Storm Water Runoff and Its Impact

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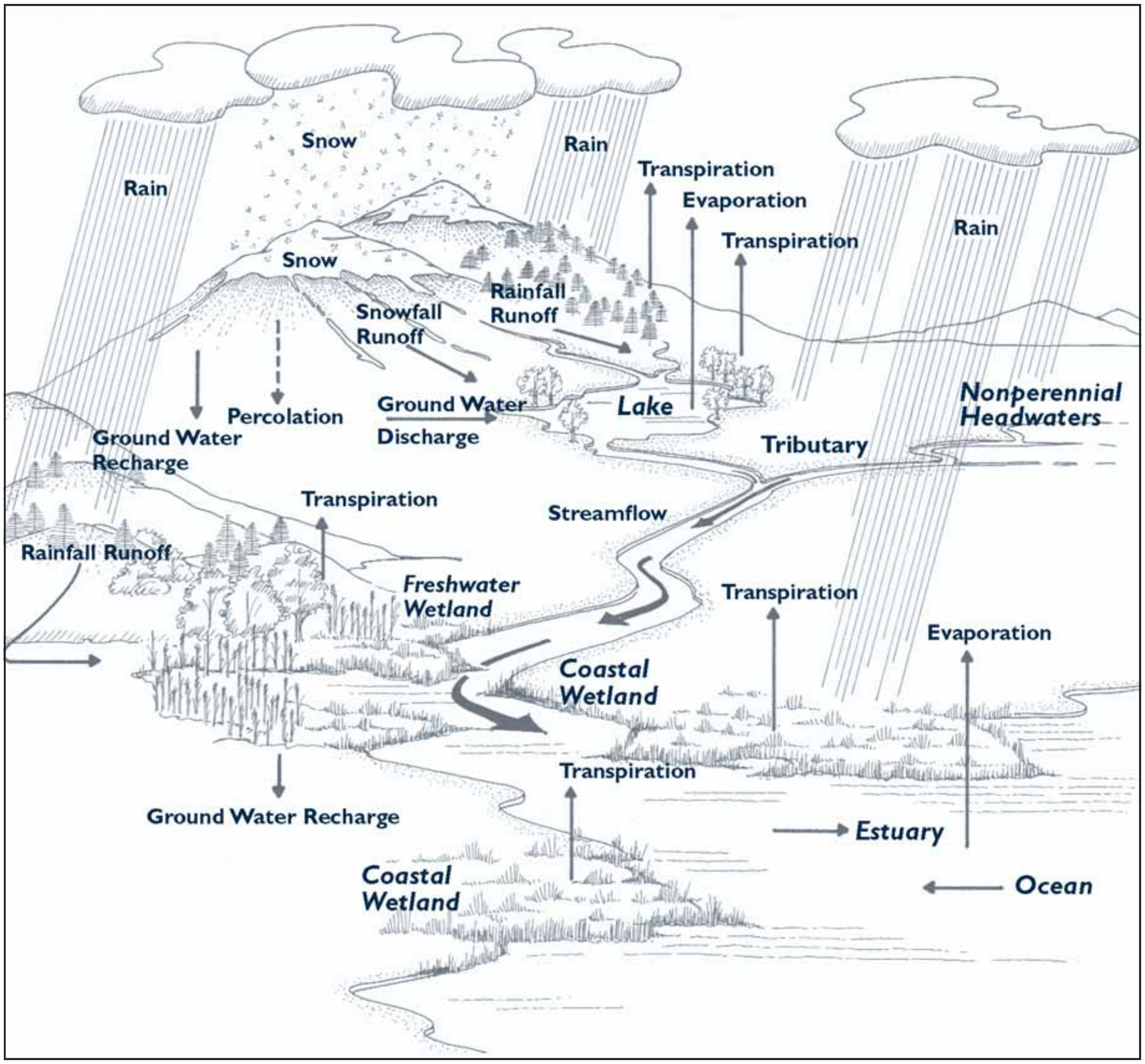
Storm water runoff is a part of the earth's hydrological cycle. The hydrological cycle is a conceptual model that describes the distribution and movement of water between the atmosphere, land, and water. The hydrologic cycle can be characterized by the diagram below.



Source: National Water Quality Inventory, U.S. Environmental Protection Agency, 1998

Water that reaches the surface of the earth may:

- Percolate directly into the ground where it can be stored as groundwater or slowly migrate toward a waterbody.
- Flow into a creek, river, wetland, lake, or other natural features.
- Be taken up by roots of trees, grass, and other plants.
- Return to the atmosphere through evaporation, which is the transformation of water from a liquid into a gas.
- Return to the atmosphere through transpiration, which is the process whereby plants release water vapor back into the atmosphere through their leaves.

INTRODUCTION TO STORM WATER RUNOFF

Precipitation that reaches the surface of the earth is either absorbed by the soil through percolation or flows overland as runoff. Vegetative cover enhances absorption by intercepting the rainfall, slowing runoff, and providing root channels that promote infiltration.

Storm water runoff is the volume of water generated by a rainfall event, snowmelt, or other forms of precipitation that falls to the earth's surface and does not infiltrate into the ground. Runoff can be directly correlated with a specific land use. Runoff associated with a forested landscape will typically be less than runoff from an urbanized landscape.

Following rainfall events or snowmelt, runoff flows overland and picks up materials including but not limited to trash, debris, sediments, and pollutants. The runoff can often contain pollutants in quantities that will affect water quality. Runoff can carry a variety of pollutants that are associated with a specific land use. These materials can remain in solution or attach to sediment and will eventually be deposited in the lowest part of the landscape or discharged to creeks, rivers, lakes, and wetlands.

Storm water volume and runoff rates are directly related to the impervious surface area in a watershed. Land development and urbanization typically increase surfaces that are impervious. During construction an increase in runoff can often be attributed to compaction by heavy equipment. Typical urban landscapes have a high percentage of impervious surfaces due to parking lots, rooftops, roads, and highways.

The remainder of this chapter will focus on the pollutants associated with construction and urbanization and their impact to water quality.

IMPACTS OF URBANIZATION

A watershed's physical, chemical, and biological characteristics are generally altered when land undergoes some type of development. The watershed's storm water runoff quantity and quality can also be significantly affected. This is particularly true when undeveloped or agricultural land is converted to urban uses. For example, the hydrologic changes in an urban watershed are often magnified due to an increase in impervious surfaces such as rooftops, streets, sidewalks, and parking lots. This increase in impervious surface area usually decreases the amount of time it takes for storm water runoff to move from remote areas of the watershed to the receiving stream or waterbody. In addition, urban development usually requires the construction of storm water conveyance systems which are typically designed to convey storm water runoff in an efficient manner without regard for its impact. Therefore, not only is it quicker for storm water runoff to flow over paved surfaces versus a natural landscape, but these conveyance systems can expedite drainage into the nearest receiving waterbody. The overall result is a significant change to the predevelopment hydrologic conditions of the watershed. A drop of water that used to take hours or days to make its way through the watershed to a receiving waterbody now takes a matter of minutes or hours.

Another impact from altering a watershed's hydrology is an increase in peak runoff volumes. Increased peak runoff volumes can increase the frequency and severity of stream flooding during storm events. Conversely, during non-storm periods the flow in the channel or stream can be diminished greatly or in some instances there may be no flow in the channel or stream.

Peak runoff volumes are typically the result of an increase in impervious surface areas. An increase in peak runoff volumes generally results in the alteration of stream channels, natural drainageways, and riparian habitats. These alterations can have a significant impact on the reduction, and in some instances the elimination, of aquatic vegetation and organisms and can degrade water quality. Other potential effects include increased streambank erosion and streambed scouring, channel siltation, increased water temperatures, decreased dissolved oxygen levels, and changes to the morphology of the watercourse.

Increased pollutant loadings and discharges are still another impact of urban storm water runoff from impervious surface areas. Pollutants associated with urban areas are specific to the type and intensity of the land use. Some examples of pollutants associated with urban land uses include sediments, nutrients, oxygen demanding substances, road deicing agents, heavy metals, oils and grease, hydrocarbons, and bacteria. Runoff from commercial land uses such as shopping centers, business districts, office parks, and parking lots or garages may contain high hydrocarbon loadings and metal concentrations. Pollutant loadings from these types of land uses can be a significant pollutant source in storm water runoff and can be attributed to heavy traffic volumes and large impervious surface areas.

Gas stations are one type of land use that is often designated as a commercial land use and are subject to the same controls as shopping centers and office parks. However, gas stations may generate higher concentrations of heavy metals, hydrocarbons, and other automobile-related pollutants. This is because of the type of day-to-day activities associated with the industry and the volume of clientele that use the facilities. There is also a higher probability for spills to occur at these facilities because of human error.

Protecting or improving water quality in existing urban areas is often difficult because of diverse pollutant loadings, large storm water runoff volumes, limited areas suitable for surface water runoff treatment systems, high costs associated with structural implementation of storm water measures, and the nonexistence of natural or manmade buffer zones. Most existing urban developments have typically been built without consideration for water quality protection. The objective during construction was more likely focused on using the land to its greatest potential for the planned land use. With this approach it is often difficult to address the reduction of pollutants after the fact due to space limitations and the inability to choose the most cost-effective and efficient measure to achieve pollutant removal. However, numerous opportunities exist to address storm water quality impacts and build storm water quality control and treatment measures into projects which propose to convert areas into urban landscapes.

The alteration of the soil probably has the greatest impact on water quality. Therefore, soil should be the first consideration for any proposed land use change. Soil is a subsystem, with a unique set of characteristics such as soil structure and permeability, within the earth's ecosystem. The primary function of soil is to support life. Therefore, there is a natural balance and interrelationship between soil, microorganisms, plants, and animals. This delicate balance can be significantly altered as a result of land use changes and construction activities. These human activities can affect the natural soil characteristics and health of the ecosystem in varying degrees. Changes to the soil ecosystem can be physical such as alteration or destruction of the soil structure while others may be biological or chemical. For example, construction and land disturbance can cause changes in the number and type of organisms that live in the soil. Loss of this soil biota leads to erosion, loss of humus (organic matter), loss of soil structure, and increased potential for soil compaction.

Soil erosion on construction sites has been said to have impacts that are more costly and severe than those of non-construction site impacts. More specifically, erosion causes the depletion of an important resource, nutrient rich topsoil, and often results in degradation of water quality. This is typically due to increased sediment loads and pollutants attached to the soil particles. Excessive sediment deposited on productive agricultural lands or forestlands can also make them sterile and unproductive.

Sediment is the most common pollutant associated with storm water runoff from construction sites. In fact, it has been shown that sediment is the number one pollutant, by volume, of surface waters of the United States. Sediment is also the primary pollutant that is addressed by state and local officials when they regulate construction projects. However, there are several other pollutants associated with construction activities. Some of these pollutants include, but are not limited to, solid wastes, nutrients, pesticides, petroleum products, and chemicals associated with construction activities.

The nature of the construction activity plays an important role in the types of pollutants that may be released from a construction site. For example, construction activities that result in massive earthmoving are likely to have a higher potential for off-site pollutant discharge. An alternative is to develop a project in phases and work with the natural landscape of the site which will result in minimal land disturbance and a reduction in the generation of pollutants. On projects where heavy equipment is utilized there is potential for the release of pollutants from vehicle refueling, fuel storage facilities, and equipment and maintenance areas.

The amount, intensity, and frequency of rainfall; soil type (infiltration rate, organic matter content, etc.); soil surface roughness; slope length and steepness; and ground cover (vegetated or unvegetated) are other factors that can have a significant impact on the amount of pollutants discharged to surface waters and ground water. In addition, the location of the construction site in relation to the receiving waters can have an overall impact on water quality.

The consequences of erosion and subsequent sedimentation can be far-reaching. It has been estimated that on average, one acre of land under construction contributes almost 30 tons of sediment to nearby lakes, rivers, and streams (Source: Wisconsin Department of Natural Resources). In fact, small streams show the most pronounced effects of sediment pollution because they are more easily clogged with sediment. This is primarily due to the stream's size. These small streams account for 86 percent of all stream and river miles in the continental United States (Source: "Protecting our Water," Delaware Nature Society). Therefore, sediment pollution is a major concern across the United States because of the high percentage of small streams and their susceptibility to clog with sediment.

In addition to clogging small stream channels, sediment accumulation is a concern because it decreases the channel's capacity to carry water. This increases the frequency of flooding and can lead to streambank erosion or scour. In fact, urbanization and associated construction activities can increase the occurrence of small floods by a factor of ten or more. High sediment loads and increased frequency of flooding also expedites the shifting or movement of a stream channel as the channel tries to compensate for its reduced capacity.

Another consequence of construction site erosion is that the resulting sediment is often deposited in low, depressional areas such as lakes, ponds, and wetlands that collect and retain surface water runoff. As sediment accumulates in the bottom of these areas, it slowly decreases the depth in which water can stand. As the water depth decreases in these enclosed ecosystems, the system loses its ability to support the plant, animal, and microorganism system it supported with the greater water depths. This issue is becoming a widely recognized problem, especially in natural wetland areas.

Wetland plants and microorganisms are very efficient at removing pollutants from surface water runoff, but as an ecosystem's capacity is diminished its filtration ability decreases. The end result is infilling of the wetland area and loss of habitat for the plants and microorganisms.

It is important to recognize that many depressional areas often serve as ground water recharge areas. As sediment accumulates in the bottom of these depressions it reduces the amount of water the depression can hold. In addition, the sediment seals over the bottom of the depression which then restricts or prevents ground water recharge.

Perhaps the most evident change to any landscape undergoing land-disturbing activities is removal or alteration of the vegetative cover. Vegetative cover plays a very important role in protecting soil resources and improving or maintaining water quality. Many plants have an inherent ability to cleanse water. They take up chemicals and heavy metals from the soil and/or water as they take up the nutrients they need to grow. Some plants are even able to alter the chemistry of the pollutants so that they can not be readily absorbed by animals and humans. The plants can then release the altered, benign pollutant(s) into the soil, water or air. Removal of vegetation can have a profound effect on soil and water quality because the ability to filter or cleanse runoff is lost with the loss of the vegetation.

Removal of vegetation from the soil surface has an immediate impact on the ecosystem. Almost immediately after vegetation is removed, the exposed soil begins to undergo erosion because plant roots are no longer available to grip the soil particles for plant stabilization and provide channels for air and water to circulate through the soil. The removal of plants also reduces the humus content, which binds the soil together in aggregates and gives the soil structure. Without plants, the structure of the soil begins to break down and the soil dries out. The soil then becomes susceptible to the erosive forces of wind and water and the negative impacts that construction equipment and machinery have on soil stability. Thus, the erosion process has begun.

Nutrients, pesticides, and heavy metals are easily absorbed onto exposed surfaces of the loosened soil particles once they have become detached and eroded. The eroded soil particles and attached contaminants are free to move throughout the environment. As these soil particles move, they can accumulate as polluted or contaminated sediments in the landscape or in waterbodies such as lakes or streams.

Vegetation has the ability to reduce storm water runoff because it slows storm water runoff velocities which in turn allows the runoff to infiltrate into the underlying soil. Grasses and larger plants such as trees often create an extensive, fibrous root system that helps bind the soil together and provides channels for the infiltration of water and air. In addition, leaf and needle

litter frequently acts as a sponge, reducing the flow of storm water runoff and increasing infiltration into the underlying soil. As these materials decay, they add humus to the soil. This helps loosen the soil and promotes the formation of soil structure which in turn promotes the infiltration of surface water.

In regard to erosion, vegetative canopies act like an umbrella to protect the soil from raindrop impact. Decaying plant stems and leaves and leaf and needle droppings provide a mulch cover over the soil surface which again protects the soil from raindrop impact.

Urban forestry management is another vegetative measure that can have an impact on soil and water quality. Trees can buffer the effects of climate extremes. For example, during summer months, they provide shade and can reduce home cooling costs. During winter months, they provide protection from the wind, reducing home heating costs and trapping snow which helps recharge soil moisture in the spring.

Source: Natural Resources Conservation Service, Iowa

A forest's age is important in protecting soil and water quality and providing food and habitat for wildlife. Leaf litter and woody debris are important food and habitat sources for animals and organisms that live in and around the ecosystem, particularly in headwater reaches of a stream. Small aquatic organisms ingest and break down the decaying plant materials. Higher-order organisms feed on the smaller organisms and may transform some of the leaf litter and debris. Areas of newly planted trees usually lack this accumulation of leaf and needle litter and vegetative understory. Areas of newly planted trees are also less effective at preventing erosion verses a well-established forest that has a dense canopy and well-established root system. Therefore, protecting and preserving established forests should be a very important component of any land use change when forests are present. It is important to note that forest succession is a lengthy process. It typically requires several years to establish a diverse, complex mix of mature trees and saplings with well-developed root systems, a well-developed understory, and an adequate cover of downed trees, leaves, and leaf and needle litter.

Another impact of urbanization is the effect it can have on food and habitat for aquatic organisms, aquatic insects, fish, amphibians, freshwater mussels, wildlife, and so on. Water quality can affect the diversity and abundance of plant and animal species living in the ecosystem, feeding and mating habits, and nesting and resting areas. Numerous studies have examined the link between watershed urbanization and its impact on stream and wetland biodiversity. These studies reveal that a relatively small amount of urbanization (as little as 10 percent impervious cover) has a negative effect on aquatic diversity. The hydrologic, physical, and water quality changes caused by watershed urbanization all stress the aquatic community and collectively diminish the quality and quantity of available habitat. As a result, these stressors generally cause a decline in biological diversity, a change in trophic structure, and a shift towards more pollution-tolerant organisms.

Urban conditions that negatively affect biodiversity include deposition of sediment in streambed substrate, large woody debris removal, stream crossings, increased water temperatures, increased pollutant loads, decreased base flows, loss of pools and riffles, channel straightening or hardening, increase in turbidity, and algae blooms.

Unfortunately, when land undergoes development much of the existing vegetation is unintentionally damaged or it is removed to provide for the construction of roads, parking areas and buildings. As vegetation is removed animals become displaced and they are required to seek other food sources and habitat. Often, these displaced animals struggle to adapt to their new environment. Aquatic organisms, aquatic insects, fish, amphibians, freshwater mussels, wildlife, and other species of animals and plants can also struggle for survival when sediment is introduced into their environment. Sediment causes turbidity (cloudiness of water) which in turn limits photosynthesis and plant growth. This can affect the entire aquatic food chain and interrupt reproduction processes. Suspended sediments can damage the gills of fish and severely reduce stream depth. Sedimentation of the channel can destroy or cover fish spawning grounds and can even limit the movement of fish upstream and downstream to get to these spawning grounds.

Urbanization usually has a negative impact on waterways and drainage channels. As storm water runoff and stream velocities increase, the potential for streambank erosion and scouring of the channel bottom is greatly increased. The eroding banks eventually slump, destroying naturally occurring undercuts that provide shade, cover and habitat for fish and other aquatic animals. This slumping process can be further exacerbated by clearing any existing riparian buffers. Streambank erosion also contributes to sediment deposition in the bottom of the channel which reduces channel depth. The waterway or drainage channel then tries to compensate for the reduction in channel depth by widening the channel. Once sediment has been introduced into the drainage system, it can remain in the system for a very long time. The following is a list of some long-term impacts associated with sediment deposition in stream channels:

- As sediment loads move through the drainage system they abrade the streambanks and destroy the food supply and habitat of aquatic organisms.
- Sandbars often increase in size, further restricting channel flow which usually results in increased flow velocities and accelerated streambank erosion.
- Reduction in channel depths leads to potentially less interchange of water, dissolved gases, and organic material between the water column and streambed.
- Macroinvertebrate diversity and numbers are decreased due to microhabitat change and degradation.
- Food supplies, spawning beds, and fish habitat is destroyed.

As shown in the previous discussion, development in one part of a watershed can have a significant impact and consequences on downstream areas of the watershed. However, when preservation and conservation measures are put into practice, nonpoint source pollution can be diminished and water quality can be maintained or even improved in some instances. Plant and animal communities can be protected and under ideal circumstances they can increase in number and diversity. Overall, water quality and the health of the entire watershed can be improved if storm water quality measures are properly installed and maintained.

Many of the previously discussed issues have rarely been addressed by local units of government when they regulate construction and land-disturbing activities. However, many communities are becoming more aware of these issues and are developing local programs to address erosion, sedimentation and storm water issues related to quantity and post-construction pollutants.

There is a wide variety of storm water quality measures that can be implemented on construction sites to prevent or minimize erosion and the associated environmental damages. These measures include both structural and nonstructural measures. Nonstructural measures are typically used to prevent or control erosion at its source. Structural measures on the other hand are designed to manage runoff and filter or allow for the settling of sediments suspended in storm water runoff. Erosion controls have a distinct advantage over sediment controls because they reduce the amount of sediment generated and transported off-site, thereby reducing the need for extensive sediment control measures. When erosion controls are used in conjunction with sediment controls, the size of the sediment control measures and associated maintenance may be reduced, resulting in decreased treatment costs.

Simple precautions such as identifying ecologically sensitive areas and marking them as “off limits” or protecting them from construction activity is one simple method of protecting the resource(s) from construction activity. This measure can be used to protect trees, native plants designated for preservation or use in the final landscaping, and animal habitats. It should be noted that erosion and soil loss is unavoidable during land-disturbing activities. While proper siting and design will help prevent areas prone to erosion from being developed, construction activities will invariably produce conditions where erosion will occur.

Pollutants that are associated with the post-construction land use can also be minimized by targeting specific pollutants and utilizing appropriate storm water quality measures. Post-construction impacts can also be reduced through planning projects that utilize natural site features and that incorporate principles that reduce impervious surfaces and the generation of pollutants.

A key element to storm water management that should be used on all projects is a storm water pollution prevention plan. This type of plan is very important in reducing the environmental impacts that are associated with active construction and post-construction land use. An effective storm water pollution prevention plan will incorporate design principles and an integrated system of structural and nonstructural storm water quality measures to minimize the adverse impacts to the watershed's ecosystem.

Following chapters of this manual provide more detailed discussion in regard to storm water pollutants associated with urbanization and identify storm water quality measures that can be used to minimize the impacts of urbanization.

POLLUTANTS ASSOCIATED WITH URBANIZATION

The previous "Impacts of Urbanization" section discussed the impacts of urbanization and the pollutants that are associated with existing development, new development, and active construction sites. The pollutants associated with existing and new development are directly related to the land use. The primary pollutant associated with construction sites is sedimentation. Sediment is the number one pollutant by volume of surface waters in the United States. In addition to sediment, other pollutants associated with construction activities may include pesticides, petroleum products, nutrients, solid wastes, and various chemicals.

Other types of activities also have specific pollutants associated with them. These pollutants are generated from the operation and maintenance of roads, highways, and bridges as well as everyday activities and have a direct impact on the environment.

Roads, Highways, and Bridges

Pollutant sources associated with roads, highways, and bridges include both those generated during construction activity as well as those that are generated once the roadway becomes operational. Sources of pollutants associated with construction activities include sedimentation, on-site fuel storage and fueling operations, solid waste generation, chemicals associated with day-to-day operations, and nutrients from soil amendments used during site stabilization. Pollutants associated with operational activities include roadway maintenance operations (e.g., fertilizers, pesticides), solid waste generated from littering, and pollutants washed from the pavement (e.g., hydrocarbons, heavy metals, deicing agents).

Highway maintenance garages and rest areas can be major contributors to pollutant loadings. Maintenance garages are typically used for refueling and storage of sand and salt materials. If not properly managed, these substances can become potential pollutants. Rest areas can contribute to pollutant loadings because of their large, impervious parking areas and the high volume of vehicles that stop at these facilities.

General Sources (Including Household, Commercial, and Landscaping)

General sources of pollutants are those that are generated as the result of day-to-day activities by the public and businesses. Household activities, lawn and garden care, turfgrass management, vehicle use and maintenance, on-site sewage disposal systems, illegal discharges, and pet and domesticated animal wastes are the primary sources of pollutants associated with general day-to-day activities.

POLLUTANTS ASSOCIATED WITH URBANIZATION

Everyday household activities generate numerous pollutants that may affect water quality. Common household waste includes paints, solvents, lawn and garden care products, detergents and cleansers, and automotive products such as antifreeze and oil. A household product that contains hazardous substances becomes household hazardous waste once the consumer no longer has a use for the product and disposes of it. These pollutants are typically introduced into the environment due to ignorance on the part of the user or the lack of proper disposal options. The public unknowingly assumes that storm drains discharge into sanitary sewers and dump materials into storm drains under the assumption that treatment will occur at the sewage treatment plant. It is also commonplace for users to dump or dispose of many of these types of products directly onto the ground, not realizing that the materials can be carried to surface waters by runoff or pollute ground water if they are leached through the soil. Hazardous waste from households is not regulated as hazardous waste under federal and Indiana laws.

Landscaping activities are another common contributor to the pollutant loading of waterbodies within a watershed. For example, improper application or overapplication of fertilizers and pesticides can impair surface waters. In addition to surface water impairment, overapplication of nitrogen fertilizers can pollute ground water when it leaches through highly permeable soils. Improper disposal of lawn trimmings also leads to increased nutrient levels in storm water runoff. Lawn trimmings deposited in street gutters can be washed into drainage systems and result in elevated nutrient loadings of the receiving waterbody.

Litter and debris are significant contributors to the degradation of surface and ground water. Smaller materials are often carried by storm water runoff and deposited in surface waters. Improper disposal of larger items such as refrigerators and air conditioners can impair water quality through the release of fluids into surface water and ground water. These items degrade the aesthetic and recreational value of surface water and are a hazard to wildlife and aquatic organisms.

Domestic pet droppings have been found to be an important contributor of nonpoint source pollution. It has been shown that these waste materials can elevate fecal coliform and fecal streptococcal bacteria levels of waterbodies. This type of pollutant is most commonly associated with dogs. However, other urban animals such as domesticated or semi-wild ducks and Canadian geese can be major contributors to the nonpoint source pollution problem in areas where their populations are high.

Potential for impairment of surface waters and ground water can be greatly reduced through the proper handling, storage, management and disposal of the pollutants discussed above. The aforementioned techniques are discussed in the post-construction sections of this manual.

Typical Urban Pollutants

Pollutant	Contaminants	Sources	Effects	Impacts
Nutrients	• Phosphorous • Nitrogen	• Septic Systems • Agricultural runoff (fertilizers, animal waste) • Urban landscape runoff (fertilizers, detergents, plant debris)	Phosphorous is typically the primary nutrient of concern in freshwater systems as is nitrogen in saltwater systems. These nutrients encourage algal growth that can contribute to greater turbidity and lower dissolved oxygen concentrations. Lower dissolved oxygen can cause the release of other substances (pollutants) into the water column. Higher levels of nitrogen (nitrates) in groundwater are most commonly associated with agricultural practices and malfunctioning septic systems.	• Can limit recreational values (swimming, boating, fishing, and other uses) • Can reduce animal habitat • Potential contamination of water supplies
Solids	• Sediment (clean and contaminated) • Floatable wastes	• Construction sites • Agricultural lands • Disturbed and/or unvegetated lands including eroding stream banks • Floatable wastes are contributed from street litter and careless disposal practices	Increased turbidity and deposition of sediment.	• When deposited, clean sediment can decrease storage capacity to waterbodies, destroy benthic habitat (including animal nesting and spawning areas), and smother benthic organisms • Suspended solids can decrease transmission of light through water and interfere with animal respiration and digestion • Contaminated sediment acts as a reservoir for particulate forms of pollutants, such as organic matter, phosphorous, or metals that could be released later • These pollutants can be toxic or can decrease dissolve oxygen levels through the process of sediment oxygen demand (SOD) • Floatable wastes reduce the aesthetic value of the resource area and can cause clogging
Pathogens	• Bacteria • Viruses	• Animal waste (including pets and birds) • Failing Septic systems • Illicit sewage connections	Presence of bacteria and viral strains including fecal streptococcus and fecal coliform, in high numbers	• Can pose health risks • Can close or restrict use of shellfish beds and beach areas
Metals	• Heavy metals including lead, copper, cadmium, zinc, mercury, and chromium	• Industrial activities and waste • Illicit sewage connections • Automobile wear, exhaust and fluid leaks • Atmospheric deposition	Increased toxicity of runoff and availability of metals that can enter into the food chain.	• Metals can accumulate in certain animal tissues that could be ingested by humans or other animals • Can affect sensitive animal species, plants and fisheries

Typical Urban Pollutants (continued)

Hydrocarbons	• Oil and grease • Petroleum-based substances • Polycyclic aromatic hydrocarbons (PAHs)	• Parking lots and roadways • Oil Leaks • Auto Emissions • Illicit sewage connections • Illegal dumping of waste oil	Degraded appearance of water surfaces; limiting water and air interactions (lowered dissolved oxygen).	• Toxic to sensitive animal species • Degrades fisheries habitats
Toxic Organics	• Pesticides • Polychlorinated biphenyls (PCBs)	• Indoor and outdoor use • Industrial activities • Illicit sewage connections	Increased toxicity to sensitive animal species and fishery resources.	• Causes loss of sensitive animal species and fishery resources
Acids	• Nitrates (NO_3) • Sulfides (SO_2)	• Incomplete combustion process coupled with atmospheric reactions (acid rain)	Increased toxicity to sensitive animal species and fishery resources.	• Causes loss of sensitive animal species and fishery resources
Humic Substances	• Plant materials such as grass clippings and leaves	• Urban and suburban landscapes	Increased loading into waterbodies of organic materials that require oxygen to decompose; lowered dissolved oxygen levels can cause the release of other substances (pollutants) into the water column.	• Degrades fishery resources • Reduces fish populations
Salt	• Sodium • Chloride	• Road salting procedures	Increased toxicity to organisms, reduction of fishery resources, and increased levels of sodium and chlorides in surface and ground waters. Could stress plant species' respiration processes through their effect on soil structure and can cause loss of other compounds necessary for plant viability.	• Causes loss of sensitive animal species, plant species, and fishery resources • Contaminates surface and ground waters

Source: Adapted from Phillips, N. 1992. Decisionmaker's Stormwater Handbook. Terrene Institute, Washington, DC