Pollution, Nonpoint Source

Contamination of streams, lakes, reservoirs, estuaries, and coastal zones is increasingly due to nonpoint source (NPS) pollution—that is, pollution from diffuse sources. NPS pollution is typically generated over large land areas, and pollutants typically classified as being from nonpoint sources include nutrients, pathogens, pesticides, chemicals, and sediment. Few regulatory measures exist to reduce NPS pollution, and therefore public involvement and education is key to improving water quality of natural water bodies.

Increasing water contamination due to nonpoint source (NPS) pollution is a major concern throughout the world. Elevated pollutant levels in water bodies create a risk to human health due to exposure to chemicals and pathogenic organisms. The World Health Organization (WHO) has estimated that approximately 3.2 million deaths each year are associated with water contamination, accounting for about 6 percent of all deaths globally (WHO 2011b). An environmental sustainability Millennium Development Goal set by the United Nations is to reduce by 50 percent the number of people without access to safe drinking water by 2015. To achieve this, the World Bank (2011) has estimated that as much as US$23 billion per year will be necessary to develop the infrastructure to provide safe water to the public. Beyond monetary investments, public involvement and awareness of the sources and practices contributing to nonpoint source pollution is key to success in improving water quality.

According to the US Environmental Protection Agency (US EPA 2011a), nonpoint, or diffuse, sources are the leading cause of water quality impairments in the United States. (Impaired waters are those that are too polluted to meet state water quality standards.) NPS pollution is greatly influenced by a combination of hydrology and land management practices. Polluted runoff generated by rain, snowmelt, or irrigation has led to the contamination of many water bodies, including streams, lakes, reservoirs, estuaries, and coastal waters. In the United States (as of 2011), the EPA had assessed 1,550,689 kilometers of streams and found that 53 percent were impaired. More than 98 percent of the assessed areas of the Great Lakes, 81 percent of assessed coastal shorelines, 69 percent of assessed lakes and reservoirs, and 66 percent of assessed estuaries were impaired. (See figure 1 on page 303.) NPS pollution differs from point source pollution in multiple ways: it is variable in time, generated over extensive land areas, event driven, difficult to monitor and regulate, and best reduced through prevention rather than treatment strategies. These factors make mitigation and control of NPS pollution challenging.

Sources of Nonpoint Source Pollution

Nearly every form of land use has the potential to generate NPS pollution. Recent assessments, however, have identified agricultural lands as the leading cause of water quality impairments of rivers, streams, lakes, ponds, and reservoirs (US EPA 2011c), whereas pollution of estuaries is primarily generated by municipal point sources, urban areas, and industries (US EPA 2011d). Common sources of NPS pollution include excess fertilizer and pesticide applications to agricultural and urban lands; toxic chemicals, heavy metals, and hydrocarbons from urban areas; erosion of sediments from poorly vegetated lands (such as agricultural or construction sites) or other susceptible lands; and stream bank erosion. Subsurface

Figure 1. Contamination Level of US Water Bodies

Data source: US EPA (2011b). Photo credits: EPA (estuaries, coastal); Pramod Pandey (streams, lakes and reservoirs, Great Lakes open water, Great Lakes shorelines).

Shown are the percentages of EPA-assessed water bodies that were identified as impaired as of 2011.

drainage of hydric soils has the potential to export high nitrate loads when managed under intensive agricultural production. (The US government defines a hydric soil as one that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part.) Additionally, pathogens from livestock, land application of animal manures, leaking septic systems, and wastes from domestic pets and wildlife contribute to water quality impairments and present an immediate risk to human and animal health in some cases.

Agriculture activities such as animal feeding operations, livestock grazing, overland flow or irrigation from cropped land, and tile drainage can degrade water quality. (See figure 2 on page 304.) (Tile drainage is a common practice used to remove excess water from subsurface soil.) Pollutants that result from agricultural NPS pollution are sediment, nutrients, pathogens, pesticides, metals, and

Figure 2. Nonpoint Sources of Pollution in an Agricultural Watershed

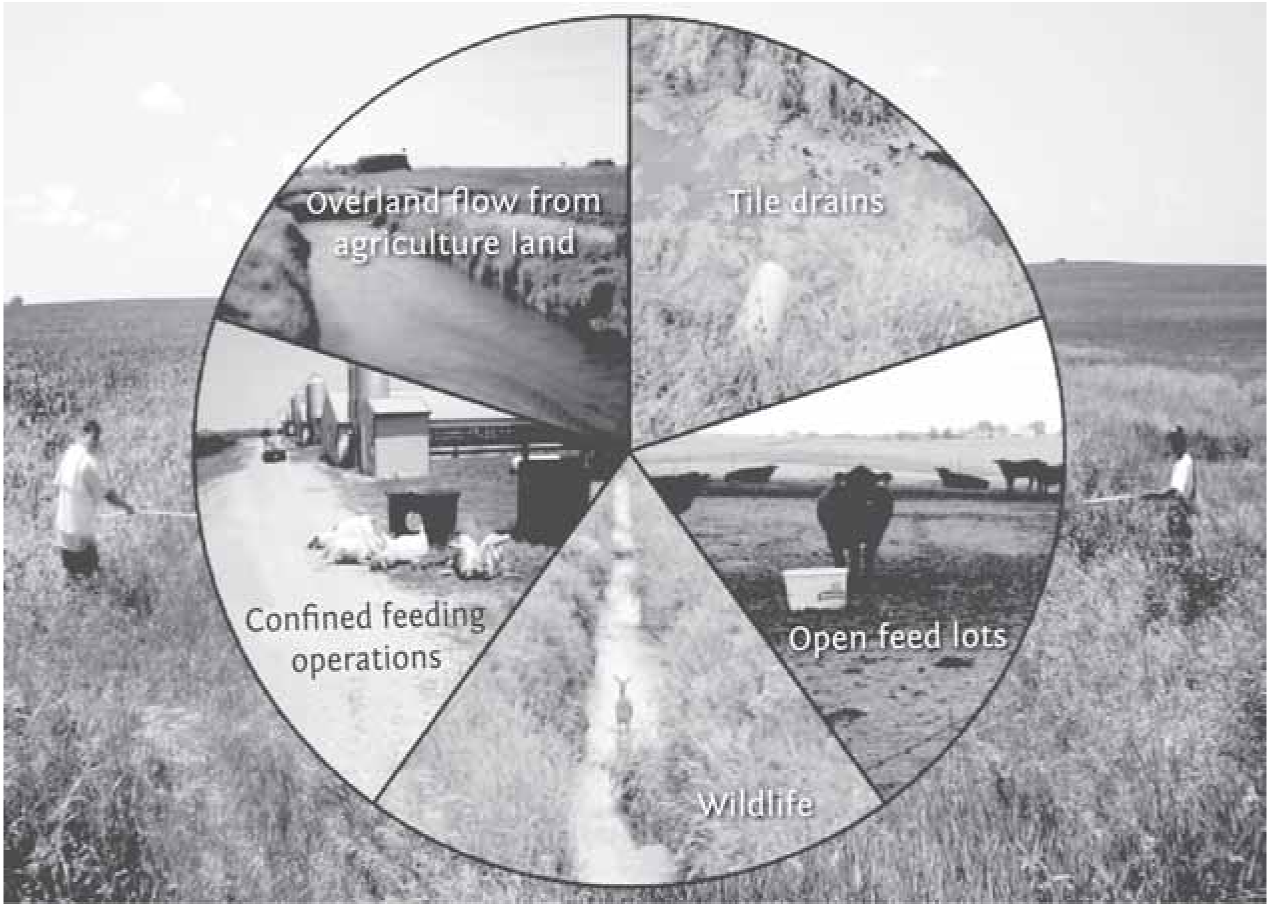

Photo credits: Pramod Pandey; Charles Velasquez; Ray Sims; David Westhoff; Andrew Paxson; Kendal Agee.

Agricultural activity is a major source of nonpoint source pollution. Overland flow from agricultural land, the outflow from tile drains from cropped land, open feedlots, wildlife, and confined feeding operations all cause nonpoint source pollution of water bodies.

salts. These pollutants are typically released from the land surface and transported by runoff into water bodies. For example, erosion from agricultural land transports enormous amounts of sediment, and the influx of these particles into nearby streams, lakes, or wetlands can eliminate aquatic organisms through destruction of habitat or direct impacts such as clogging fish gills. Runoff with excessive nutrients also leads to degraded water quality. For example, to ensure maximum crop yields, land managers may apply abundant nutrients, including nitrogen, phosphorus, potassium, and manure. Excess nutrients that are not utilized by plants, or that are applied prior to rains, are potentially carried by the runoff from agricultural land to water bodies, where high nutrient levels cause algae blooms to proliferate, leading to an uninhabitable environment for aquatic life. Other NPS pollutants, such as pesticides, can also be toxic to aquatic life.

Livestock production is another source of NPS pollution. In the United States, animal feeding operations produce hundreds of millions of tons of manure each year. The animal production industry in the United States accounts for 55 percent of soil and sediment erosion, 80 percent of antibiotic usage, and more than 30 percent of the total nitrogen and phosphorous loading to national drinking water resources (Pew Commission on Industrial Animal Production 2011). For instance, effluent from animal feeding operations (AFO) contributes considerable amounts of pollutants such as pathogens, nitrogen, phosphorous, sediments, hormones, and antibiotics to ambient water bodies (US EPA 2011e). In addition, livestock overgrazing can lead to increased erosion, invasive plants, and degraded or eliminated riparian vegetation (that is, vegetation along the banks of waterways). An increase in livestock populations results in greater volumes of nitrogen- and phosphorus-rich animal waste, which is typically disposed of through application as fertilizer to crop and pasturelands. When such manure is applied to the land based on the crop nitrate requirements, a buildup of soil phosphorus is often observed, increasing the risk for transport of nitrogen- and phosphorus-enriched water to surface waters.

In addition to agriculture, urban runoff can generate NPS pollution. More than 50 percent of the world's population lives in urban areas, and the migration from rural areas to cities continues. Insufficient urban infrastructure makes cities a central point for environmental health concerns. According to the EPA (as of 2011), almost 56,000 kilometers of US streams and significant portions of US coastal shorelines were impaired due to storm water discharges and other urban runoff. An increase in impervious surfaces and storm water discharges has resulted in increased associated pollutant loads (such as solid waste and chemicals) into adjacent water bodies. Current trends show that future human populations will increasingly be concentrated within urban areas. Therefore, the urban environment will play a critical role in water quality and public health.

Another nonpoint source of pollution is abandoned mining operations. Runoff from these lands has great potential to impact water bodies. Mining operations in the mid-Atlantic region have led to acidification of surrounding water bodies. Runoff from abandoned mines can transport solids, oils, minerals, and metals such as zinc and arsenic to water bodies. Particles containing sulfur can lead to the formation of sulfuric acid and iron hydroxide, which can dissolve heavy metals such as copper, lead, and mercury. This acts to change water body chemistry, making the environment toxic to aquatic life and unsuitable for public and industrial uses. According to the EPA (as of 2011), about 8,240 kilometers of streams have been contaminated in the eastern United States by runoff from abandoned coal mines; coal mines in the mid-Atlantic region alone caused low pH values in 7,656 kilometers of streams.

Nonpoint source pollution from silviculture (the development and care of forests) can also cause significant water quality problems. The movement of heavy machinery in forested areas can remove vegetation, leading to increased erosion. Activities such as logging can generate considerable amounts of NPS pollution, particularly sediment, due to removal of streamside vegetation, road construction, and timber harvesting. For example, in the Lake Superior drainage basin, approximately 75 percent of the basin is forested, and 50 percent of the basin has highly erodible red clay soils. According to the EPA (as of 2011), approximately 9 percent of the water quality problems in assessed streams were caused by forestry activities. Road construction and road use contributed up to 90 percent of the total sediment from forestry operations. In addition to upland erosion, silviculture activities modify or remove riparian vegetation, which can also harm aquatic species and wildlife through limiting food and habitat.

Impacts of NPS Pollution

According to the EPA, nitrate is the most prevalent agriculture pollutant in drinking water, and approximately 1.5 million people are exposed to elevated levels in their drinking water wells (US EPA 2011f). In water bodies, algal growth from elevated nutrient levels results in low oxygen levels. This process, called *eutrophication*, can cause fish kills and reduced diversity in aquatic life. Nitrogen and phosphorus from agricultural land can contribute to eutrophication and associated algae blooms.

Nonpoint source pollution has been associated with over four hundred hypoxic zones in the world. The largest US hypoxic zone, in the Gulf of Mexico, is about 17,000 square kilometers. Hypoxia is due to low oxygen in water (less than 2 milligrams per liter), at which aquatic life cannot survive. Recent increases in the occurrence of hypoxic zones has been related to anthropogenic activities such as intensive use of fertilizers on agriculture land, erosion of soils with nutrients, and discharges from sewage treatment plants. For instance, the hypoxic zone in the Gulf of Mexico is primarily caused by excess nutrient loading to the Mississippi River. Studies have shown that in the last half of the twentieth century, nitrogen and phosphorus concentrations in the Lower Mississippi River have increased considerably, and this has been attributed to the increased use of nitrogen and phosphorus fertilizers on cropped land. The hypoxia in the Gulf of Mexico is of particular concern because Gulf fisheries generate billions of dollars annually.

Another potential health risk from NPS pollution is exposure to waterborne pathogens. The World Health Organization (WHO) has estimated that 88 percent of the global disease burden is attributable to contaminated waters, particularly pathogen-contaminated waters. About 62.5 million people suffer each day from diarrheal diseases, and intestinal worms infect about 10 percent of the population in developing counties. Water contamination by pathogens causes potential health risks to humans all over the world. For instance, more than 200 million people are infected with schistosomiasis, and more than 300 million suffer from malaria that is linked with contaminated waters (WHO 2011c). In developing countries in Africa, waterborne pathogens infect millions. Guinea worm disease, a parasitic infection caused by *Dracunculus medinensis*, begins when a person drinks contaminated water infested by the larvae of the guinea worm.

Even in developed countries such as the United States, pathogens are a major source of pollution in water bodies.

Approximately 900,000 illnesses and 900 deaths occur in the United States each year because of exposure to waterborne pathogens (Arnone and Walling 2007). Human diseases such as gastrointestinal illness, including vomiting, diarrhea, and fever, have been related to high levels of pathogenic bacteria in recreational waters. In the United States most beach closings result from elevated level of pathogens; the source is often untreated sewage. Waterborne pathogen contamination is a threat not only to human health but also to wildlife, livestock, and aquatic life. For example, massive frog die-offs in the US states of Colorado and Arizona and the Australian state of Queensland have been attributed to the chytrid fungus—a pathogen that lives in fresh water. In the US state of Massachusetts, bacterial contamination in shellfish and recreational waters is blamed for the loss of millions of dollars each year in the local economy.

Future Challenges

In addition to natural water bodies (i.e. streams, lakes, estuaries, coastal waters), designing new water resource structures has serious implications for water quality. Large reservoirs may increase pathogen contamination, particularly schistosomiasis. A study by the parasitologist Alan Fenwick (2006) reported that the development of water resources, particularly in Africa, has increased the transmission of waterborne diseases. For example, the Gezira Irrigation Scheme and the Sennar Dam, the first major dam across one of Africa's great rivers (the Blue Nile), have been associated with increased schistosomiasis. Approximately 103 million out of 779 million people infected by schistosomiasis live in close proximity to large reservoirs and irrigation schemes (Daszak, Cunningham, and Hyatt 2000). It has been noted that such projects increase suitable aquatic snail species, which are the intermediate hosts of the larvae of schistosomiasis.

Contamination of water by high levels of nitrogen and phosphorus is an increasing concern in the United States. According to the EPA, about 50 percent of US water bodies are negatively impacted by nitrogen and phosphorus pollution (US EPA 2011h). Excessive levels of nitrate in drinking water over time can increase risk for thyroid cancer in women. Nitrate in drinking water also puts young children at risk for blue-baby syndrome (methemoglobinemia), where the oxygen-carrying capacity of the blood is lowered, resulting in bluish skin color. Conventional drinking water treatment processes cannot remove nitrate. Instead, expensive treatment methods are required such as reverse osmosis and biological denitrification (Elyanow and Persechino 2005). According to the EPA, the costs to pollutant sources for implementing total maximum daily loads (TMDL) to control contamination are expected to be between approximately $1 billion and $3.4 billion per year (US EPA 2001).

Changing environmental conditions may alter the virulence of existing diseases and increase the possibility of new diseases. Many pathogens currently exist in a dormant stage in water bodies, but an increase in water temperature may alter this. Therefore, future work is needed to increase our understanding of how changes in climate and rainfall will impact NPS pollution. Only 2.5 percent of all water available on Earth is fresh, and approximately 15 percent of the world's population lives in regions with limited water supply. Access to freshwater is critical to support life. Improving water quality is a major but necessary challenge to protect human and animal health and quality of life. In summary, reduction of nonpoint sources of pollution is needed to protect public health and provide clean water to humans and animals. Controlling NPS will require interdisciplinary collaboration among various disciplines such as hydrology, soil science, agriculture, ecology, environmental science, and engineering in order to develop land and water management practices which are eco-friendly and sustainable. In addition to scientists, it will require *public involvement and education,* which is a key to improving the water quality of our ambient water bodies.

Pramod Kumar PANDEY and Michelle Lynn SOUPIR
Iowa State University

See also Agricultural Intensification; Agroecology; Ecosystem Services; Eutrophication; Groundwater Management; Irrigation; Large Marine Ecosystem (LME) Management and Assessment; Marine Protected Areas (MPAs); Pollution, Point Source; Rain Gardens; Road Ecology; Soil Conservation; Stormwater Management; Water Resource Management, Integrated (IWRM)

Further Reading

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