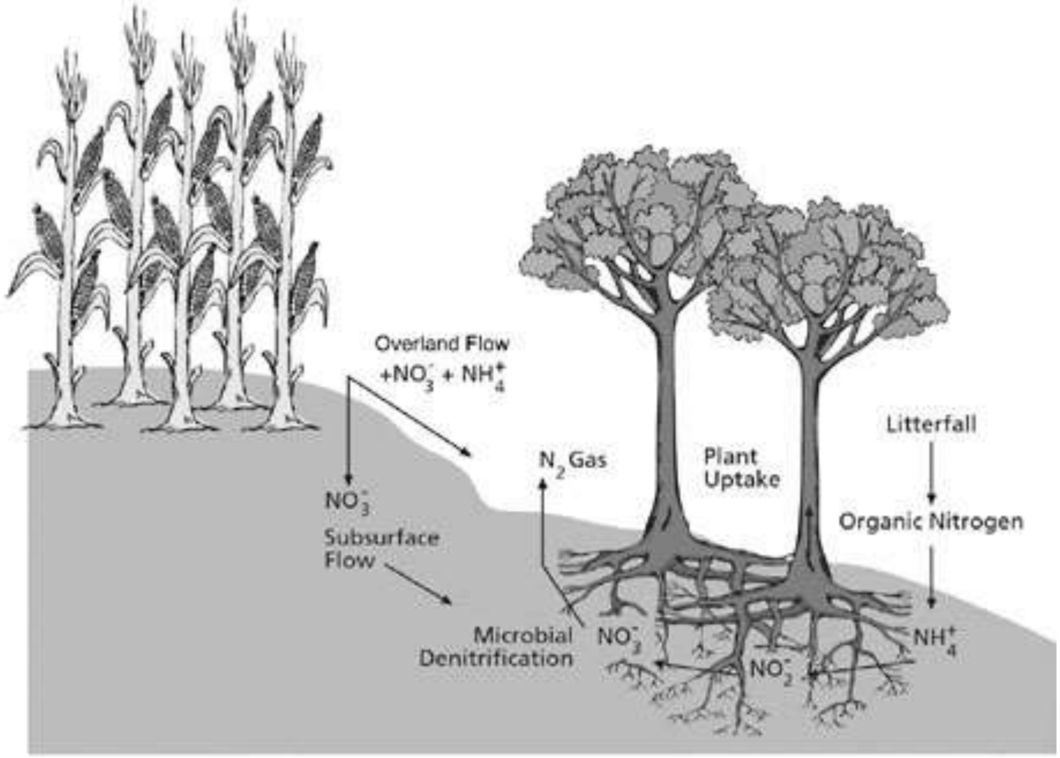
Nitrogen Cycle

Nitrogen is an essential component of proteins, genetic material, chlorophyll, and alkaloids. All organisms require nitrogen in order to live. Nitrogen ranks fourth behind oxygen, carbon, and hydrogen as the most common chemical element in living tissues. Until human activities began to alter the natural cycle, however, nitrogen was only scantily available to much of the biological world. As a result, nitrogen served as one of the major limiting factors that controlled the dynamics, biodiversity, and functioning of many ecosystems.[23]

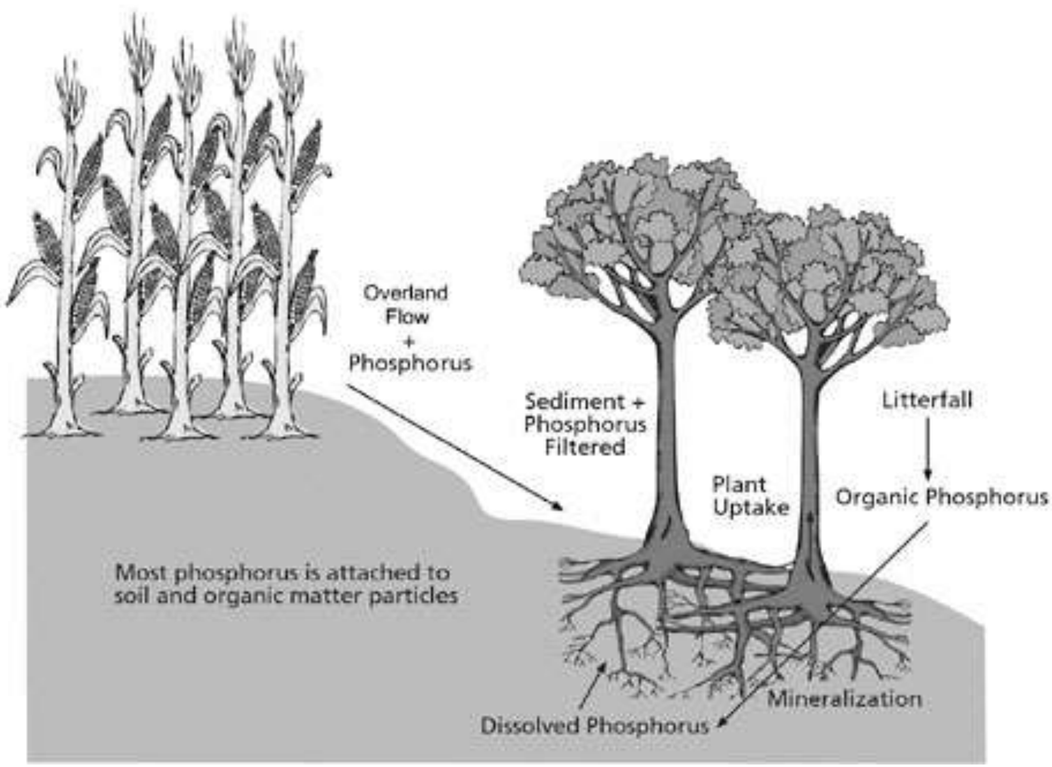
The earth's atmosphere is 78 percent nitrogen gas, but most plants and animals cannot use nitrogen gas directly from the air as they do carbon dioxide and oxygen. Instead, plants—and all organisms from the grazing animals to the predators to the decomposers that ultimately secure their nourishment from the organic materials synthesized by plants—must wait for nitrogen to be "fixed." In other words, nitrogen is pulled from the air and bonded to hydrogen or oxygen to form inorganic compounds, mainly ammonium (NH_4^+) and nitrate (NO_3^-), that the plants can use.[24]

The atmosphere commonly is overlooked as a nonpoint source of nutrient and pesticide contamination. Yet, more than 3 million tons of nitrogen are deposited in the United States each year from the atmosphere. The nitrogen is derived either naturally from chemical reactions or from the combustion of fossil fuels, such as coal and gasoline.

"The Quality of Our Nation's Waters–Nutrients and Pesticides," USGS



Nitrogen fate and transport, from [Riparian Areas: Functions and Strategies for Management](#).
Credit: National Academy of Sciences



Phosphorus fate and transport, from [Riparian Areas: Functions and Strategies for Management](#).
Credit: National Academy of Sciences

The amount of gaseous nitrogen being fixed at any given time by natural processes represents only a small addition to the pool of previously fixed nitrogen that cycles among the living and nonliving components of Earth's ecosystems. Most of that nitrogen, too, is unavailable, locked up in soil organic matter—partially rotted plant and animal remains—that must be decomposed by soil microbes. These microbes release nitrogen as ammonium or nitrate, allowing it to be recycled through the food web. The two major natural sources of new nitrogen entering this cycle are nitrogen-fixing organisms and lightning.[25]

Nitrogen-fixing organisms include a relatively small number of algae and bacteria. Many of them live free in the soil, but the most important ones are bacteria that form close symbiotic relationships with higher plants. Symbiotic nitrogen-fixing bacteria live and work in nodules on the roots of peas, beans, alfalfa, and other legumes. These bacteria manufacture an enzyme that enables them to convert gaseous nitrogen directly into plant-usable forms.[26]

Human Impact on Nitrogen Cycle

Most of the human activities responsible for the increase in global nitrogen are local in scale, from the production and use of nitrogen fertilizers to the burning of fossil fuels in automobiles, power generation plants, and industries. However, human activities have not only increased the supply, but enhanced the global movement of various forms of nitrogen through air and water. Because of this increased mobility, excess nitrogen from human activities could have serious and long-term environmental consequences for large regions of the earth.[27]

> "The cycling of water and our global interconnections mean that all of us are "living downstream"—everyone on this planet. Thus, we need to step back and take a clear, dispassionate look at the world's supply of water, using all available tools, from the nanoscale to the global scale."
>
> Dr. Rita R. Colwell, former Director of the National Science Foundation in
>
> *Abel Wolman Distinguished Lecture speech*

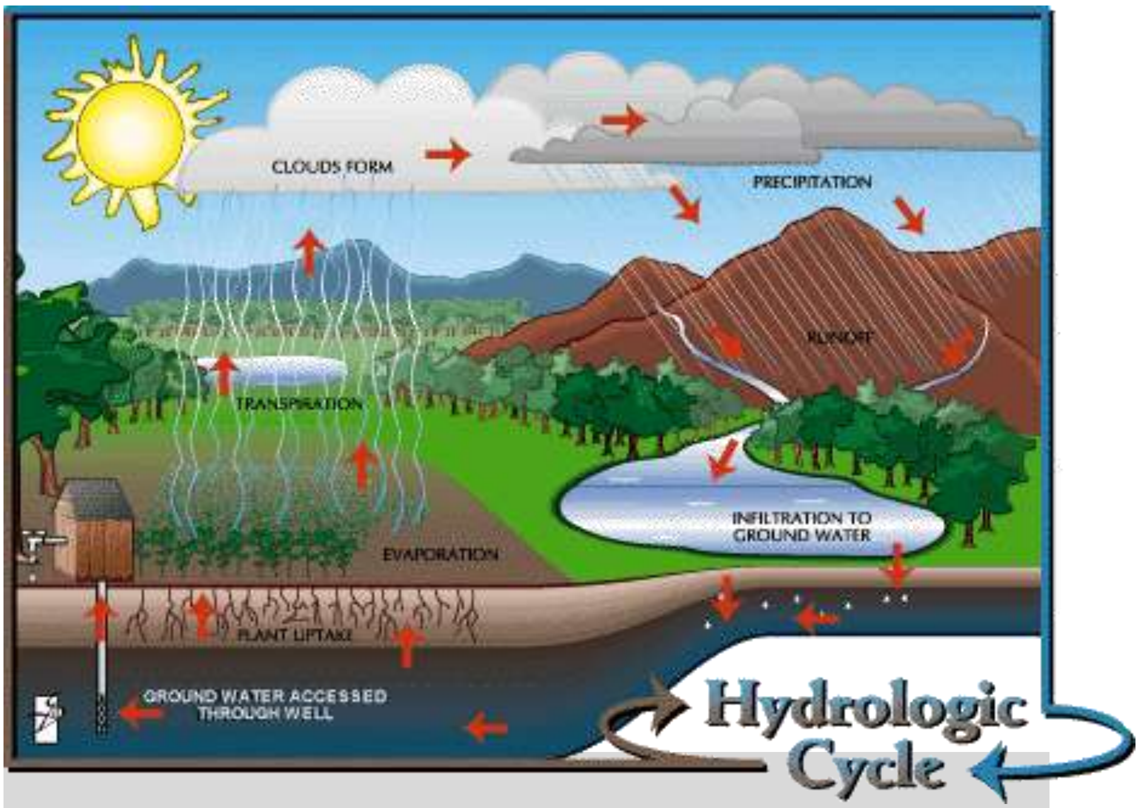
The impacts of human domination of the nitrogen cycle that have been identified with certainty include:

- increased global concentrations of nitrous oxide (N_2O), a potent greenhouse gas, in the atmosphere as well as increased regional concentrations of other oxides of nitrogen (including nitrogen oxide, NO and dinitrogen trioxide, N_2O_3) that drive the formation of photochemical smog.
- losses of soil nutrients such as calcium and potassium that are essential for long-term soil fertility.
- substantial acidification of soils and of the waters of streams and lakes in several regions.
- greatly increased transport of nitrogen by rivers into estuaries and coastal waters where it is a major contaminant.[28]

For more information on the nitrogen cycle, refer to "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences" from the Ecological Society of America.

Hydrologic Cycle

Understanding the hydrologic cycle is a key to understanding NPS contamination of water, particularly the contamination from agricultural runoff. Inflows and outflows of the cycle can result from nature or human activity. Population increases, rising standards of living, and industrial and economic growth have placed greater demands on natural water resources. Human activities can create an imbalance in the hydrologic equation and affect the quantity and quality of natural water resources available to current and future generations.[29]



Credit: U.S. EPA

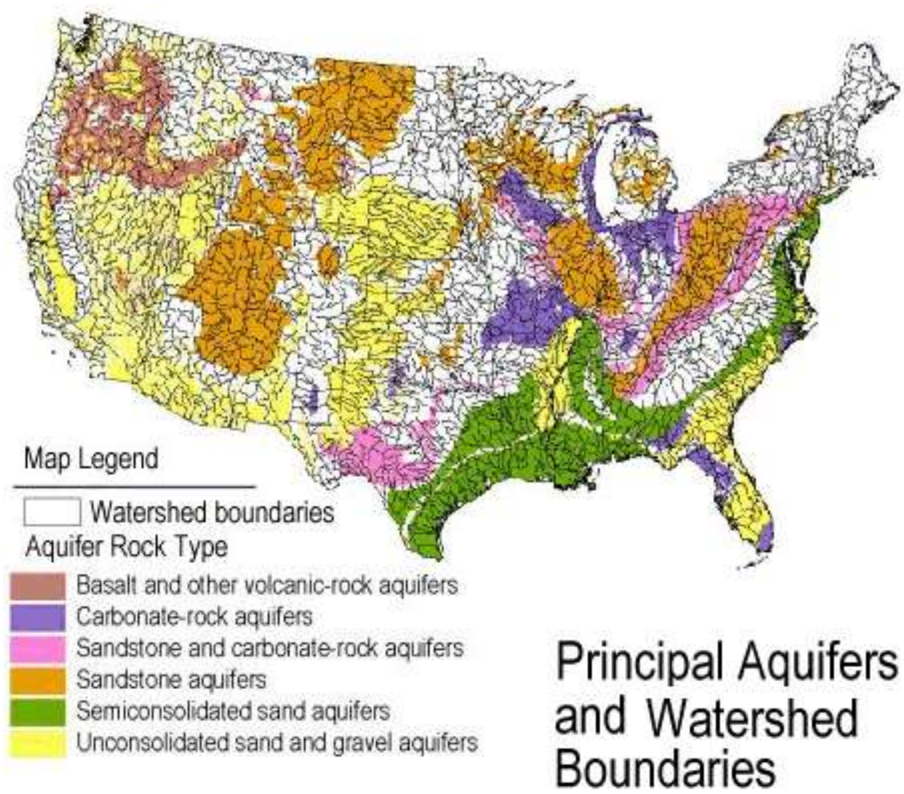
For more information on the hydrologic cycle and the impact of human activities, refer to "Point Source Water Contamination" in this *Technology and Environmental Decision-Making* series of modules and to *The Ground Water Primer* from the U.S. EPA.

Watersheds

Another major influence on the fate and transport of chemicals in the environment is the geography of the terrain in which pollutants exist. It determines when, where, and how chemicals affect their surroundings. For water resources, one of the most important transport vehicles is the watershed.

A watershed, or drainage basin, is a bowl-like landform defined by high points and ridge lines that descend into lower elevations and stream valleys. A watershed carries water that is "shed" from the land after rain falls and snow melts. Drop by drop, water is channeled into soils, ground water, creeks, and streams, making its way to larger rivers and eventually to the sea.[30]

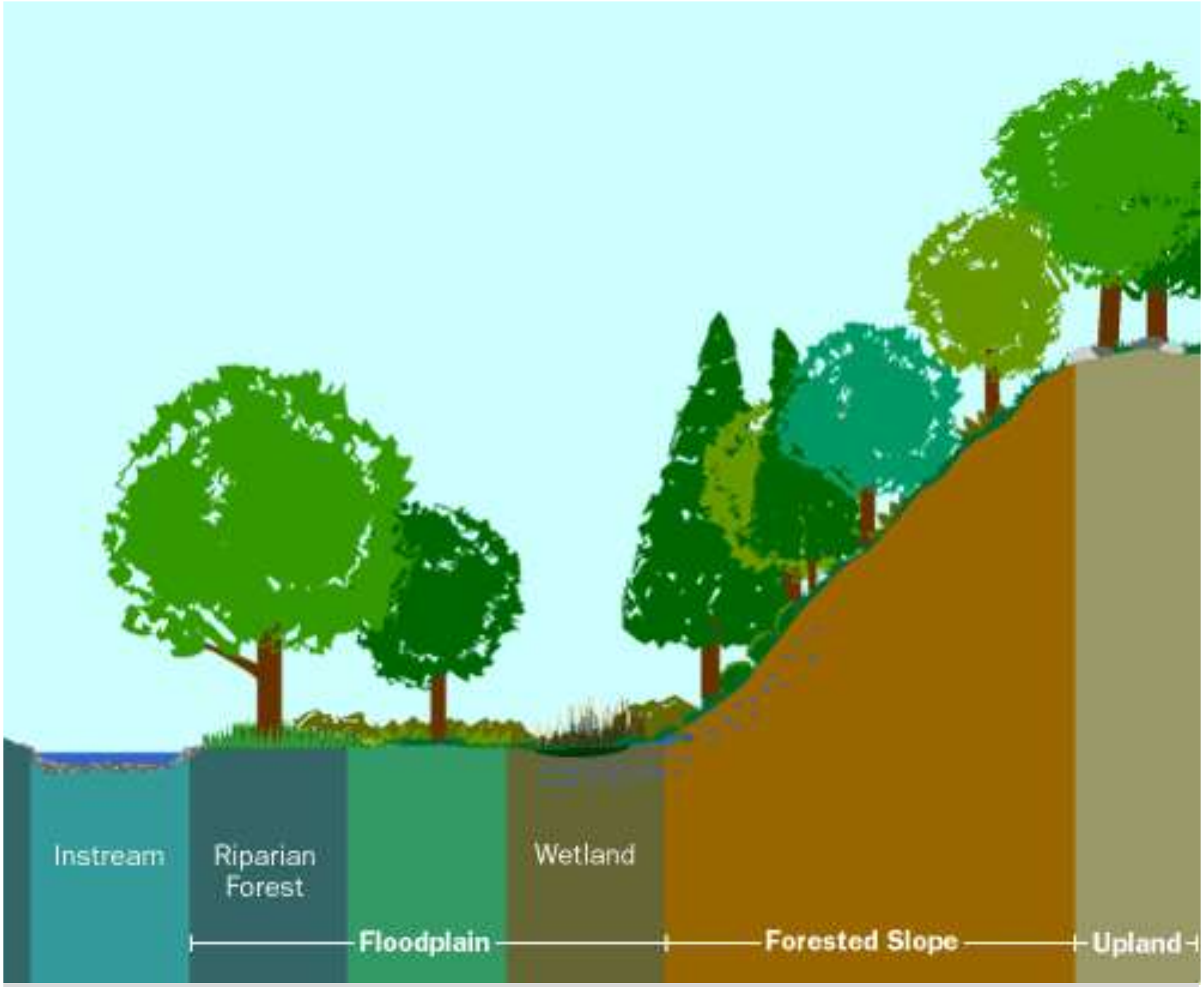
Generally speaking, water is a universal solvent, affected by all that it comes in contact with—the land it traverses and the soils through which it travels. The most important thing humans need to understand about watersheds is that what people do on the land affects water quality for all communities living downstream.[31]



Credit: U.S. EPA

Watersheds are associated with creeks, streams, rivers, and lakes, but they are much more. A watershed is a highly evolved series of processes that convey, store, distribute, and filter water. That water, in turn, sustains terrestrial and aquatic life. Much of our drinking water is supplied through the watershed system.[32]

A watershed typically contains several distinct types of terrain, including instream, floodplain (riparian forest, wetland), forested slope, and upland.[33]



Credit: Pennsylvania Environmental Council,
"Watershed Atlas of the Monongahela and Allegheny Rivers"

Instream

An estimated 80 to 90 percent of streams in U.S. watersheds are headwater streams starting in forested woodlands. Moving constantly downstream, a stream widens, its shape and structure changes, and so do its aquatic habitats, temperatures, and food sources.[34]

Floodplain

A floodplain is typically a broad, flat terrace higher than the stream adjacent to it. Floodplains occur where running waters over the course of thousands of years have overflowed their banks during high water events such as rainstorms and snowmelts and deposited sediments on the inside bend of the stream channel. Floodplains sometimes, but not always, exist on both sides of a stream.[35]

When high waters slow down and eventually recede, fine silts and sediments settle out, creating a nutrient-rich environment. Occasionally saturated, but seasonally dry, floodplains are often populated with wetland plant species. Floodplains receive water from floods, precipitation, runoff, and springs emanating from forested slopes. Floodplains usually have shallow water tables and don't store water underground. Their greatest function is to check the velocity of fast-moving waters.[36]

Riparian Forest. A riparian forest refers to forest vegetation occurring alongside streams and rivers. Riparian forests may occur on the high side of a floodplain, or right up to and leaning over a streambed. These areas offer the last opportunity for runoff waters to exchange nutrients and contaminants with vegetation and soils before entering streams and rivers.[37]

Undisturbed riparian vegetation is usually made up of mature, native forest trees like red maples, sycamores, and willows, with a range of native shrubs and grasses that tolerate wetter soils.[38]

Riparian forests are considered to be the single most effective means of controlling NPS contamination. They clean water coming off the land and maintain healthy aquatic habitats.[39]

Riparian forests function in a variety of ways.

- Filters—runoff from rain or snow is intercepted by riparian vegetation, where it slows down and drops out sediments.
- Transformers—plants take up excessive nutrients from fertilizers and reduce or transform them to safer compounds.
- Sinks—nutrients and contaminants carried by runoff drop down into soil substrates where they are processed and broken down by plants and soils.
- Sources—overhanging vegetation offers shade for fish, maintains cool stream temperatures, provides habitat to insects, and contributes leaf detritus for the downstream aquatic food chain—critical components for aquatic ecosystems.
- Stabilizers—interwoven root systems of streamside vegetation stabilize stream banks and prevent erosion during high water events.[40]

Wetlands. Wetlands can be any of a variety of types of vegetated, water-soaked soils, such as spring-fed meadows, vernal pools, bogs, marshes, fens, oxbow lakes, river back channels, and forested wetlands. Wet environments, together with large amounts of nutrients, are rich in plant species. These, in turn, provide food, cover, shelter, and breeding grounds for birds, waterfowl, insects, amphibians, and mammals. Wetlands exhibit a richer diversity of plants and animals, and greater biological productivity, than the non-wetland areas around them.[41]

Many plants associated with wetlands play significant roles in cleaning runoff waters. These plants slow the speed of incoming water. Sediments carried along in the water drop out and are deposited in the wetland area. Physically or chemically attached contaminants (e.g., oil from roads) or excessive nutrients (e.g., fertilizers) are absorbed and processed within the soil or within the biomass of the wetland plants. The cleansed water is then slowly re-released into the ground water or a nearby stream. In this way, wetlands also effectively reduce flooding.[42]

For more information on wetlands, refer to The Watershed Atlas.

Nahant Marsh in Davenport, Iowa.
Credit: ATEEC

Forested Slope

Forested slopes receive water from uplands in the form of underground springs and runoff during extended rainfalls. Forested slopes also have open areas to receive precipitation.[43]

Because trees are closely intertwined with soils, they help absorb incoming water. Tree leaves reduce the impact of raindrops falling hundreds of feet. Leaf litter creates forest floor mats during winter that allow rain and snowmelt penetration into soils, while preventing erosion. Tree and shrub roots hold soils in place, stabilizing slopes. Uncompacted leaf litter and root penetration allow water to permeate soils and replenish ground waters. Forest trees are crucial in the process of storing water underground. An estimated 20 percent of all freshwater on earth is stored underground.[44]

Forests have diverse mechanisms for collecting and storing water, including the process of transpiration. Transpiration occurs when trees and plants draw water out of the soil, use it in photosynthesis, and return it to the air as water vapor. Forests act as sponges during storm events. They are capable of absorbing and storing huge amounts of water, thereby reducing runoff that contributes to flooding downstream.[45]

Upland

Uplands receive water from precipitation (i.e., rain, sleet, hail, and snow). Water from these sources permeates the terrain, sinking into soils. Trees tend to absorb most soilborne water in the process of transpiration. Water not taken up into trees and shrubs moves deeper into soils as ground water. If the ground is saturated from rain, water will run over the soil surface (runoff) to a low point, or until it is absorbed.[46]

For more information on watersheds, their components, and their functions, refer to:

- Online Training in Watershed Management from the U.S. EPA.
- Federal Stream Corridor Restoration Handbook from the USDA.
- The Watershed Atlas.
- Riparian Areas: Functions and Strategies for Management from the National Research Council.
- Wetlands Monitoring and Assessment from the U.S. EPA.
- Science in Your Watershed from the USGS.
- National Wetlands Inventory from the U.S. Fish and Wildlife Service.
- Riparian Forest Buffer Fact Sheets from New York State Soil and Water Conservation Committee.

Agriculture and Common Contaminants

Modern economic activity requires the use, handling, transportation, and storage of materials used in agricultural processes. These processes can create the pollutants—sediment (from erosion), pesticides, fertilizers, herbicides, and animal waste—that are the main sources of agricultural NPS water contamination.[47]

Erosion and deposition of soil are natural and beneficial processes in a watershed. Sediment transport and storage are essential for long-term soil development. The redeposition of sediments on floodplains is another important watershed function, rejuvenating soils and influencing the productivity and diversity of riparian ecosystems. But the large-scale clearing of natural vegetation for agricultural and urban uses has changed the balance of the beneficial sedimentation process. When the normal sediment-carrying capacity of a watershed is exceeded, sediment becomes a contaminant.[48]

Overapplied or misapplied fertilizers, herbicides, insecticides, and fungicides could introduce contaminants into a watershed.

- Many organic compounds
- Excess nitrogen
- Excess phosphorus
- Cadmium
- Chloride
- Mercury
- Selenium[49]

Feedlots are also potential contamination sources due to the animal waste, which can be a source of:

- nitrate.
- coliform bacteria.
- total dissolved solids.
- sulfates.[50]

For more information on:

- different sources of agricultural contamination, refer to "Agricultural Sources of Contamination" in the U.S. EPA's Ground Water Primer.
- Priority List of Hazardous Substances, refer to the CDC's Agency for Toxic Substances and Disease Registry.
- hazardous materials contamination, refer to the U.S. EPA's National Contaminant Occurrence Database (NCOD).
- environmental impacts on water quality in the United States, refer to the National Water Quality Portal.

For contaminant charts with details of drinking water standards levels, health risks, and water treatment methods, refer to the U.S. EPA's Ground Water Primer.

Aids to Understanding provides resources and activities.

Measuring and Monitoring

Environmental Measurements

Ground water monitoring wells.
Credit: U.S. Geological Survey

When discussing environmental contamination, the words "measuring" and "monitoring" tend to bring to mind high-tech processes, such as subparticle instrumentation, computer analysis, simulations, etc. But the effectiveness of the equipment (especially water simulation models and qualitative judgments for measuring, monitoring, and remediation techniques) is limited by the scientist's ability to make efficient and accurate field and laboratory measurements. This limitation holds true for properties as fundamental as stream flow, and as complex as the concentrations of a trace contaminant in different media (water, sediment, and tissue).[51]

In today's complicated global water environment, a combination of computer-aided data collection utilizing Geographic Information Systems (GIS) and physical field sampling techniques is likely to produce the most useful water data collection and analysis.

NASA's Observatorium Earth Observatory organizes the field of environmental measuring and monitoring into a logical format that allows even the most high-tech satellite data collection systems to be put into perspective.

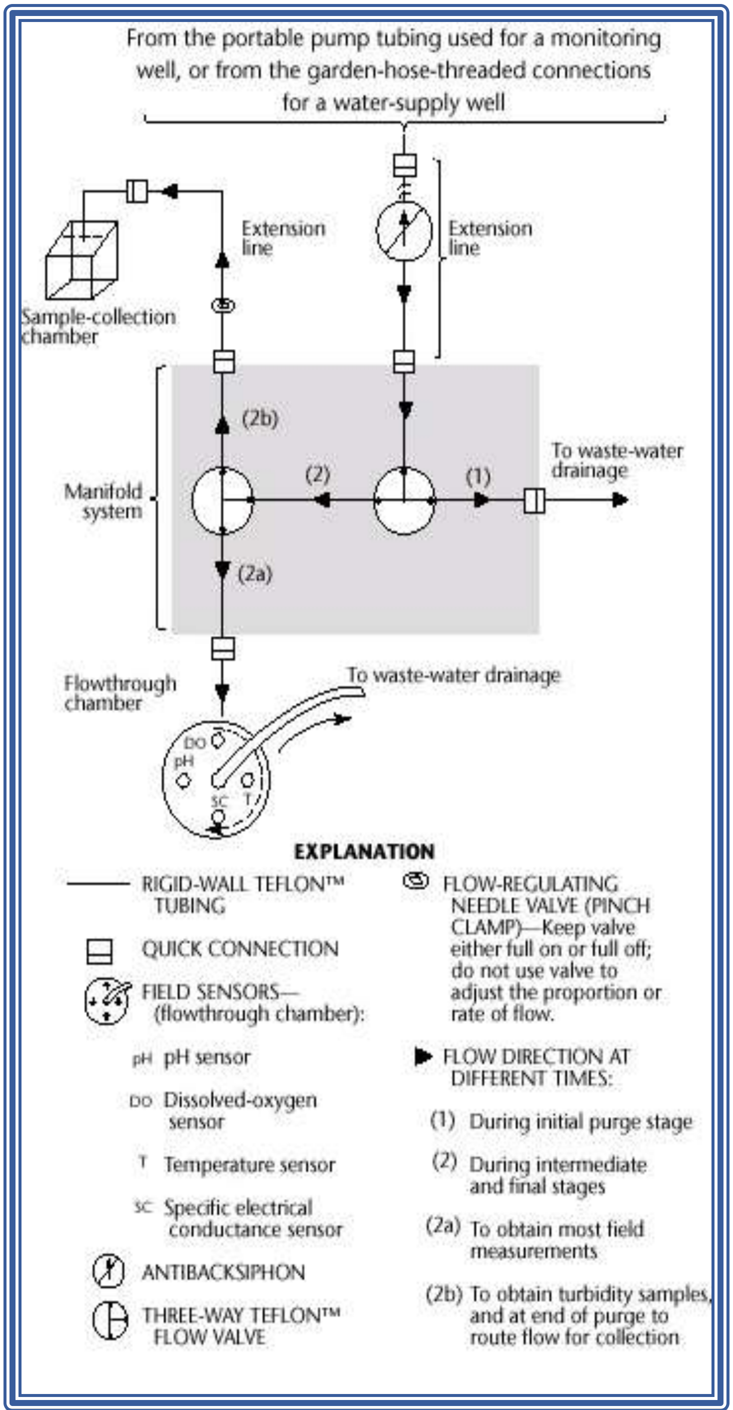
- Collect the data (e.g., field sampling, remote sensing).
- Organize the data (e.g., field notebook, GIS).
- Analyze the data (e.g., physical and/or computer modeling).
- Display the data (e.g., maps, 3D graphics).

For online tutorials on geospatial analysis and GIS with ArcGIS10 software, refer to Tufts University's GIS Tip Sheets.

For details on environmental measurements, refer to "Environmental Health – Toxic Substances" from the U.S. Geological Survey.

Water Contamination Measurement Techniques–Field Methods

The *National Field Manual for the Collection of Water-Quality Data* describes protocols and provides guidelines for personnel who collect data used to assess the quality of surface water and ground water resources. These personnel must perform field trip preparations (including selection of sample-collection sites), site reconnaissance and well selection for studies of water quality, and must establish electronic files and field files for a sampling site.[52]



Sample field manual page.
Source: *National Field Manual for the Collection of Water-Quality Data*, U.S. Geological Survey

Generally, the process of measuring water contamination includes:

- collection by direct measurement.
- collection of environmental data.
- application of hydraulics.
- hydrologic analysis/interpretation.
- laboratory analysis.
- data processing and computations.
- Modeling.[53]

For further details on water quality data collection/analysis, refer to:

- Environmental Measurement Methods for Use in the Field (USGS)
- Water Quality Methods and Techniques (USGS)
- *National Water Quality Handbook* (USDA)
- Clean Water Act Analytical Methods and Methods Approved to Analyze Drinking Water Samples to Ensure Compliance with Regulations (U.S. EPA)

Data Collection

Maps have traditionally been used to explore the earth and to exploit its resources. GIS technology, as an expansion of cartographic (mapping) science, has enhanced the efficiency and analytic power of traditional mapping. GIS technology is becoming an essential tool in the effort to understand environmental consequences of human activity. Various map and satellite information sources can be combined in modes that simulate the interactions of complex natural systems.[54]

GIS and related technology are an immense help in the management and analysis of these large volumes of data. The technology allows for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.[55]

Through a function known as visualization, GIS can be used to produce images—not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before, and to capture, store, manipulate, and display spatial or geographic information. The images often are equally helpful in conveying the technical concepts of GIS study subjects to non-scientists.[56]

The condition of the earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years.

The United States Geological Service (USGS) is a primary source of GIS data. The data and information is presented in a spatially and geographically precise format including the National Map, Earth Explorer, GloVIS, LandsatLook, etc. Software such as ArcGIS Online from the Environmental Systems Research Institute (ESRI), allows students to interact with generated maps and retrieve information about any map feature. GIS can be linked with computer models to run simulations of given environments and variables in a specified timeframe.

The interactive capabilities of GIS are particularly valuable in this application to help illustrate, to high school and first-year college students, the impact of human activities on the environment. Data visualization tools allow students to see and explore relationships that might be lost to them when the data appears solely as arrays of numbers.

Credit: USGS Current Water Data for the Nation

For more information on GIS and water applications, including educational curricula, refer to the GeoTech Center website and the USGS Maps and GIS Data.

Satellite Data Collection

Most GIS applications now receive data through satellite technology. The National Aeronautical and Space Administration (NASA) manages the Earth Science Enterprise program that uses Earth-Observing System (EOS) satellites and other tools to intensively study the earth and expand knowledge of the interaction between natural processes and human activities.

Earth-Observing Satellites. Credit: NASA

The Earth Science Enterprise has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include clouds, water and energy cycles, oceans, chemistry of the atmosphere, land surface, water and ecosystem processes, glaciers and polar ice sheets, and the solid earth.

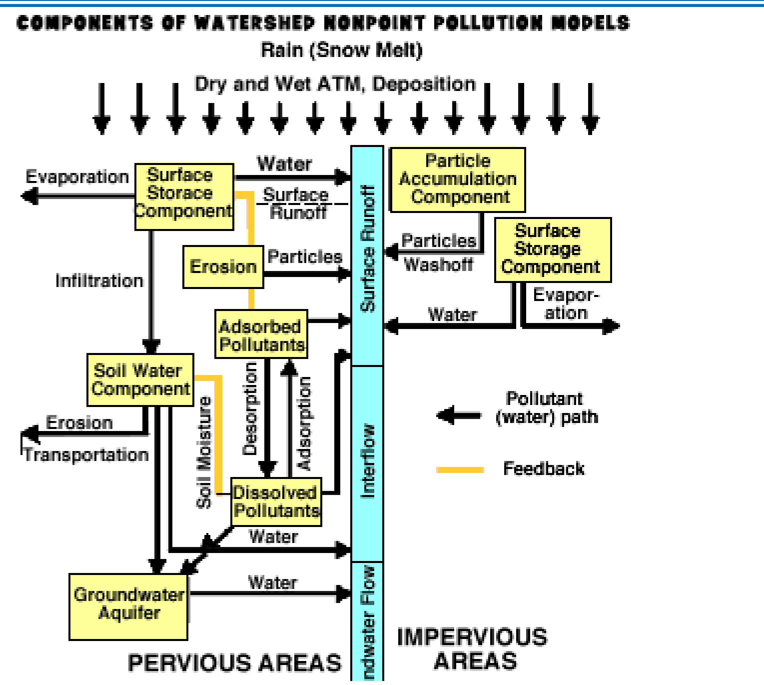
For example, NASA’s TERRA satellite provides detailed measurements of clouds, aerosols, and the earth's radiative energy balance. The equipment measures the land surface and its interaction with the atmosphere through exchanges of energy, carbon, and water. TERRA’s measurement instruments contribute to the detection of global environmental changes and thereby accelerate understanding of the total earth system, including the systems that affect causes and consequences of NPS contamination.

NASA provides more information on earth-observing missions.

Computer Modeling

In general, models are representations of systems or processes. Some of the oldest forms of models were actual miniature physical representations of natural systems. Mathematical models are also representations of systems, using a series of mathematical equations. The number, form, and interconnections of these equations in a model can range from very simple to highly sophisticated.[57]

Models are tools used in combination with many other assessment techniques. Models are a reflection of the user's understanding of the targeted system. As with any tool, the answers they give are dependent on how the tool is applied, and the quality of these answers is only as good as the quality of the user's understanding of the system.[58]



Credit: NASA

Surface water computer models attempt to represent an actual system, such as a watershed, with a mathematical counterpart. The conceptualization of how and where water originates in the flow system of the watershed, and how and where it leaves the system, is critical to development of an accurate model. The mathematical representation of these boundaries in the model is important because many hydrologic boundary conditions can be mathematically represented in more than one way. The determination of the most appropriate mathematical representation of a boundary condition usually depends on a particular study's objectives.[59]

For detailed information on water models and tools, refer to EPA's Methods, Models, Tools, and Databases for Water Research.

Aids to Understanding provides resources and activities.

For more information about computer modeling in action, see "Climate Change" in this Technology and Environmental Decision-Making series of modules.

Decision-Making

The Clean Watersheds Needs Survey (CWNS) is conducted periodically as a requirement of the *Clean Water Act*. The CWNS collects information on wastewater collection and treatment, stormwater control activities, nonpoint sources, and programs designed to protect the nation's estuaries. The data are used to produce a report that provides an estimate of clean water needs for the United States.

For the past several decades, water contamination issues and regulations have focused on point source contamination and industrial point sources in particular. While this problem has certainly not been resolved, public and political awareness have at least made some headway. (For more on point source contamination, refer to “Point Source Water Contamination.” For more on decision-making, refer to “Environmental Decision-Making” in this *Technology and Environmental Decision-Making* series of modules.)

The progress and lessons learned in the area of point source contamination have instigated awareness of nonpoint source contamination (NPS) as well. NPS water contamination is getting more and more attention from the public, and as a result, from government agencies.

The case study in this module concerns decisions that are being made by the U.S. government to reduce the amount of contaminant runoff, mainly from excess agricultural nutrients, to the Mississippi River Basin that drains to the northern Gulf of Mexico. For information on the use of science in this decision-making process, and regulations and programs pertaining specifically to this problem, refer to the case study in this module on the Gulf of Mexico’s dead zone.

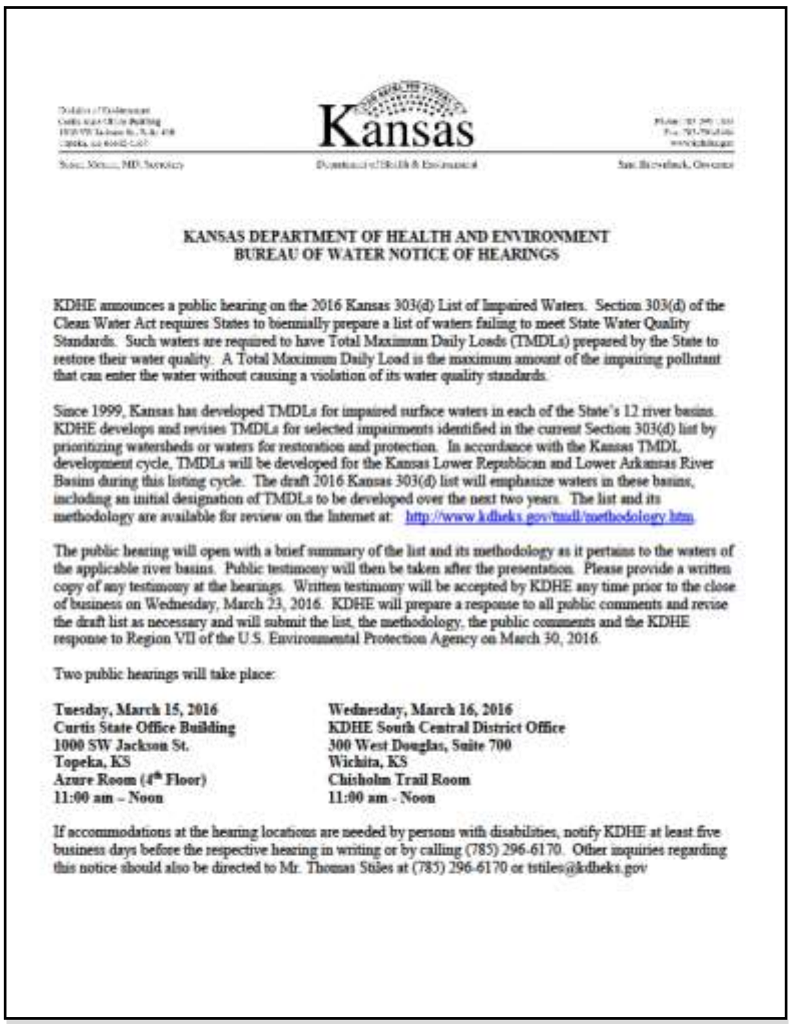
Public Meetings and Hearings

Ideally, U.S. government regulations are the result of what the majority of U.S. citizens want. To ensure that a law continues to reflect the public’s needs and interests, many of the regulations dealing with NPS water contamination actually mandate the solicitation of public input on pertinent decisions covered by these statutes. For example, Section 303(d) of the Clean Water Act (CWA) requires that the public be notified (usually in the Federal Register) and provided the opportunity to comment on any new or revised criteria for water pollutants.

Public Participation as Defined by U.S. Law (40 CFR 25)

"Public participation is that part of the decision-making process through which responsible officials become aware of public attitudes by providing ample opportunity for interested and affected parties to communicate their views. Public participation includes providing access to the decision-making process, seeking input from and conducting dialogue with the public, assimilating public viewpoints and preferences, and demonstrating that those viewpoints and preferences have been considered by the decision-making official. Disagreement on significant issues is to be expected among government agencies and the diverse groups interested in and affected by public policy decisions. Public agencies should encourage full presentation of issues at an early stage so that they can be resolved and timely decisions can be made. In the course of this process, responsible officials should make special efforts to encourage and assist participation by citizens representing themselves and by others whose resources and access to decision-making may be relatively limited."

The mandated opportunity for public input is usually carried out through regional and/or state public comment periods or public meetings. For example, the Kansas Department of Health and the Environment disseminated this notice:



Kansas

Department of Health & Environment

KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT
BUREAU OF WATER NOTICE OF HEARINGS

KDHE announces a public hearing on the 2016 Kansas 303(d) List of Impaired Waters. Section 303(d) of the Clean Water Act requires States to biennially prepare a list of waters failing to meet State Water Quality Standards. Such waters are required to have Total Maximum Daily Loads (TMDLs) prepared by the State to restore their water quality. A Total Maximum Daily Load is the maximum amount of the impairing pollutant that can enter the water without causing a violation of its water quality standards.

Since 1999, Kansas has developed TMDLs for impaired surface waters in each of the State's 12 river basins. KDHE develops and revises TMDLs for selected impairments identified in the current Section 303(d) list by prioritizing watersheds or waters for restoration and protection. In accordance with the Kansas TMDL development cycle, TMDLs will be developed for the Kansas Lower Republican and Lower Arkansas River Basins during this listing cycle. The draft 2016 Kansas 303(d) list will emphasize waters in these basins, including an initial designation of TMDLs to be developed over the next two years. The list and its methodology are available for review on the Internet at: http://www.kdheks.gov/tmdl/methodology.htm

The public hearing will open with a brief summary of the list and its methodology as it pertains to the waters of the applicable river basins. Public testimony will then be taken after the presentation. Please provide a written copy of any testimony at the hearings. Written testimony will be accepted by KDHE any time prior to the close of business on Wednesday, March 23, 2016. KDHE will prepare a response to all public comments and revise the draft list as necessary and will submit the list, the methodology, the public comments and the KDHE response to Region VII of the U.S. Environmental Protection Agency on March 30, 2016.

Two public hearings will take place:

Tuesday, March 15, 2016
Curtis State Office Building
1000 SW Jackson St.
Topeka, KS
Azure Room (4th Floor)
11:00 am – Noon

Wednesday, March 16, 2016
KDHE South Central District Office
300 West Douglas, Suite 700
Wichita, KS
Chisholm Trail Room
11:00 am - Noon

If accommodations at the hearing locations are needed by persons with disabilities, notify KDHE at least five business days before the respective hearing in writing or by calling (785) 296-6170. Other inquiries regarding this notice should also be directed to Mr. Thomas Stiles at (785) 296-6170 or tstiles@kdheks.gov

Credit: Kansas Department of Health and Environment

Because of the nonspecific and multi-source nature of NPS pollution, the decisions made at the town or city level are often the most effective in controlling contaminants. Important decisions may be made during public hearings on stormwater permitting or urban planning that determine a community's capability in managing NPS pollution over the long term. Notices about local hearings often appear in the newspaper or in government office buildings.[60]

> To participate in public discussion of NPS water contamination issues and education, see the *NPSINFO Forum Resource Center.*

Citizen's Groups and Partnerships

Citizen's groups and partnerships are traditional ways to facilitate public decision-making and encourage individual involvement. For the issue of water quality, the watershed organization is becoming an increasingly effective tool for bringing together disparate groups with the common interest of water quality.

A watershed organization incorporates the ideas and resources of many different groups into a single organization. The groups can include local governments, citizens, nonprofit environmental groups, local educational institutions, etc. The purpose of a watershed organization is to restore, protect, and promote the natural resources of the watershed. To accomplish this, a watershed organization might set goals for and subsequently implement public education and storm water management programs, stream cleanup events, or restoration activities.[61]

For more information on:

- the benefits of a watershed framework approach to pollution prevention and remediation, refer to the Remediation section in this module.
- watershed organizations, refer to "Building Local Partnerships—A Guide for Watershed Partnerships" from Purdue University.
- local and national watershed and watershed organization information, refer to Surf Your Watershed from the EPA.

Volunteer Monitoring

Another effective tool in NPS public decision-making is volunteer monitoring—the gathering of scientific data for use in the decision-making process. Local groups organize volunteers of all skill levels to gather water quality data. The consistency and quality of data gathered may vary among the different volunteer organizations, but at the very least the information can help government agencies and the general public understand the magnitude of NPS pollution.

Hundreds of volunteer monitoring groups currently operate throughout the United States. Volunteers conduct a variety of activities, including:

- analyzing water samples for dissolved oxygen, nutrients, pH, temperature, and many other water constituents.
- evaluating the health of stream habitats and aquatic biological communities.

- conducting an inventory of streamside conditions and land uses that may affect water quality.
- cataloging and collecting beach debris.
- restoring degraded habitats.

To locate monitoring programs, refer to the National Directory of Volunteer Monitoring Programs from the EPA.

Water Regulations

The following are summaries of some major regulations that directly or indirectly play a part in regulating NPS water contamination, including:

- Clean Water Act
- Safe Drinking Water Act
- Coastal Zone Management Act
- Rivers and Harbors Appropriation Act
- Watershed Protection and Flood Prevention
- North American Wetlands Conservation Act

Clean Water Act (CWA)

Clean Water

The objective of the Clean Water Act (CWA), also known as the Federal Water Pollution Control Act, is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." CWA goals and policies are to:

- reach zero discharge of pollutants.
- provide funding for the construction of publicly owned treatment works (POTWs).
- create a NPS pollution program.
- make the waters of the U.S. "fishable and swimmable."[62]

Safe Drinking Water Act (SDWA)

Drinking Water

In 1974, the Safe Drinking Water Act was enacted with the general intent to protect the quality of drinking water that the public receives from public water systems. To accomplish this, the SDWA focuses on two approaches:

- Assure the quality of drinking water coming from the tap.
- Prevent the contamination of water that may be a source for drinking water.[63]

The Act focuses on all waters actually or potentially designed for drinking use, whether from aboveground or underground sources.

Coastal Zone Management Act

Coastal Zone

The intent of the Coastal Zone Management Act is to preserve, protect, develop, and restore or enhance the coastal zone. States are encouraged to implement coastal zone management programs. Another intention of the Act is to respond to changing circumstances of coastal environments. Nonpoint sources of coastal water pollution are targeted by the amendments of 1990. Part of the Act is the Coastal Nonpoint Source Pollution Control Program (Section 6217).

Rivers and Harbors Appropriation Act

Rivers & Harbors

Section 10 of the Rivers and Harbors Appropriation Act of 1899 establishes a program to regulate activities affecting navigation in U.S. waters, including wetlands.

Watershed Protection and Flood Prevention

Watershed Protection & Flood Prevention

Title 16 of the U.S. Code of Federal Regulations contains the country's major conservation legislation. Chapter 18 specifically requires watershed protection and flood prevention to preserve, protect, and improve land and water resources and the quality of the environment. The law specifically recognizes the national ramifications of damage from erosion, floodwater, and sediment.

North American Wetlands Conservation Act

Wetlands

The U.S. Congress recognized the importance of wetland ecosystems by passing the North American Wetlands Conservation Act to provide:

- habitat for migratory birds, fish, shellfish, and other wildlife.
- flood and storm control.
- water availability and quality.
- recreational and aesthetic areas.

For further discussion on the role of science in public policy and decision-making, refer to "Environmental Decision-Making" in this *Technology and Environmental Decision-Making* series of modules.

Aids to Understanding provides resources and activities.

Remediation

In most cases, it is impossible or impractical to directly treat nonpoint source contamination (NPS) of surface water. The most logical method for remediation is usually to remove or reduce the source(s) of contamination, let nature take its course, and allow ecological processes to restore the water quality.

Improperly managed agricultural practices are a major source of NPS water contamination. But in a world with more than seven billion[64] human beings who must eat to survive, the complete removal of pesticides and fertilizers from use on farms may not be a logical or practical option. Currently, farmers are becoming more educated and often adopting precision agriculture techniques that promote reduction of agricultural contaminants and restoration of natural controls for the contaminants as the primary methods of remediation.

Reduction of Nutrient Loads

Best Management Practices (BMPs)

Applying research-based best management practices (BMPs) can help producers optimize systems for comprehensive farm planning. BMPs for contaminant reduction and pathway control allow farmers to practice good environmental stewardship and maintain the long-term economic viability of their businesses.[65]

Researchers examine a buffer zone.
Credit: Agricultural Research Service

In addition to the environmental consequences of NPS nutrient contamination, excess fertilizer use in agriculture can be economically costly. Fertilizer is a major input cost for crop production. More precise fertilizer management avoids waste, saves money, and provides the economic incentive to implement BMPs.

The remediation strategies presented in this section are BMPs that emphasize the importance of the appropriate use of nutrients in crop production systems and proper land/watershed management.

For further details and research on BMPs in agriculture, refer to a wide variety of university extension collections, including BMPs from Iowa State University Extension.

Precision Agriculture Methods

One heavily emphasized aspect of precision agricultural practices is to reduce NPS contamination from pesticides and nutrients. For example, Integrated Pest Management (IPM) techniques can be applied based on the specific soils, climate, pest history, and crop for a particular field. IPM helps limit pesticide use and manages the necessary applications to minimize the chemicals' movement from the field.[66]

Precision agricultural methods can also help minimize the amount of chemicals necessary for crop production. Precision farming, also referred to as site-specific farming, is an emerging technology that allows farmers to adjust for variability in field characteristics like soil fertility and weed populations.

Low insecticide bait application.
Credit: USDA Agricultural Research

Global positioning system (GPS) technology provides spatial data. Geographic information system (GIS) technology provides analysis of the data. Using GPS technology, satellites transmit signals to a farm's receivers in order to define the receiver's location. Once defined, on-board sensors on farm equipment can use GIS technology to monitor crop yields and guide the application of crop inputs, such as fertilizers and herbicides.

Precision agricultural techniques can reduce farming costs by specifying more efficient and effective applications of crop inputs. It can also reduce environmental impacts by allowing farmers to apply crop inputs only where they are needed and at the appropriate rate.

For more information on IPM, refer to:

- Integrated Pest Management from the USDA.
- Introduction to Integrated Pest Management from EPA.
- Integrated Pest Management information from university extension services such as Iowa State University and Michigan State University.

For more information and tutorials on the applications of GPS and GIS in agriculture, refer to GIS Matters to Agriculture.

Sediment Management

Credit: Natural Resources Conservation Service

Farmers and ranchers can reduce erosion and sedimentation by 20 to 90 percent by applying management measures to control the volume and flow rate of runoff water, keep the soil in place, and reduce soil transport.[67]

Irrigation Management

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 residues deep into the soil, excessive irrigation can concentrate pesticides, nutrients, disease-carrying microorganisms, and salts—all of which impact water quality—in the top layer of soil. Farmers can reduce NPS pollution from irrigation by improving water use efficiency. Actual crop needs can be measured with a variety of equipment.[68]

Grazing Management

Overgrazing by livestock exposes soils, increases erosion, accelerates stream bank erosion, encourages invasion by undesirable plants, destroys fish habitat, and reduces the filtration of sediment necessary for building stream banks, wet meadows, and floodplains. Remedies include adjusting grazing intensity, keeping livestock out of sensitive areas, providing alternative sources of water and shade, and revegetating rangeland and pastureland. [69]

Summary of Agricultural Conservation Methods

A variety of methods can lead to improved agricultural conservation.

- **Crop rotations** are a planned sequence of different crops in the same field to improve soil quality.
- **Soil quality analysis** is the testing of soil's physical, chemical, and biological properties in order to support plant life and to maintain water and air quality.
- **Crop residue management** is the planned use of crop residue to protect the soil surface (e.g., no-till).
- **Contour farming** involves conducting tillage, planting, and harvesting operations around a hill or slope as near to the contour as is practical to reduce erosion.
- **Contour strip cropping** is a system of growing crops in strips or bands on or near the contour to reduce soil erosion.
- **Conservation buffers** are areas or strips of land maintained in permanent vegetation to help control pollutants and manage other environmental problems.

- **Cover crops** are chosen to reduce soil erosion and add organic matter to the soil.
- **Integrated Pest Management** (IPM) is a common-sense approach in combination with genetic, biological, cultural, or chemical methods to provide effective, environmentally-friendly pest control.
- **Grassed waterways** are natural or constructed swales where water usually concentrates as it runs off a field.
- **Stream bank protection** limits livestock access and establishes runoff filters to reduce erosion and maintain water quality.
- **Terraces and diversions** are earthen, cross-slope channels that intercept runoff to reduce erosion.
- **Prescribed grazing systems** direct the forage and grazing times to promote healthier plants, reduce erosion, and maintain water quality.
- **Nutrient management** is the planned use of organic and inorganic materials to provide adequate nutrients for crop production while protecting water quality.
- **Pasture and hayland planting** is the establishment of a forage in such a way that reduces erosion and improves soil quality.
- **Barnyard runoff control** reduces the amount of runoff from a barnyard, feedlot, or other animal concentration area in order to keep it from affecting clean water.[70]

Monitoring stream quality in a buffer zone.
Credit: Tom Jorgensen, DOE/NREL

From an economic point of view, the results of some agricultural conservation techniques may not show an immediate profit. It is often difficult, especially for small farm operations, to justify an initial outlay of time and/or capital that may take years to result in a return on the investment. For example, in the past farmers tilled their fields directly after fall harvest to prepare in advance for spring planting. The rationale was that this allowed for slightly earlier spring planting and a slightly longer growing season and crop yield. But the exposure of soil to winter weather causes significant erosion, eventually resulting in less fertile soil. No-till crop management postpones the tilling until spring, leaving crop residue over the winter to protect soil from erosion and provide long-term benefit.

To encourage the use of conservation techniques, the U.S. Department of Agriculture offers a variety of financial incentive programs to agriculture producers, including the Environmental Quality Incentives Program.

Restoration of Natural Nutrient Controls

Some of the emerging environmental technologies involved in remediation of NPS contamination are not at all what is usually considered "high-tech." But research has shown that riparian areas are highly effective in controlling certain types of contamination, particularly for excess nutrients from agricultural runoff.

A watershed's riparian areas, particularly the wetlands, are capable of removing a majority of incoming nitrate-nitrogen. Wetlands and riparian areas appear to be able to clean up nitrate-containing waters with a very high degree of efficiency and are of major value in providing natural pollution controls for sensitive waters.[71] The table below provides a summary of the functions of the watershed's riparian areas.

Functions of Riparian Areas and their Relationship to Environmental Services*			
Examples of Functions	**Indicators that Functions Exist**	**On-site or Off-site Effects of Functions**	**Goods and Services Valued by Society**
Hydrology and Sediment Dynamics			
Stores surface water over the short term	Floodplain connected to stream channel	Attenuates downstream flood peaks	Reduces damage from flood waters (Daly et al., 1997)
Maintains a high water table	Presence of flood-tolerant and drought-intolerant plant species	Maintains vegetation structure in arid climates	Contributes to regional biodiversity (e.g., forest canopy) provision (Szaro, 1991; Ohmart, 1996; James, et al., 2001)
Accumulates and transports sediments	Riffle-pool sequences, point bars, and other features	Contributes to fluvial geomorphology	Creates predictable yet dynamic channel and floodplain dynamics (Beschta et al., 1987a; Klingeman et al., 1999)
Biogeochemistry and Nutrient Cycling			
Produces organic carbon	Balanced biotic community	Provides energy to maintain aquatic and terrestrial food webs	Supports populations of organisms (Gregory et al., 1991; Meyer and Wallace, 2001)
Contributes to overall biodiversity	High species richness of plants and animals	Reservoirs for genetic diversity	Contributes to biocomplexity (Szaro, 1991; Naiman and Rogers, 1997; Pollock et al., 1998)
Cycles and accumulates chemical constituents	Good chemical and biotic indicators	Intercepts nutrients and toxicants from runoff	Removes pollutants from runoff (Bhowmilk et al. 1980; Peterjohn and Correll, 1984)
Carbon sequestration in soil	Organic-rich soils	Contributes to nutrient retention and sequestration of carbon dioxide from atmosphere	Potential to ameliorate global warming (Van Cleve et al. 1991)
Habitat and Food Web Maintenance			
Maintains streamside vegetation	Presence of shade-producing forest canopy	Provides shade to stream during warm season	Creates habitat for cold-water fish (Beschta et al., 1987b; McCullough 1999)
Supports characteristic terrestrial vertebrate populations	Appropriate species having access to riparian area	Allows daily movements to annual migrations	Supplies objects for birdwatching, wildlife enjoyment, and game hunting (Green and Tunstall, 1992; Flather and Cordell, 1995)
Supports characteristic aquatic vertebrate populations	Migrations and population maintenance of fish	Allows migratory fish to complete life cycles	Provides fish for food and recreation (Nehlsen et al. 1991; Naiman et al. 2000)

*Effects of functions sometimes are expressed off-site. Indicators are often used to evaluate whether or not a function exists, and are commonly used as shortcuts for evaluating the condition of riparian areas. The functions listed are examples only and are not comprehensive.

Source: National Research Council, *Riparian Areas: Functions and Strategies for Management*

Riparian Buffer Zones

A riparian buffer zone can be recreated to perform the watershed functions noted in the table above and at least partially remediate the effects of NPS contamination. While restoration of all natural riparian zones may not be economically or socially acceptable, recreation of streamside buffer systems along many miles in the riparian zone is possible.[72]

"Whether in their natural or in their restored and managed state, riparian buffer systems are true stewards of our streams."

"*Stewards of Our Streams: Riparian Buffer Systems*," Iowa State University Extension

A riparian zone managed as a buffer strip system can be re-established in an area that has been cleared of native vegetation and is no longer functioning properly. Many of the same benefits provided by a natural riparian zone can be provided through restoration of a 66- to 100-foot-wide riparian buffer strip on land that presently is cropped or heavily grazed. A restored, or managed, riparian buffer strip system may be done in several ways, depending on the region and its location within a watershed.[73]

Landowners can use any or a combination of these three components to create a riparian buffer.

- Multi-species buffer strip (tree-shrub-grass).
- Streambank stabilization area (vegetative bioengineering).
- Small, constructed wetland at field tile outlets (wetland).[74]

Model buffer strip adjacent to field crops. Credit: Iowa State University Extension

Wetland constructed at a field tile outlet. Credit: Iowa State University Extension

A multi-species buffer strip is a vegetative area extending a minimum of 66 feet on both sides of a stream where row crops are grown. This width is needed to trap sediment and provide enough time for water moving across the land and into the soil to interact with this "living filter" area. Ideally, the strip should consist of four or five rows of trees planted parallel and adjacent to the stream, with one or two rows of shrubs, and a 20- to 24-foot strip of native warm-season prairie grasses.[75]

Cool-season grasses used in lawns and most pastures do not provide sufficient stems and roots to be effective. In grazed pastures where stream bank stabilization is the major concern, the buffer strip can be 20- to 30-feet wide and livestock should be kept out of the area. The strip can accommodate rotational grazing and controlled water access.[76]

For more information on riparian buffer zones, refer to Multi-Species Buffer Strip Design, Establishment and Maintenance from Iowa State University Extension.

The stabilization of stream banks involves the use of live and dead plant material (trees, shrubs, and grasses), fiber matting, and rock to protect bare stream banks that are easily eroded by the current. Collapsing banks produce up to 50 percent of the sediment in streams. The goal of stream bank stabilization is to re-shape stream banks with permanent vegetation.[77]

Live plant material, typically willow, is placed into the streambed and bank, and anchoring bundles of dead trees are placed as revetments at the toe of the bank in the water. A narrow band of large rocks also can be used in place of the dead plant material. The bundled trees absorb fast-flowing water, physically trap debris and soil, and allow willows to be placed among the bundles to help anchor both into the bank.[78]

A small wetland can be constructed if the adjacent field crop is drained by tile. The wetland should be located within the 66- to 100-foot buffer strip where tiles enter the stream. The idea is to use the natural water purification processes of a wetland. Basically, the wetland provides annual organic matter from cattails to nourish millions of microbes. These microbes consume nitrogen and immobilize many of the herbicides that enter the wetland with the tile water.[79]

The general rule for sizing a constructed wetland is one acre of wetland for every 100 acres of row crop drained by the tile line. To construct a wetland, a small depression is excavated near the tile outlet and a water outflow structure is installed to control water retention time and level. Cattails and bulrushes are planted in the depression, surrounded by a berm that can be planted in prairie grasses and forbes.[80]

For more information on wetland construction, restoration, and enhancement, refer to Wetland Restoration, Enhancement, Creation, & Construction from the USDA and Constructed Wetlands from the U.S. EPA.

Instream Techniques

In addition to riparian buffer zones, instream techniques are sometimes a necessary component in the restoration of a contaminated watershed. Instream techniques are applied directly in the stream channel (e.g., channel reconfiguration and realignment to restore geometry, meander, sinuosity, substrate composition, structural complexity, re-aeration, or stream bank stability).[81]

Balancing and integrating instream, riparian, and surrounding watershed approaches is essential. Any restoration plan could involve a combination of techniques, depending on environmental conditions and stressors to be addressed. Instream and riparian techniques directly restore the integrity of stream habitat, whereas surrounding watershed techniques focus on the elimination or mitigation of stress sources that cause the habitat degradation.

Because surrounding watershed techniques tend to facilitate a system's ability to restore itself, instream techniques may not always be necessary.[82]

Watershed Management Approach—Prevention and Remediation Tool

In the last decade, the U.S. has made some headway in addressing NPS contamination. At the federal level, recent NPS control programs include the Nonpoint Source Management Program established by the 1987 Clean Water Act Amendments, and the Coastal Nonpoint Pollution Program established by the 1990 Coastal Zone Management Act Reauthorization Amendments.[83]

In addition, public and private groups have developed and used pollution prevention and pollution reduction initiatives and NPS pollution controls, known as management measures, to clean up water efficiently. Water quality monitoring and environmental education activities supported by government agencies, tribes, industry, volunteer groups, and schools are providing information about NPS contamination and are helping to determine the effectiveness of management techniques.[84]

As a result of these experiences, the watershed approach has become one of the most effective strategies for protecting and restoring aquatic ecosystems and protecting human health. This strategy's premise is that many water quality and ecosystem problems are best solved at the watershed level rather than at the individual water body or discharger level. Major features of a watershed approach are:

- targeting priority problems.
- promoting a high level of stakeholder involvement.
- integrated solutions that make use of the expertise and authority of multiple agencies.
- measuring success through monitoring and other data gathering.[85]

For more information on the watershed approach to remediation and prevention, refer to:

- California Watershed Assessment Manual from University of California–Davis.
- Watershed approach to water quality management from Texas A&M University.
- What is a Watershed? from the U.S. Forest Service.
- Principles of Watershed Management and Online Watershed Management Training from the U.S. EPA.
- Watershed Management from the Illinois EPA.
- Watershed Management from the West Virginia Department of Environmental Protection.
- Watershed Plans from the State of New York.

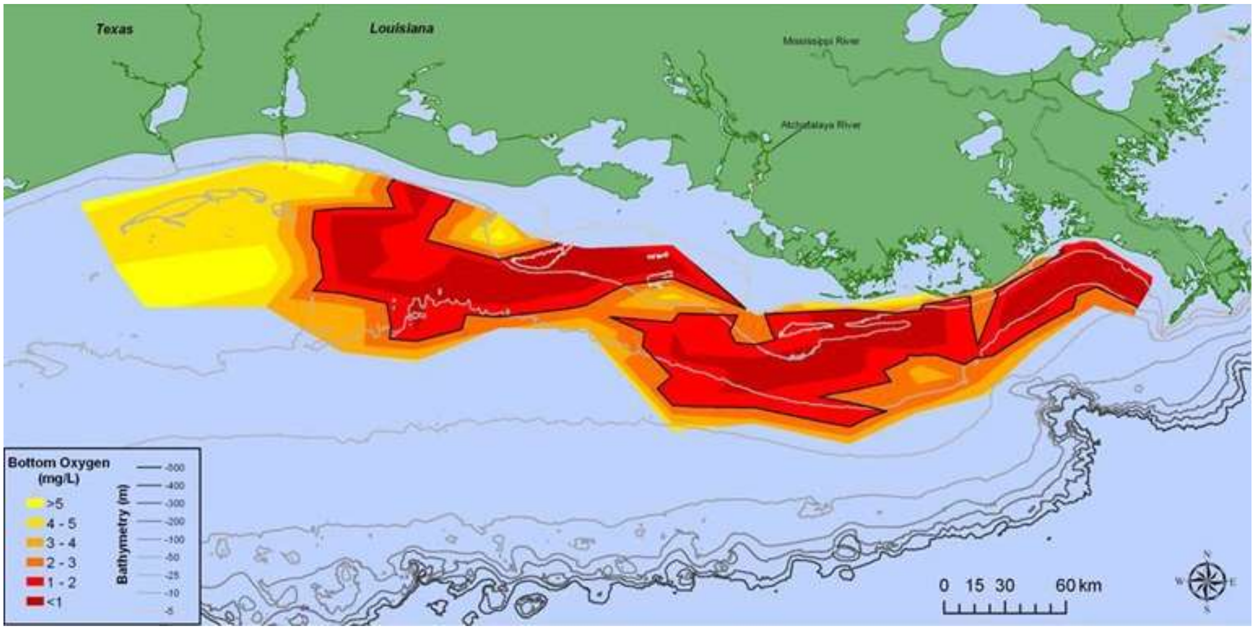
Aids to Understanding provides resources and activities.

Case Study–The Northern Gulf of Mexico's "Dead Zone"

Introduction

Satellite photo of Mississippi River delta. Credit: NASA

Scientific investigations in the Gulf of Mexico have documented a large area of the Louisiana continental shelf with seasonally depleted oxygen levels (< 2 mg/l). Most aquatic species cannot survive at such low oxygen levels. The oxygen depletion, referred to as hypoxia, begins in late spring, reaches a maximum in midsummer, and disappears in the fall. This hypoxic zone, shown above as the cross-hatched area, forms in the middle of the most important commercial and recreational fisheries of the contiguous United States and could threaten the economy of this region of the Gulf.[86] Because most marine life is unable to survive in such an environment, hypoxic zones have been dubbed "dead zones."



Distribution of bottom-water dissolved oxygen July 28-August 3, 2015 (west of the Mississippi River delta).
Black line indicates dissolved oxygen level of 2 mg/L.
Data: Nancy R. Rabalais, LUMCON, and R. Eugene Turner, LSU. Credit: NOAA

One of these dead zones forms each summer in the Gulf of Mexico just west of the mouth of the Mississippi River. From the 1993 Mississippi River floods to 2015, the zone ranged in size from 16,000 to 22,000 km^2 (9,942 to 13,670 sq. mi.). At 20,000 km^2 it was roughly the size of the state of New Jersey. The summer of 2002 saw the zone area increase to a record 22,000 km^2 (13,670 sq. mi.), extending into the Texas coastal waters. From fall to early spring, the area experiences a seasonal recovery. Researchers now agree that the hypoxic zone is partly the result of the huge loads of nutrients that pour out of the Mississippi and Atchafalaya Rivers every year during farming season. This nutrient load combines with seasonal warm temperatures and Gulf mixing patterns that separate surface waters from bottom waters, creating hypoxic conditions each year.[87]

Contour maps are available online that depict the latest scientific measurements of the oxygen depletion in the ocean bottom. See NOAA's Gulf of Mexico Hypoxia Watch, EPA's Mississippi River/Gulf of Mexico Hypoxia Task Force, and research from the Louisiana Universities Marine Consortium Network.

Multiple sources (both point and nonpoint) contribute to excessive nutrients in watersheds. The transport and delivery of these nutrients is a complex process that is controlled by a range of factors, including the chemistry, ecology, hydrology, and geomorphology of the various portions of both the watershed and the receiving system.[88]

The nutrient of main concern in the northern Gulf is nitrogen, accumulated primarily from the many watersheds in the Mississippi River. Together, the cities, suburbs, and farms in the Mississippi River watershed contribute an estimated 90 percent of the nutrient flow into the Gulf of Mexico.[89]

Mississippi/Atchafalaya River Basin

Credit: EPA

The natural capacity of the Mississippi/Atchafalaya River Basin (MARB) to remove nutrients has been diminished by a range of human activities. The Mississippi is one of the most heavily engineered rivers in the U.S. Over time, the character of the old river meanders and floodplains have been modified for millions of acres of agriculture and urbanization. Many of the original freshwater wetlands, riparian zones, and adjacent streams and tributaries along the Mississippi have been disconnected from the river by levees and other engineering modifications. This has caused a loss of habitat for native plants and animals and has reduced the biological productivity of the entire river basin.[90]

Over a period of 200 years, from the 1780s to the 1980s, the continental United States lost an estimated 53 percent of its original wetlands. Ohio, Indiana, Illinois, and Iowa have had more than 80 percent of their wetlands drained. Indiana, Illinois, Iowa, Minnesota, Missouri, Ohio, and Wisconsin collectively have lost the equivalent of 14.1 million hectares (35 million acres) of wetlands. Louisiana, Mississippi, Arkansas, and Tennessee have also experienced wetland losses that collectively exceed 50 percent.[91]

Major causes of wetland loss and riparian zone degradation include both human actions and natural processes, sometimes resulting from or accelerated by human actions far removed from the river basin itself.[92]

Human actions include:

- drainage for agriculture
- dredging and stream channelization
- deposition of fill material
- dams and levees
- tilling for crop production
- logging
- mining
- construction
- runoff
- air and water pollutants
- changing nutrient levels
- toxic chemicals
- introduction of non-native species
- grazing by domestic animals[93]

Natural processes include:

- erosion
- subsidence
- sea level rise
- droughts
- hurricanes and other storms[94]

Satellite photo of Mississippi River Basin. Credit: NASA

The Upper Mississippi River Basin—Downstream Effects

Most of the excess nutrient load in the Mississippi River originates in the Upper Mississippi River (UMR) Basin. In 1986, Congress recognized the UMR Basin as a nationally significant ecosystem. The UMR extends northward more than 850 miles, from the confluence of the Mississippi and Ohio rivers to the Twin Cities in Minnesota. The floodplain includes 2,110,000 acres of land and water. The UMR is part of a major migration corridor for waterfowl and provides habitat for more than 150 fish and 40 freshwater mussel species.[95]

Since 1824, the federal government has implemented numerous changes on the UMR. The river was first modified by removing snags and sandbars. Changes then progressed to rock excavation, elimination of rapids, closing of side channels, and the construction of hundreds of wing dams, 27 navigation dams, and miles of levees.[96]

Construction of the navigation dams (mostly during the 1930s) significantly altered the northern 650 miles of the UMR (north of St. Louis, Missouri) by increasing the amount of open water and marsh areas. Wing dams and levees altered aquatic habitats south of St. Louis (the open river) by reducing open-water habitats and isolating the river from much of the floodplain. Most of the changes to the river ecosystem were designed either for navigational improvements or to control the movement of river water (e.g., flooding, recreation).[97]

> "Hypoxia is the result of living in an over-fertilized society. **We fertilize the living daylights out of the Midwest.**"
>
> "*Can Ecotechnology Cure the Dead Zone*?" Environmental News Network

The loss of wetlands and other riparian areas along the UMR is a major problem in controlling NPS runoff from agriculture in the Midwest. The U.S. Fish and Wildlife Service (FWS), responsible for studying the status and trends of U.S. wetlands, notes that the years from the mid-1950s to the 1970s saw dramatic wetlands losses, calculated at 458,000 acres per year. From the mid-1970s to the mid-1980s, the annual wetland loss rate was calculated at 290,000 acres per year, a reduction of about 37 percent from the previous two decades. The latest data indicate that the rate of overall wetland loss has slowed even further, although the United States is still losing more than 58,000 acres of wetlands annually.[98]

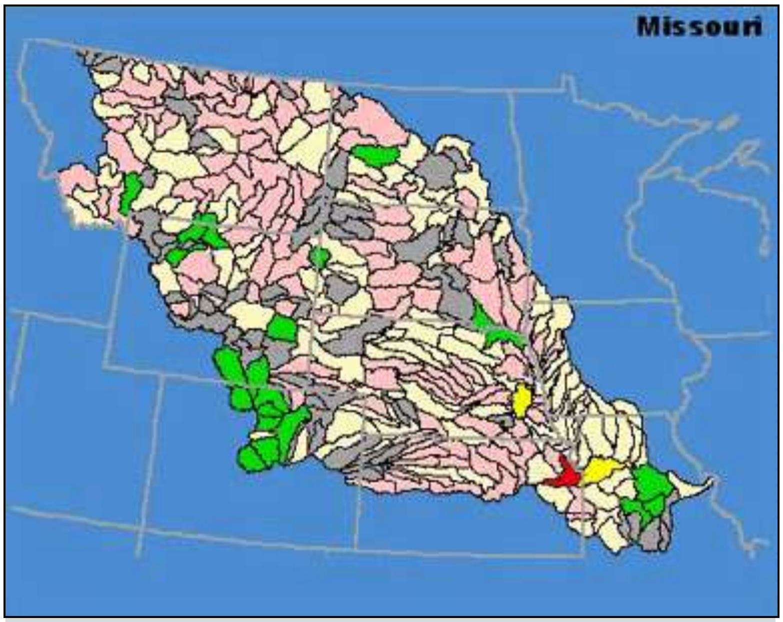
The FWS also found that certain areas in the southeast U.S., primarily freshwater wetlands of the Atlantic and Gulf coastal plains, experienced the greatest share of the loss. This is particularly important to studies of the Mississippi River Basin, since coastal wetlands are a major component of its delta as it flows into the northern Gulf of Mexico.[99]

Louisiana's coastal zone contains 41 percent of U.S. coastal wetlands and 25 percent of all U.S. wetlands, making it one of the earth's largest and richest estuarine areas. The loss of these wetlands influences the amount of nitrogen that can be removed from the aquatic system before it flows into the Gulf.[100]

Six Major MARB Subbasins

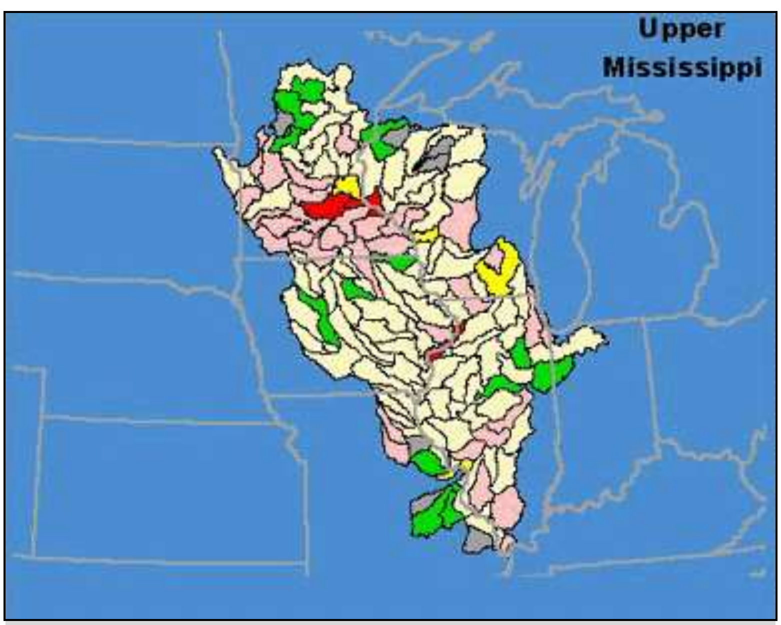
The following illustrations depict the major subbasins of the Mississippi/Atchafalaya River Basin, percent of total nitrogen load, and the U.S. EPA water quality estimate.[101]

- Missouri/Platte–13%



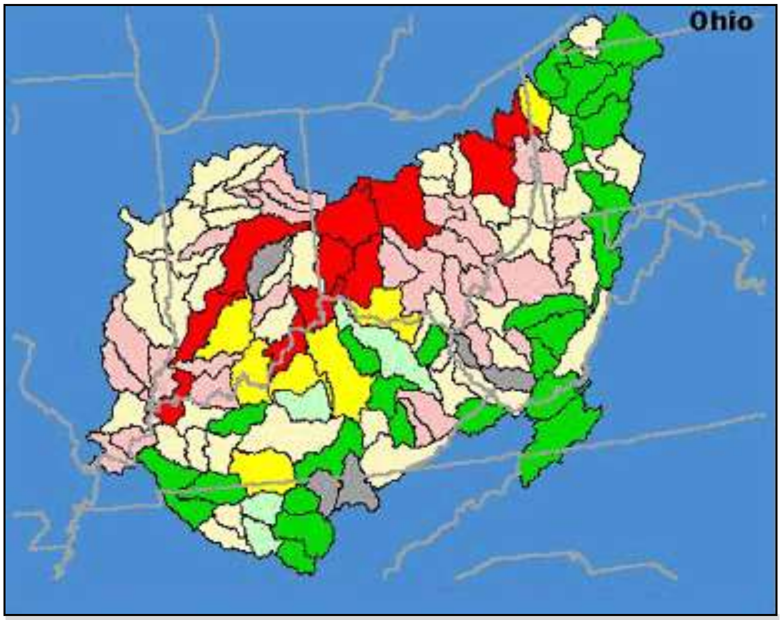
Credit: U.S. EPA

- Upper Mississippi–39%

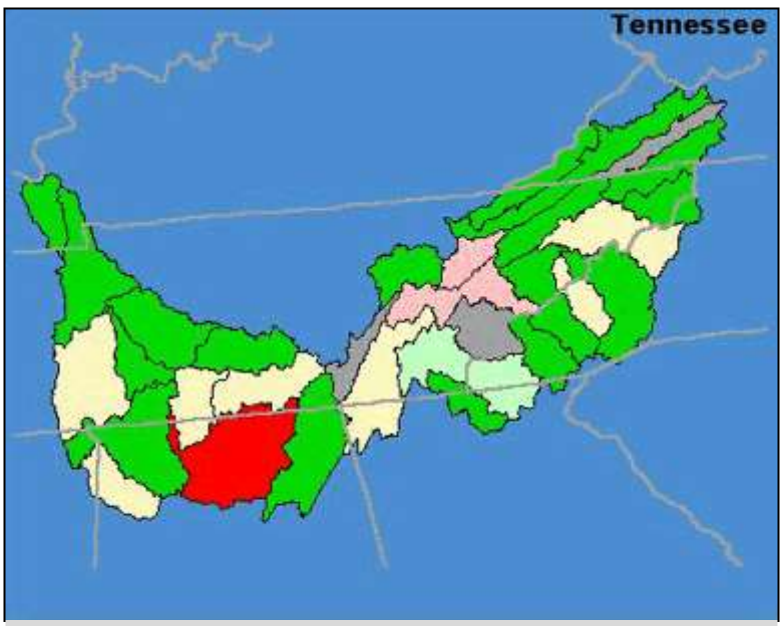


Credit: U.S. EPA

- Ohio/Tennessee–41%

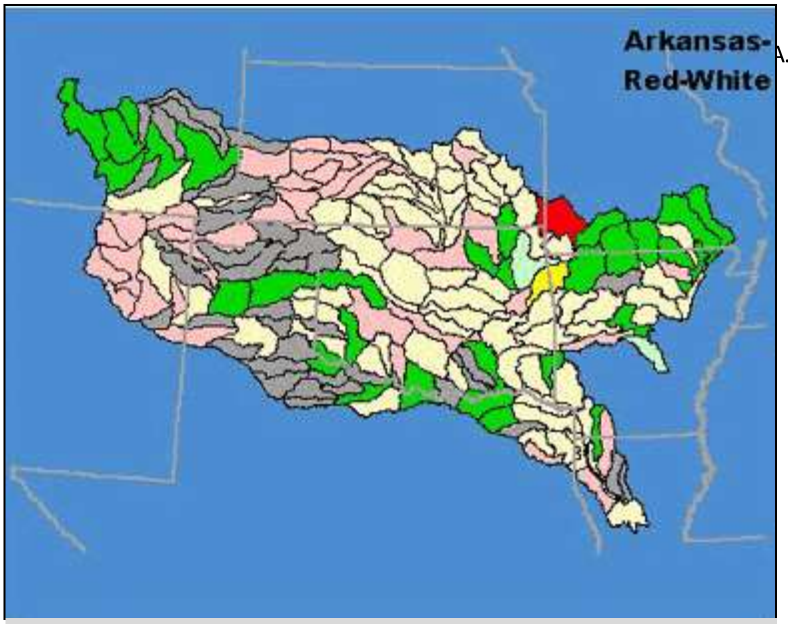


Credit: U.S. EPA



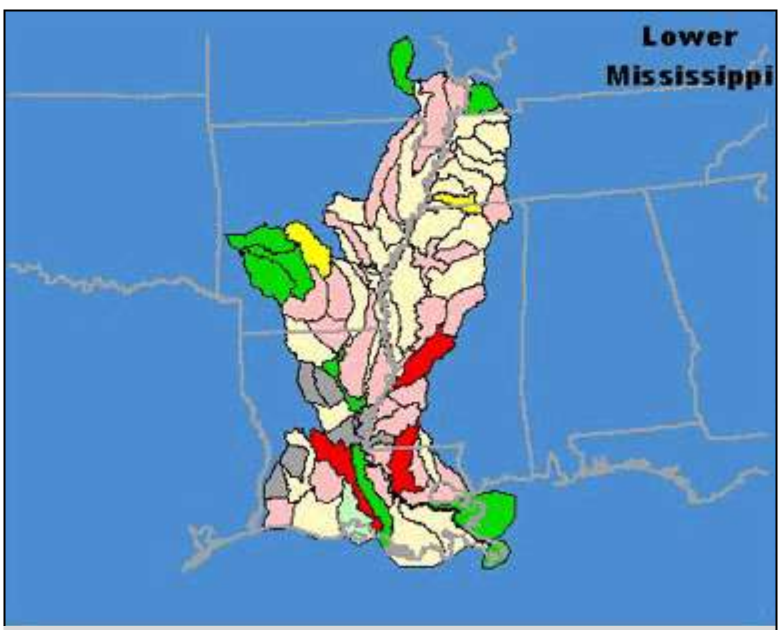
Credit: U.S. EPA

- Arkansas-Red-White–6%



Credit: U.S. EPA

- Lower Mississippi/Atchafalaya–1%



Credit: U.S. EPA

Threats and Contaminants

Nutrients—primarily nitrogen and phosphorus, but sometimes also including silica, iron, zinc, and magnesium—are necessary for plant growth. An overabundance of these nutrients, combined with enough light and warm, slow-moving, poorly-mixed water, can result in an algae bloom. This bloom is the first step in the chain of reactions that can lead to hypoxia.[102]

These overabundant nutrients may come from point sources such as wastewater treatment plant discharges and nonpoint sources such as agricultural activities, urban runoff, groundwater, and atmospheric deposition. The amount of contaminants generated and the rate at which they reach rivers, estuaries, and coastal waters are increased by human activities such as the destruction of wetlands, grasslands, and forests in favor of urban or suburban landscapes and poor agricultural practices.[103]

Hypoxia and the Northern Gulf of Mexico

> "Scientists have found this year's [2015] Gulf of Mexico dead zone—an area of low to no oxygen that can kill fish and marine life—is, at 6,474 square miles, above average in size and larger than forecast by NOAA in June. The larger than expected forecast was caused by heavy June rains throughout the Mississippi River watershed.
>
> The largest previous Gulf of Mexico dead zone was in 2002, encompassing 8,497 square miles. The smallest recorded dead zone measured 15 square miles in 1988. The average size of the dead zone over the past five years has been about 5,500 square miles, nearly three times the 1,900 square mile goal set by the Hypoxia Task Force in 2001 and reaffirmed in 2008."
>
> *"2015 Gulf of Mexico dead zone 'above average',"* NOAA

Hypoxia means "low oxygen." In aquatic ecosystems, low oxygen usually means a concentration of less than 2 to 3 milligrams of oxygen per liter of water (mg/l). A complete lack of oxygen (0 mg/L) is called anoxia. These areas are sometimes called "dead zones," since only organisms that can live without oxygen (such as some microbes) can survive there. Hypoxia is primarily a problem in estuaries and coastal waters, although it can also be a problem in freshwater lakes. The direct effects of hypoxia include fish kills, which deplete valuable fish stocks and damage the ecosystem, are unpleasant for local residents, and can harm local tourism.[104]

The largest area of hypoxia in the Atlantic Ocean forms in the Gulf of Mexico during spring of most years when the Mississippi River delivers its highest load of freshwater and accompanying nutrients. The nutrients, particularly nitrogen and phosphorus, stimulate the growth of microscopic plants, the phytoplankton. These single-celled plants are either assimilated into the marine food web or end up as organic debris on the sea floor. The decomposition of this organic matter by bacteria depletes the oxygen to a point lower than what is necessary to sustain the life of most marine animals.[105]

A crucial component to formation of hypoxia is water stratification, or layering. In the northern Gulf, summer heat, calm winds, and low waves create conditions in which the nutrient-laden water delivered from the Mississippi and Atchafalaya Rivers does not mix well with the heavier saltwater near the bottom. While dissolved oxygen remains in the lighter surface water, the oxygen in the bottom layer of water is continuously depleted from the decay of organic matter. This two-layer system prevents the mixing patterns that normally separate surface waters from bottom waters and prevents oxygen from reaching the bottom.

Oxygenated water is necessary for aquatic animals to breathe. Mobile animals, such as adult fish, can often survive hypoxia by moving into oxygenated waters. When they cannot, such as when young fish need to spend time in the habitat that has become an hypoxic area, the result is a fish kill. Non-mobile animals, such as clams, cannot move into healthier waters and are often killed by hypoxic episodes. This causes a severe reduction of the amount—or in extreme cases the complete loss—of animal life in hypoxic zones.[106]

> "Some 7 million metric tons of nitrogen, about 30% of the total flowing into the gulf, come from fertilizer, and that total has risen sixfold over the last 50 years. 56% of the nitrogen inputs into the Mississippi are from five heavily farmed Midwestern states, with Iowa and Illinois the biggest sources."
>
> *"Keeping the Stygian Waters at Bay,"* Science magazine

Because hypoxia often occurs in estuaries or near shore areas where the water is poorly mixed, nursery habitat for fish and shellfish is often affected. Without nursery grounds, the young animals cannot find the food or habitat they need to reach adulthood. This causes years of weak recruitment to adult populations and can result in an overall reduction or destabilization of important stocks.[107]

Fish-eating birds and mammals, such as herons or otters, cannot live where there are no fish. Hypoxic areas may also be more susceptible to overfishing, pest outbreaks, storm damage, or other stresses.[108]

Chemical reactions between hypoxic water and bottom sediments can release contaminants stored in the sediments, further fueling the hypoxic conditions or otherwise polluting the ecosystem.[109]

A recent report from the National Research Council, *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*, concluded that:

- Nutrient over-enrichment of coastal ecosystems generally triggers ecological changes that decrease the biological diversity of bays and estuaries.
- While moderate nitrogen (N) enrichment of some coastal waters may increase fish production, over-enrichment generally degrades the marine food web that supports commercially valuable fish.
- The marked increase in nutrient contamination of coastal waters has been accompanied by an increase in harmful algal blooms, and in at least some cases, contamination has triggered these blooms.

- High nutrient levels and the changes they cause in water quality and the makeup of the algal community are detrimental to the health of coral reefs and the diversity of animal life supported by seagrass and kelp communities.
- Research during the past decade confirms that N is the chief culprit in eutrophication and other impacts of nutrient over-enrichment in temperate coastal waters, while phosphorus (P) is most problematic in eutrophication of freshwater lakes.
- Human conversion of atmospheric N into biologically useable forms, principally synthetic inorganic fertilizers, now matches the natural rate of biological N fixation from all the land surfaces of the earth.
- Both agriculture and the burning of fossil fuels contribute significantly to nonpoint flows of N to coastal waters, either as direct runoff or airborne contaminants.
- N from animal wastes that leaks directly to surface waters or is volatilized to the atmosphere as ammonia may be the largest single source of N that moves from agricultural operations into coastal waters.[110]

Science in Decision-Making

As part of the decision-making process for considering options for response to the hypoxia problem, the EPA formed a hypoxia task force in 1997. The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force is a collaboration of a variety of organizations to support management decisions and actions intended to reduce excess nutrients in the Mississippi River Basin and hypoxia in the northern Gulf of Mexico.

In 1998, Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act (latest update in 2014) requiring that an integrated assessment be conducted to provide scientific information as a basis for decision-making and that an action plan be developed based on the assessment. As part of the Mississippi River/Gulf of Mexico Task Force, the National Science and Technology Council's Committee on Environment and Natural Resources (CENR) coordinated the assessment effort.

In addition to initial and subsequent hypoxia assessments, action plans have been developed and implemented to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico.

Final Integrated Assessment

Several key points are identified in the integrated assessment.

- Hypoxia in the northern Gulf of Mexico is caused primarily by excess nitrogen delivered by the Mississippi-Atchafalaya River Basin in combination with stratification of Gulf waters.
- About 90 percent of the nitrate load to the Gulf comes from nonpoint sources. About 56 percent of the load enters the Mississippi River above the Ohio River, and the Ohio basin adds 34 percent. Principal sources are basins draining agricultural lands in Iowa, Illinois, Indiana, southern Minnesota, and Ohio.

- Gulf ecosystems and fisheries are affected by hypoxia. Mobile organisms leave the hypoxic zone for healthier waters, and those that cannot leave die at varying rates, depending on how low the oxygen level gets and for how long. Fish, shrimp, zooplankton, and other important fish prey are significantly less abundant in hypoxic bottom waters.
- A 40 percent reduction in total nitrogen flux to the Gulf is necessary to return to loads comparable to those during 1955 to 1970.
- Based on basin-scale analyses, the primary approaches to reduce hypoxia in the Gulf of Mexico appear to be to: (1) reduce nitrogen loads to streams and rivers in the Basin and (2) restore and enhance denitrification (a process that removes nitrogen from the system) and nitrogen retention within the Basin.
- While this assessment suggests that changes in agricultural practices could provide many elements of a solution at least cost to society overall, analyses contributing to this assessment identified several possible approaches to sharing the burden of nutrient load reductions among all sectors in the Mississippi drainage. There are no single solutions to managing hypoxia in the Gulf.
- Increasing the acreage of wetlands and vegetated riparian buffers within the Basin would enhance denitrification, increase nitrogen retention, and decrease the amount of nitrogen entering streams and rivers.
- A comprehensive monitoring program is needed to measure environmental pressures and responses and programmatic progress in the Gulf and in the Basin.[111]

For complete details, refer to NOAA's integrated assessment.

Action Plan

The current Hypoxia Action Plan is a national plan to reduce the size of the hypoxic zone by about half the average size over the next 15 years. States, tribes, and the relevant federal agencies along the Mississippi and Atchafalaya river basins and the Gulf agreed to the actions in the plan including preparing watershed strategies to reduce the amount of nutrients, particularly nitrogen, entering their waters.[112]

These strategies may include setting reduction targets for nitrogen discharges to surface waters, establishing a baseline of existing efforts for nutrient management, identifying opportunities to restore flood plain wetlands (including restoration of river inflows) along and adjacent to the Mississippi River, and detailing needs for additional assistance to meet their goals. The best current scientific understanding of the hypoxic zone indicates that these strategies should aim at achieving a 30 percent reduction in nitrogen discharges to the Gulf over the next 15 years.[113]

"The northern gulf 'is not too far gone,' says Robert Diaz [of the Virginia Institute of Marine Science], who thinks that the waters run the risk of reprising conditions in the Black Sea in the 1970s and 1980s: hypoxia year-round. By choking off nitrogen at its source, Diaz says, 'the gulf will turn around.'"

"Keeping the Stygian Waters at Bay," Science magazine

Under the action plan, states, tribes, and relevant federal agencies, working as river-basin committees, would have flexibility to develop the most effective and practical strategies to reduce discharges of excess nutrients to their waters. The strategies are expected to rely heavily on voluntary and incentive-based approaches for dealing with agricultural and urban runoff, restoring wetlands, and creating vegetative or forested buffers along rivers and streams within priority watersheds.[114]

States, tribes, and federal agencies along the Mississippi River Basin and Gulf have committed to pursue continued research and monitoring to better understand this problem and use the information as a basis to modify restoration goals and actions as necessary in the future. The action plan calls for new resources to fund these activities.[115]

Uncertainty in the Scientific Data

Gathering and analyzing large quantities of scientific data does not ensure that scientists and decision-makers will reach the same conclusions based on that data. Consider these varying opinions.

> Experts say they have made a compelling case tracing the bulk of the nitrates to human activity. In a study in [the July 2001] *Eos*, "Transactions," American Geophysical Union, hydrologist Donald Goolsby of the U.S. Geological Survey (USGS) in Denver used water-quality monitoring data from 42 watersheds in the Mississippi Basin to model the nitrogen cycle throughout the basin. Some seven million metric tons of nitrogen, about 30 percent of the total flowing into the gulf, came from fertilizer, and that total has risen sixfold over the last 50 years. An equal amount came from soil decomposition and the rest from sources such as animal manure, sewage treatment plants, airborne nitrous oxides, and industrial emissions. Goolsby also found that 56 percent of the nitrogen inputs into the Mississippi are from five heavily farmed Midwestern states, with Iowa and Illinois the biggest sources. Other studies have come to similar conclusions.
>
> While acknowledging that the dead zone is real, farm advocacy groups…argue that the link between the use of nitrogen-based fertilizers and the dead zone remains unproven. "We need a cause-and-effect relationship before we can successfully pursue any remedial actions in this area, and those simply don't exist," says the American Farm Bureau Federation.
>
> Jonathan Pennock of the University of Alabama's Dauphin Island Sea Lab and his colleagues issued a report in May 1999 that cast doubt on the role of fertilizer, instead blaming increases in river flow and organic matter swept downstream. The Fertilizer Institute, a Washington, DC-based industry trade group, funded the report.
>
> The most visible skeptic is Derek Winstanley, chief of the Illinois State Water Survey, who argues that nitrogen levels have always been high in rivers that feed the Mississippi, and that the dead zone is a natural phenomenon that may have plagued the gulf for centuries. Winstanley has roused political opposition to any dead zone fix that focuses on cutting nitrogen runoff in upstream states.[116]

Habitat Loss and Restoration

Throughout the Mississippi River Basin, significant quantities of habitat have been lost, ecosystems altered, and hydrologic regimes changed. These have resulted in alterations to the way water moves from one end of the basin to the other. These alterations have also resulted in seasonal pulses and distribution of flow, nutrients, and sediments.

> "The bottomland hardwood-riparian wetlands along the Mississippi River once stored at least 60 days of floodwater. Now they store only 12 days because most have been filled or drained."
>
> *"America's Wetlands: Our Vital Link Between Land and Water," U.S. EPA*

The navigation system (as it extends from the Gulf of Mexico to the Twin Cities to the north, Omaha to the west, and Pittsburgh to the east) has resulted in alteration of habitat as well as the way the rivers interact with their floodplain. For example, dams, channel straightening, and levees (constructed to minimize property damage during flooding) increase the risk of flooding and habitat change downstream.

Above the confluence with the Missouri, the Upper Mississippi River is not a free flowing river, but a series of shallow lakes where the water level is maintained at a specific depth to support navigation. The Ohio River has been altered in a similar manner. The creation of this series of lakes has resulted in significant changes to floodplain habitat, flora and fauna, as well as the inundation and drying that would occur naturally. In the Mississippi Delta region, roughly 95 percent of the floodplain forest has been lost.

Technology Tools for Watershed Management

One of the main watershed management technology tools being used to address Mississippi River watershed nonpoint source pollution is the Better Assessment Science Integrating Nonpoint and point Source (BASINS) software. The U.S. EPA's water programs and their counterparts in states and pollution control agencies are increasingly emphasizing watershed and water quality-based assessment and integrated analysis of point and nonpoint sources.[117]

Satellite photo of Mississippi River delta. Credit: NASA

BASINS is a multi-purpose environmental analysis system that is used by regional, state, and local agencies to perform watershed and water quality-based studies. The software integrates a geographical information system (GIS), national watershed data, and environmental assessment and modeling tools.[118]

BASINS is intended to address three main objectives.

- Facilitate examination of environmental information.
- Provide an integrated watershed and modeling framework.
- Support analysis of point and nonpoint source management alternatives.[119]

For an online overview of surface water modeling, refer to the U.S. EPA Watershed Academy's Watershed Modeling module.

For more information on:

- modeling software for specific functions, refer to Measuring and Monitoring in this module.
- BASINS software and accompanying educational materials, refer to the BASINS website.

Aids to Understanding provides resources and activities.

Aids to Understanding

Contaminant Formation and Environmental Impact

Several sites provide good background information about ground water.

- Groundwater Basics at the Groundwater Foundation.
- Ground Water Fundamentals at the National Ground Water Information Center.
- The Universities Water Information Network (UWIN) Home page at Southern Illinois University.

Resources

The U.S. EPA has several good Web pages related to contaminant formation and the impact on the environment.

- Consider the Source: A Pocket Guide to Protecting Your Drinking Water
- How EPA Regulates Drinking Water Contaminants
- National Water Quality Inventory Report

The RunningDry.org website provides information on global and national water use issues, including videos.

- Running Dry
- The American Southwest: Are We Running Dry?
- Running Dry: Beyond the Brink

Fate and Transport

Resources

"Research on Processes that Control Nutrient Transport, Fate, and Effects in the Mississippi River Basin," USGS.

The Syracuse Research Corporation has an excellent Environmental Fate Database available as an eBook.

For access to a variety of Surface Water Models, see the EPA's website.

See EPA's Contaminant Fate and Transport.

The Ralph M. Parsons Laboratory at the Massachusetts Institute of Technology conducts an extensive research program in environmental chemistry and biology, hydrology, and fluid mechanics.

The U.S. EPA website has several informative links related to fate and transport of ground water contaminants.

- Fate, Transport and Transformation Test Guidelines
- EPA Center for Exposure Assessment Modeling (CEAM)
- "Computer models for the simulation of contaminant transport and fate"

The Conservation Technology Information Center at Purdue University provides "Groundwater and Surface Water: Understanding the Interaction," an excellent source of basic information.

The USDA has a wealth of online information about agricultural effects on water quality, from its various departments, including Agricultural Research Service, Natural Resources Conservation Service, National Agriculture Library, and more.

For a detailed analysis of the fate and transport of chemicals, see *Chemical Fate and Transport in the Environment* (Third Edition) by Harold F. Hemond and Elizabeth J. Fechner-Levy, 2014, Burlington, MA: Academic Press.

Activities

The websites below are excellent sources for activities related to water contaminant formation and environmental impact:

From the U.S. EPA's Watershed Information Network:

- Surf Your Watershed
- Online Watershed Academy
- State Watersheds

The U.S. EPA offers many resources for learning activities on water and water related science in Lesson Plans, Teacher Guides, and Online Resources for Educators.

The U.S. Fish and Wildlife Service's National Wetlands Inventory offers several resources for activities, including an interactive mapping tool and downloadable maps and data.

The state of Washington's Department of Ecology offers "Classroom Curriculum Guides" for educators.

Take a virtual Watershed Tour from Ohio State University Extension.

The Nature Conservancy offers "Forest to Faucet: Educator Resources," with lesson plans and resources to help connect students with our natural lands and waters.

Activity: Local Watersheds

Assign students the task of using the resources provided in this module, as well as local resources, to determine if local watersheds are or have ever been contaminated from a nonpoint source. Conduct a class discussion or assign a report or class presentation to discuss the findings.

Measuring and Monitoring

Resources

ASTM International has published consensus standards for materials, products, systems, and services in 130 industry areas. The ASTM publications below relevant to ground water may be ordered via the ASTM International website.

- *ASTM E943-08 Standard Terminology Relating to Biological Effects and Environmental Fate.*
- *ASTM E1527-13 Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process.*
- *ASTM E1903-11 Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process.*

The Federal Remediation Technologies Roundtable's Field Sampling and Analysis Technologies Matrix is an online encyclopedia that provides information about technologies used in the field to characterize contaminated soil and ground water and to monitor remediation progress.

The U.S. Geological Survey conducts extensive water research programs. The websites below provide additional information.

- USGS National Research Program
- Modeling Software
- Water Resources Surface Water Software
- Water Resources of the United States
- "National Field Manual for the Collection of Water-Quality Data"

The U.S. EPA's National Aquatic Resources Survey (NARS) group develops data and application tools to monitor and assess the status and trends of national ecological resources. The NARS website provides a wealth of data, documents, and links to additional water-related resources.

Several useful resources are available on the U.S. EPA website.

- Field Analytical and Site Characterization Technologies: Summary of Applications
- Performance Based Measurement System
- Analytical Methods Approved for Drinking Water Compliance Monitoring
- Field Analytic Technologies
- Methods, Models, Tools, and Databases for Water Research
- Drinking Water Analytical Methods
- Clean Water Act Analytical Methods
- Potential Contaminant Source Inventory Process Manual

The U.S. Department of Agriculture hosts the Water Quality Information Center, an online database of information about water and agriculture.

Printed resources include:

- *Standard Methods for Examination of Water and Wastewater* by the American Public Health Association, the American Water Works Association, and the Water Environment Federation, 2012.
- *Statistical Methods for Detection and Quantification of Environmental Contamination* by Robert D. Gibbons and David E. Coleman, John Wiley & Sons, Ltd., 2001.

Activities

The websites below are excellent sources for activities related to ground water contaminant formation and environmental impact.

- Evaluating the Condition of Your Private Water Supply and Evaluating the Condition of Your Public Water Supply, and Interpreting Drinking Water Test Results
- Water Data and Tools
- Real-Time Water Data
- National Water Quality Assessment Program (NAWQA)
- Water Science School
- Toxic Substances Hydrology Program Investigations

The University of Minnesota's "Water on the Web" program offers several related lesson plans. Try Modeling Water Quality, which includes three exercises in data analysis and interpretation integrating RISS data interpretation, GIS analyses, and modeling exercises.

The National Geospatial Data Asset website offers online water-related map creation, tools that allows individuals to create custom maps of their own communities.

The U.S. Fish and Wildlife Service's National Watershed Inventory website includes a Wetlands Interactive Mapper Tool, with wetlands data, high-resolution hydrology and transportation, and fish and wildlife refuges. The map allows students to zoom into areas by county, city, ZIP code, FWS refuge, or latitude/longitude.

The Canada Center for Remote Sensing, part of the Natural Resources Canada, offers the tutorial Fundamentals of Remote Sensing on its website.

NOAA's Ocean Service Education website provides lesson plans and activities on water.

Decision-Making

Resources

Note: For further details on the role of science in public policy and decision-making, refer to "Environmental Decision-Making" in this *Technology and Environmental Decision-Making* series of modules.

Useful U.S. EPA documents include:

- Regulatory Information By Topic: Water
- Water Quality Standards: Regulations and Resources

The non-profit National Council for Science and the Environment sponsored the first National Council on Science, Policy, and the Environment in December 2000. The report from that conference includes *Recommendations for Improving the Scientific Basis for Environmental Decisionmaking*.

Activities

Activity: Local Watershed and Public Policy

The National Park Service (NPS) provides a free mapping activity called How Much Water Is In My Backyard? It introduces students to geographic information science, while gathering and implementing the data to investigate the quality of your local watershed.

Remediation

Resources

Chapter 2 of The Nature Conservancy Conservation Forestry Program's Forest Operations Manual focuses on "Protecting Water Quality."

The USDA's Agriculture Research Service offers a tremendous amount of online data about remediation techniques used throughout the U.S. on its Water Management Systems Research website. It contains projects, publications, software, and much more.

The U.S. EPA offers easy-to-read guides to remediation and technology.

- Technologies for Cleaning Up Contaminated Sites
- "A Citizen's Guide to Bioremediation"

The U.S. Geological Survey provides excellent resources on natural attenuation.

- "Bibliography of Research Publications on Natural Attenuation and Biodegradation"
- "Cross-Cutting Topics: Natural Attenuation and Biodegradation of Contaminants"

Activities

Lesson Planet provides teachers with a variety of activities on water pollution and wetlands restoration.

Watershed management lesson plans are available from the Ohio Watershed Network, including "Modeling a Watershed;" "Phosphates, Nitrates and Eutrophication;" and "Lab on Pollution Source."

Utah State University Extension offers teacher resources on its Water Pollution Lesson Plans webpage.

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