

Land Use and Water Quality

Streams, rivers, and lakes are an important part of the landscape, as they provide water supply, recreation, and transportation for humans, and a place to live for a variety of plants and animals. Groundwater also is an important water resource that serves as a source of drinking water for more than 140 million people in the United States.

The fate of rain that falls on the land is strongly affected by land use. In a forest or grassy area, most rain soaks into the soil (infiltrates), where it eventually is used by growing plants or percolates to ground water. Ground water flows slowly into streams, usually over a period of months, providing steady base flow (flow in streams in times without rainfall) that fish and other aquatic life need. By contrast, most rain that falls on a parking lot runs off immediately, often draining into storm sewers that transport it to a stream or ditch.

In some areas, contamination from natural and human sources has affected the use of these waters. For example, naturally occurring minerals within bedrock can impair the taste of groundwater and in some cases limit its use. The spilling, leaking, improper disposal, or intentional application of chemicals at the land surface can result in runoff that contaminates nearby streams and lakes, or infiltration that contaminates underlying aquifers (see the illustration on page 2).

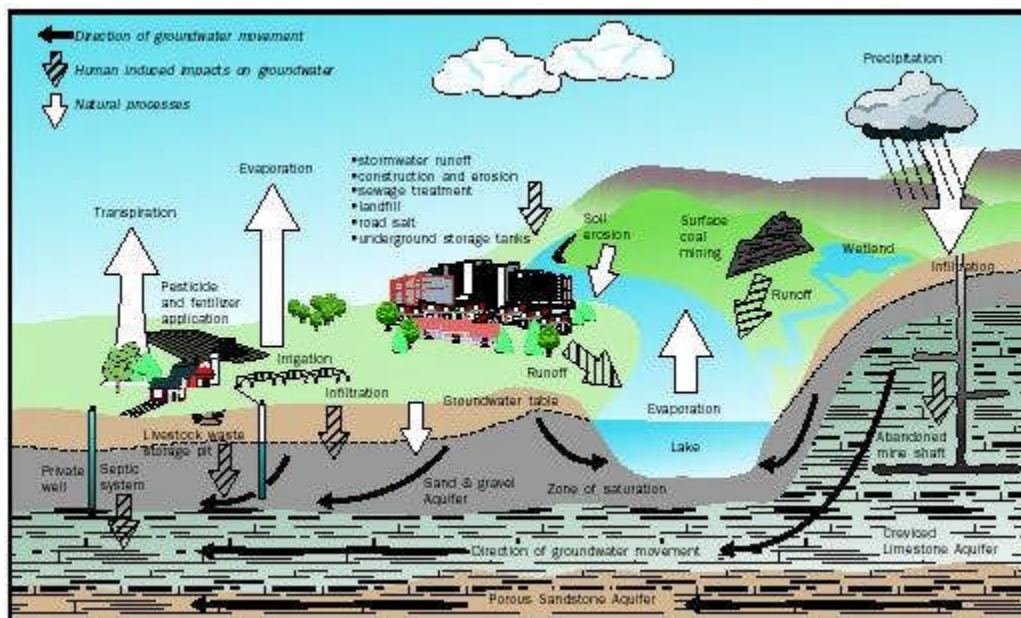
The type and severity of water contamination often is directly related to human activity, which can be quantified in terms of the intensity and type of land use in the source areas of water to streams and aquifers. The analysis of patterns of land use and population provides a tool in the investigation of sites with known contamination, and in the prediction and prevention of future contamination of downstream waters. Studies of contamination sources and transport pathways that affect surface water and groundwater draw upon several disciplines,

including hydrology, geology, biology, soil science, agriculture, physics, chemistry, and engineering.

Groundwater Contamination and Land Use

A relatively simple way to study the effects of land use on groundwater quality is to compare the predominant land uses within a given area to the concentrations of selected contaminants in water drawn from shallow aquifers within that area. Analysis of the relation between land use and the magnitude of contamination in a specific area primarily is based on the following two assumptions.

First, it is assumed that contaminated groundwater at a well originated as uncontaminated recharge (precipitation) that passed through a contaminated area before reaching the well. The area from which a well derives its water (and associated contaminants) is known as the well's groundwater "contributing area." A well's contributing area can be delineated on a map



Land use and land cover largely determine the type and amount of contaminants entering streams, lakes, and underground pathways, including aquifers. Some contaminants occur and move naturally (white arrows), whereas others are produced by human activities (hatched arrows), and their movement often is accelerated as a result of rainfall that accentuates runoff and infiltration.

through an analysis of aquifer characteristics and the direction and velocity of groundwater flow near the well.

Second, it is assumed that the contaminants detected in groundwater were present within the well's contributing area and were transported by groundwater flow to the well. The source(s) of contaminants within a contributing area, such as buried septic systems and leaking underground fuel tanks, can be difficult to identify and locate. In many instances, these sources can be inferred from the type and intensity of land use within the contributing area.

Factors that can affect the movement of contaminants from source areas to wells are:

- The chemical nature of the contaminant;
- The physical properties of the soil and aquifer material;
- The amount and timing of recharge; and
- The direction and velocity of groundwater movement.

Despite the complexity of contaminant hydrology, the effects of certain land uses on groundwater quality have been scientifically documented in many areas. For example, relationships have been found between land use and five common groundwater contaminants: nitrogen, bacteria, road salt, pesticides, and volatile organic compounds.

Nitrate.

Nitrate (a form of nitrogen) is essential for plant growth, but an overabundance can contaminate streams and groundwater. In high concentrations it causes methemoglobinemia in infants.

Nitrate can originate from domestic sewage and lawn fertilizers in residential areas, and from crop fertilizers and manure in agricultural areas. Land-use data on population, housing density, and agricultural practices can provide reliable indications of the likelihood of nitrate contamination of underlying aquifers.

Nitrogen-bearing lawn and crop fertilizers can readily leach through the soil and contaminate the groundwater after heavy rains or irrigation. As a result, nitrate

concentrations in well water in residential and agricultural areas can be correlated with application rates of water and fertilizer. In agricultural areas, the nitrate concentration in groundwater also can be directly correlated with animal density. In unsewered residential areas, the rate of sewage discharge from domestic septic tanks can be estimated from population and housing density.

Bacteria.

Human sewage and manure from cattle, hogs, chickens, geese, and other animals contain bacteria and other pathogens that can cause human illness. Many outbreaks have resulted from wells contaminated by fecal waste. Land-use data on densities of septic tanks and animals therefore are useful indicators of the presence of bacteria in wells.

Road Salt.

Storm runoff and snowmelt in areas with salt-treated roads can carry sodium and calcium chlorides into the groundwater. Data on road density, salt application rate, and locations of salt storage piles can provide useful indicators for detection of elevated chloride concentrations in wells.

Pesticides.

Pesticides are used to kill unwanted pests, such as termites, ants, and rodents around homes; nematodes in soil; and fungi and insects in crops. Similarly, herbicides kill undesirable weeds and grasses in lawns, along roads, and in agricultural areas.

The types and amount of pesticides used can be related to land-use factors such as population, housing density, number of roads, and the type of cropland. In recent studies, the concentrations of most pesticides in well water have rarely exceeded state or federal standards for drinking water. However, the effects of

chronic, low-level exposures to pesticides on ecological and human health have not yet been fully assessed.

Volatile Organic Compounds.

Volatile organic compounds (VOCs) have affected groundwater locally throughout the United States. Many VOCs are carcinogenic; thus, their presence in groundwater creates a serious problem for water suppliers.

VOCs commonly are detected in groundwater in industrial and commercial areas where petroleum fuels and organic solvents are used. A major source is leaking fuel tanks, which contaminate the underlying aquifers with compounds such as benzene, toluene, ethylbenzene, and xylenes (BTEX) and methyl tert-butyl ether (MTBE), an additive used in gasoline to reduce smog-producing vehicular emissions.

The presence of VOCs in groundwater is directly related to urban and suburban development. A 1995 national survey of wells in near-surface aquifers found that the presence of MTBE was directly related to the population density near the wells. Assessments of the density of industrial and commercial development also can be used to estimate the number of potential sources of VOCs such as chlorinated solvents like trichloroethene (TCE) in underlying aquifers.



Runoff of urban stormwater carries litter and other debris in addition to sediment and chemicals. A storm drain carries these substances to its outlet, which could be a nearby river, wetland, recharge basin, estuary, or (as shown here) an ocean beach.

Surface-Water Contamination and Land Use

A variety of natural and human factors can affect the quality and use of streams, lakes, and rivers, known as surface water. One of the most important factors that can affect the quality of a surface-water body is the land use within its watershed. A number of studies have shown that the density of population and housing can affect the concentration of chloride, nitrate, and a variety of pesticides in streams that drain urban and suburban settings. For example, studies of the water supplies that serve New York City have shown that the lowest chloride and nitrate concentrations occur in water from areas dominated by forested land, whereas elevated chloride and nutrient concentrations occur in areas with high densities of housing with septic systems. Chloride concentrations in streams also were linked to the wintertime application of road salt in the populated areas.

Pollution Sources and Contaminant Pathways.

Pollution sources that affect surface water may be separated into two categories: point and nonpoint. Point sources include sewage treatment plants, industrial discharges, or any other type of discharge from a specific location (commonly a pipe) into a stream. By contrast, nonpoint sources—which include runoff from lawns, roads, or fields—are diffuse sources of contaminants that are not as easily identified or measured as point sources. Typically, the contaminant concentration from nonpoint sources will increase as flow increases during storm runoff; conversely, concentrations from point sources generally decrease through dilution during storm runoff. The type and severity of these pollution sources often are directly related to human activity, which can be quantified in terms of the intensity and type of land use and the associated densities of humans and livestock in source-water areas.

Contaminants can travel from a variety of sources through multiple pathways into nearby stream channels or lakes (see previous illustration). Thus, scientific assessments of the origin of a nonpoint-source contaminant can be difficult

because its source(s) usually is dispersed throughout a landscape. For example, chloride (a component of salt) can have multiple sources



Soil erosion and water runoff from cropland into nearby streams can be a major source of sediment, nutrients, and pesticides in watersheds dominated by agricultural land. This photograph shows poor cropland management in which the tilled field extends to the edge of an unvegetated (and eroding) streambank. Implementation of soil and water conservation measures, such as buffer strips of undisturbed land between cropland and adjacent streams, can provide an effective control that reduces contaminant entry into aquatic systems.

in a watershed, including road salt and sewage. Chloride can be flushed into streams when snow melts from roads where it has been applied, or it can move underground from septic systems, through the groundwater system, and into nearby streams; it also can be discharged from wastewater treatment plants directly into streams. In a similar way, nitrogen that is applied as lawn fertilizer and also is present in sewage can travel from lawns, septic systems, and sewage pipes to streams.

Sediment.

Sediment is eroded and transported mostly during heavy rainfall events and the associated high streamflows, particularly floods. Sediment can become a problem because its deposition in streams and lakes can ruin the habitat for aquatic plants and animals; it also can fill stream channels, lakes, and harbors, which then require costly dredging. Studies have shown that the amount of suspended sediment in surface-water bodies can be related to natural factors such as soil type and geology. In general, however, the most important factor for sediment transport is the amount of land cleared of vegetation. Sediment sources typically are lacking in developed areas, but during tillage or construction, when

little vegetative cover or pavement exists, the exposed soil can be easily eroded during storms and deposited in downstream waterways.

Sediment in rivers and lakes also is a concern because many contaminants can attach (adsorb) and move with the sediment particles. Different types of contaminants can be transported with sediment, such as phosphorus (a nutrient which can cause excessive plant growth in rivers and lakes) and persistent organochlorine compounds such as PCBs and DDT. A national study of DDT in stream sediments recently showed that nearly 30 years after DDT was banned, this persistent insecticide is still present in nearly 40 percent of the streams surveyed. DDT most often was associated with sediment in streams that drain urban areas, although it was also found in streams in agricultural areas.

Wastewater Discharges.

Discharge of wastewater from municipal sewage treatment plants, industrial and commercial sources, and confined animal feedlots can contain a variety of contaminants that may impair the quality of the receiving waters. Municipal sewage, for example, contains high concentrations of organic compounds that may seriously deplete the dissolved oxygen content of water downstream from the discharge. Depleted oxygen levels, combined with elevated concentrations of ammonium that are typically found in the treated wastewater, can be toxic to benthic (bottom dwelling) fauna and fish. Municipal wastewaters also contain significant amounts of phosphorus and nitrogen, which can cause eutrophication of lakes and estuaries. The volume (and the environmental consequence) of these wastewater discharges often is directly related to urbanization within the contributing watershed.

Emerging Contaminants

The environmental occurrence of recently studied "emerging contaminants" includes human and veterinary pharmaceuticals, industrial and household wastewater products (such as caffeine, detergent byproducts, and insect repellants), and reproductive and steroidal hormones. Reconnaissance studies on a national scale have shown that many organic wastewater contaminants can persist in water bodies far down gradient of their discharge points, which commonly are found in cities and livestock production areas. Studies since the 1990s have shown that concentrations of these organic contaminants were typically low, often at trace-levels, but they frequently were found in rivers and aquifers that supply drinking water.

The toxicological significance is unknown for many of these contaminants, particularly for the effects of long-term exposures at low levels. Continued monitoring of these and other emerging contaminants will provide additional knowledge about their presence and movement in water. Further analysis of land use and the associated human population and livestock densities in watersheds will provide an additional tool for scientists as they work to define and control the diverse sources of water contaminants.

Table 1. Runoff Expected from Four Types of Land Use with 4 inch rainfall

Land uses	Runoff from a 4-inch rainfall (inches)	Runoff volume from 4-inch rainfall on 1 acre (gallons)	Average yearly runoff* from this land use in central Indiana
Forest	0.5 inch	13,600	0.3 inches
Grass (meadow, lawns, parks)	0.8 inches	21,700	0.4 inches
Corn/soybeans	2.0 inches	54,300	1.1 inch
Roofs/pavement	3.9 inches	105,900	19 inches

Roofs, pavement, and other hard surfaces that generate such high runoff amounts are often referred to as impervious areas. Impervious areas include both buildings (such as houses, factories, and stores) and transport-related areas

(such as roads, driveways, and parking lots). Although the area occupied by both is increasing, transport-related areas are increasing at a faster rate. Transport-related areas now often comprise more than half the impervious area in residential and commercial areas. The sharp rise over the last 20 years in vehicle ownership and miles traveled, both total and on a per capita basis, have caused planners to increase the size of the transport component. This increase usually affects water resources.

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