THE CAUSES OF URBAN STORMWATER POLLUTION

Some Things To Think About

Runoff pollution occurs every time rain or snowmelt flows across the ground and picks up contaminants. It occurs on farms or other agricultural sites, where the water carries away fertilizers, pesticides, and sediment from cropland or pastureland. It occurs during forestry operations (particularly along timber roads), where the water carries away sediment, and the nutrients and other materials associated with that sediment, from land which no longer has enough living vegetation to hold soil in place.

This information, however, focuses on runoff pollution from developed areas, which occurs when stormwater carries away a wide variety of contaminants as it runs across rooftops, roads, parking lots, baseball diamonds, construction sites, golf courses, lawns, and other surfaces in our City. The oily sheen on rainwater in roadside gutters is but one common example of urban runoff pollution.

The United States Environmental Protection Agency (EPA) now considers pollution from all diffuse sources, including urban stormwater pollution, to be the most important source of contamination in our nation's waters. [1] While polluted runoff from agricultural sources may be an even more important source of water pollution than urban runoff, urban runoff is still a critical source of contamination, particularly for waters near cities -- and thus near most people. EPA ranks urban runoff and storm-sewer discharges as the second most prevalent source of water quality impairment in our nation's estuaries, and the fourth most prevalent source of impairment of our lakes. Most of the U.S. population lives in urban and coastal areas where the water resources are highly vulnerable to and are often severely degraded by urban runoff.

Urban stormwater continues to impair the nation's waterways, years after passage in 1972 of the law now known as the Clean Water Act. The main reason why urban stormwater remains such an important contributor to water pollution is the fact that in most areas, stormwater receives no treatment before entering water bodies. The storm-sewer system merely collects the urban runoff and discharges it directly to the nearest river, stream or lake.

Since 1972 water pollution control efforts have focused primarily on certain process water discharges from facilities such as factories and sewage treatment plants, with less emphasis on diffuse sources. While these efforts have led to many water quality improvements, efforts are needed to address the remaining sources of water pollution, including urban runoff pollution.

Since 1992, cities with a population over 100,000, certain industries, and construction sites over 5 acres have had to develop and implement stormwater plans under Phase I of the National Pollutant Discharge Elimination System (NPDES) stormwater regulations. States and the EPA have issued permits affecting operators, including larger cities operating separate storm sewer systems, which requires them to develop stormwater management plans. A number of stormwater discharges from industrial activities are also subject to NPDES stormwater permit requirements.

On December 8, 1999, EPA promulgated a rule requiring smaller municipalities, those with populations of fewer than 100,000 people located in urbanized areas (where population density is greater than 1,000 persons per square mile) to develop stormwater plans. Municipalities not in urbanized areas that have more than 10,000 residents and a population density greater than 1,000 persons per square mile will also have to develop stormwater plans if the state so designates. Under this so-called "Phase II" rule, the EPA and states will develop "tool boxes" from which the smaller local governments can choose particular stormwater strategies, including the strategies presented in this report, to develop their stormwater plans.

Stormwater must be distinguished from other urban sources of pollution largely caused by wet weather since each separate source is regulated differently. Sanitary Sewer Overflows (SSOs) occur when sanitary sewers, often because of leaks and cracks, become surcharged in wet weather and overflow, often through manholes or into basements. SSOs are more of a problem with older systems while stormwater is an issue for all metropolitan areas, especially growing areas.

Remarkably, studies have shown that stormwater alone can be almost as contaminated as these sewage/stormwater mixtures. Stormwater runoff was nearly last to be regulated in most of the nation's populated areas.

The Water Cycle

To fully understand the stormwater pollution problem, it is helpful to step back and review the water cycle, also known as the hydrologic cycle. The water cycle is simply the constant movement of water from the sky to the ground and back again. The main components of the water cycle are precipitation, infiltration, evapotranspiration (evaporation and transpiration, the process by which plants release water they have absorbed into the atmosphere), surface and channel storage, and groundwater storage. As part of that cycle, when rainwater falls to the ground, or when snow or hail on the ground melt, that water may take several paths.

While the magnitude of these effects varies across the country depending on the precipitation patterns, soil types and other factors, the underlying principles remain the same. In a typical undeveloped area, for example, with natural ground cover such as forests or meadows, a large fraction -- perhaps 50 percent -- of the water infiltrates the soil. Much of this water may remain near the surface from which it often resurfaces into lakes or streams. Other infiltrated water descends to a deeper level, perhaps recharging an underground aquifer used for drinking water. A significant share -- 40 percent in this example -- of the water returns to the atmosphere through evapotranspiration. Only a small amount of the water -- the remaining 10 percent, in this example -- typically remains on the surface of undeveloped land to run off into streams and other waterbodies.

Urbanization can dramatically alter this water cycle, increasing runoff and reducing, at times to almost zero, infiltration. This can completely alter the physical and chemical character of the receiving waterbody.

The Causes of Stormwater Pollution

The stormwater pollution problem has two main components: the increased volume and velocity of surface runoff and the concentration of pollutants in the runoff. Both components are directly related to development in urban and urbanizing areas. Together, these components cause changes in hydrology and water quality that result in a variety of problems including habitat loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion, as well as affects on our health, economy, and social well-being. The following is a discussion of the sources of these problems.

Impacts from Increases in Impervious Surfaces

	Resulting Impacts				
Increased Imperviousness Leads to:	**Flooding**	**Habitat Loss (e.g., inadequate substrate, loss of riparian areas, etc.)**	**Erosion**	**Channel Widening**	**Streambed Alteration**
Increased Volume	•	•	•	•	•
Increased Peak Flow	•	•	•	•	•
Increased Peak Flow Duration	•	•	•	•	•
Increased Stream Temperature		•			
Decreased Base Flow		•			
Changes in Sediment Loadings	•	•	•	•	•

Source: *Urbanization of Streams: Studies of Hydrologic Impacts*, EPA 841-R-97-009, 1997

INCREASED VOLUME AND VELOCITY: THE IMPERVIOUS COVER FACTOR

Types of Impervious Cover

Some impervious cover, such as exposed rock or hardpan soil, is natural. Land development, however, greatly increases it. Human-made impervious cover comes in three varieties: rooftop imperviousness from buildings and other structures; transport imperviousness from roadways, parking lots, and other transportation-related facilities; and impaired pervious surfaces, also known as urban soils, which are natural surfaces that become compacted or otherwise altered and less pervious through human action. Examples of the hard soils include the base paths on a baseball diamond or a typical suburban lawn.

Transport imperviousness generally exceeds rooftop imperviousness in urban areas of the United States. Cumulative figures show that at least one third of all developed urban land is devoted to roads, parking lots, and other motor vehicle infrastructure. In the urban United States, the automobile consumes close to half the land area of cities. Transport imperviousness can constitute approximately two-thirds of total imperviousness in residential and commercial areas. This distinction is important because rainfall on transportation surfaces drains directly to a stream or stormwater collection system that discharges to a waterbody usually without treatment, whereas some roofs drain into seepage pits or other infiltration devices. There is a strong relationship between curb density and overall imperviousness in residential areas suggesting that roads lead to the creation of other impervious surfaces.

The creation of additional impervious cover also reduces vegetation, which magnifies the effect of the reduced infiltration. Trees, shrubs, meadows, and wetlands, like most soil, intercept and store significant amounts of precipitation. Vegetation is also important in reducing the erosional forces of rain and runoff. Conversion of forest to impervious cover can result in an estimated 29 percent increase in runoff during a peak storm event.

Imperviousness Thresholds

Research has shown that when impervious cover reaches between 10 and 20 percent of the area of a watershed, ecological stress becomes clearly apparent. After this point, stream stability is reduced, habitat is lost, water quality becomes degraded, and biological diversity decreases. As a result, more water, having nowhere else to go, runs off the surface picking up pollutants from activities occurring on the impervious surfaces.

To put these numbers into perspective, typical total imperviousness in medium-density, single-family home residential areas ranges from 25 percent to nearly 60 percent. Total imperviousness at strip malls or other commercial sites can approach 100 percent.

Increased Volume of Runoff

The effect of impervious surfaces on the volume of stormwater runoff can be dramatic. For example, a 1-inch rainstorm on a 1-acre natural meadow would typically produce 218 cubic feet of runoff (0ne cubic foot equals 1’ x 1’ x 1’), enough to fill a standard size office to a depth of about 2 feet. The same storm over a 1-acre paved parking lot would produce 3,450 cubic feet of runoff, nearly 16 times more than the natural meadow, and enough to fill three standard size offices completely.

On a larger scale, the effect is even greater. When agricultural or urban development covered 10 percent of the land area, the river's median annual discharge was 4 cubic feet per second. Today, when development covers approximately 70 to 80 percent of that same area, the median annual discharge has been 700 to 800 cubic feet per second, 175 to 200 times the earlier discharge level.

Greater Stream and Runoff Velocity During Storm Events

Impervious surfaces increase the speed of runoff as it drains off the land. Unlike grassy meadows or forests, hard, impervious cover, such as parking lots and rooftops, offers little resistance to water flowing downhill, allowing it to travel faster across these surfaces. In addition, the faster rate of runoff delivers more water in a shorter time to receiving waters than would occur under natural conditions. The increased velocity and delivery rate greatly magnifies the erosive power of water as it flows across the land surface and once it enters a stream.

Increased Peak Discharges

Increased imperviousness not only changes the volume of stormwater flows, but also the distribution of flows over time. When land is undeveloped, the initial stormwater flow following a rain event is relatively small, since the land absorbs and infiltrates much of the water. However, impervious cover forces rainwater or snowmelt to run off the land immediately, causing a sharp peak in runoff immediately following the rain event. Impervious cover can double, triple, quadruple or even quintuple peak discharge. Streams receiving these increased urban peak flows are described as "flashy," meaning that they are prone to sporadic and unstable discharges including flash floods or sudden high pulses of storm flows. An increase in peak flow can have significant impacts on the human and natural environment. Greater peak flows lead to increased flooding, channel erosion and widening, sediment deposition, bank cutting, and general habitat loss.

Reduced Stream Base Flow

Because impervious cover reduces infiltration and forces stormwater to run off the land immediately, it also typically reduces the amount of groundwater available to recharge streams when there is no rain. Hydrologists often refer to groundwater zones under urban areas as "starved" since they are not replenished. This groundwater-charged stream flow, known as base flow, can fall to 10 percent of the regional average when the level of imperviousness in the stream watershed reaches 65 percent. Prolonged low flow can have a significant impact on aquatic life and, in some cases, a greater impact than extreme peak flows. Reduced infiltration can also lead to shortages of drinking water supplies.

Decreased Natural Stormwater Purification Functions

Government flood control agencies often replace the beds of creeks, streams, and other drainage ways with concrete open channels, or completely replace those drainage ways with subsurface concrete storm drain lines. These changes degrade or eliminate habitat and dramatically alter hydrology. Channelizing, diking, and levying disconnects a river from its floodplain and reduces its ability to modify floods naturally. Similarly, this and other development fills, converts, or otherwise eliminates swamps, marshes and other wetlands. Eliminating these natural drainage ways reduces flow storage and detention and soil moisture maintenance and can increase overall flooding and erosion. In addition, natural streambeds and floodplains provide a hydrologic link between groundwater and surface water and can naturally clean waters. By capturing and slowing stormwater, these areas trap sediment, trace metals, and soluble forms of nutrients. Wetlands can retain up to 100 percent of the metals present in water. Wetlands reduce nitrogen discharges, both through the process of bacterial denitrification and through plant uptake, but less effectively reduce phosphorous when soils are saturated.

Similarly, other natural areas can reduce pollutant loads. A riparian forest can remove 89 percent of the nitrogen and 80 percent of the phosphorus from runoff. Forests also typically absorb 70 to 80 percent of atmospherically deposited nitrogen. Trees and other plants stabilize the soil, giving it structure that prevents erosion, and reduce runoff by intercepting and storing precipitation. When rapid stormwater flows have already created erosion on bare soils, plants on downhill slopes slow those flows and allow sediment, as well as other pollutants, to settle onto the land rather than in a waterbody.

However, use of wetlands, streams, and other natural systems is not desirable unless stormwater is delivered at a rate at which pollutants can be assimilated. Natural wetlands, while playing an important role in managing the quality and quantity of runoff, should not be viewed as a sink for polluted runoff. While wetlands help remove pollutants from runoff, some pollutants can accumulate in wetlands or be converted to more potent forms, thereby degrading the natural ecosystem functions and values of these systems and impact the organisms living there. Furthermore, the US EPA recommends protection for any wetland or riparian area which removes pollutants. Therefore, use of these systems for stormwater management should be carefully considered, realizing that these systems need quality water delivered at an appropriate rate to function properly.

INCREASED DEPOSITION OF POLLUTANTS

The second aspect of urbanization that contributes to urban stormwater pollution is the increased discharge of pollutants. As human activity increases in a given area, the amount of waste material deposited on the land and in drainage systems increases. The principal contaminants of concern for stormwater fall into seven categories. The following table lists these categories and provides examples.

While all activities can be a source of some contaminants, certain activities are particularly large contributors. Industrial sites can be major sources of metals and organic chemicals. Animal feedlots are a large source of pathogens, nutrients, and BOD. Agricultural and timber operations discharge high quantities of sediment. This information focuses on those activities in urbanized and urbanizing areas, practices of homeowners, businesses, and government agencies that also contribute many of these contaminants.

Categories of Principal Contaminants in Stormwater	
Category	**Examples**
Metals	zinc, cadmium, copper, chromium, arsenic, lead
Organic chemicals	pesticides, oil, gasoline, grease
Pathogens	viruses, bacteria, protozoa
Nutrients	nitrogen, phosphorus
Biochemical oxygen demand (BOD)	grass clippings, fallen leaves, hydrocarbons, human, and animal waste
Sediment	sand, soil, and silt
Salts	sodium chloride, calcium chloride

Vehicle Use

Driving a car or truck contributes a number of different types of pollutants to urban runoff. Pollutants are derived from automotive fluids, deterioration of parts, and vehicle exhaust. Once these pollutants are deposited onto road and parking surfaces, they are available for transport in runoff to receiving waters during storm events. Brake pad wear contributed 50 percent of the total load, and 25 percent came from atmospheric deposition -- the eventual settling of metals from tailpipe emissions onto the ground. Other car- and truck-related sources of metals include tire wear, used motor oil and grease, diesel oil, and vehicle rust. Tire ware is a substantial source of cadmium and zinc; concentrations at outfalls often exceed acute toxicity levels. Engine coolants and antifreeze containing ethylene glycol and propylene glycol can be toxic and contribute high BOD to receiving waters.

Vehicle exhaust contributes the nutrient nitrogen to our nation's waters. Studies estimate that deposition of nitrogen from power plant and vehicle exhaust contributes 17 pounds per year of nitrogen and 0.7 pounds per year of phosphorus to a typical acre of land. In general, fossil fuel combustion is the largest contributor of nitrogen to the waters of the United States.

Oil, grease, and other hydrocarbons related to vehicle use and maintenance also contaminate our waters. These come from disposal of used oil and other fluids on the ground or into storm drains, spills of gasoline or oil, and leaks from transmissions or other parts of automobiles and trucks. The stormwater discharge from one square mile of roads and parking lots can yield approximately 20,000 gallons of residual oil per year. Runoff from residential car washing also contributes oil, grease, grit, and detergents to the stormwater system. Even gas vapor emitted when filling tanks can subsequently mix with rain, contributing significantly to polluted runoff.

Roads and Parking Lots

In many communities, most impervious cover is related to the transportation system. Material accumulates on these surfaces during dry weather conditions, only to form a highly concentrated first flush during storm events. One study found streets to be the impervious surface with the highest pollutant loads in most land use categories. Another found that transportation related land uses have the second highest level of pollutant concentrations; only piped industrial sources were higher.

Sources of Heavy Metals from Transportation									
Source	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Gasoline	•			•				•	•
Exhaust							•	•	
Motor Oil & Grease		•			•		•	•	•
Antifreeze					•				•
Undercoating								•	•
Brake Linings				•	•		•	•	•
Rubber	•			•				•	•
Asphalt				•			•		•
Concrete				•			•		•
Diesel Oil	•								
Engine Wear					•	•	•	•	•
Source: Local Ordinances: A Users Guide, Terrene Institute and EPA, Region 5, 1995.									

Home Landscaping and Public Grounds Maintenance

Landscaping practices are another potential source of pollutants in urban runoff. Turf management chemicals including fertilizers used at home and on golf courses, cemeteries, and public parks can add nutrients to runoff. Monitoring has shown a direct link between the chemicals found in lawn care products and urban water quality. While there remain questions on some details of the contribution of turf management to receiving water quality, it is clear that the type, quantity, and timing of materials used make a significant difference.

One important variable is the quantity of chemicals being applied. Over or improper application at homes and other places is far too common. Experts estimate that residential fertilizer use accounts for one-third of the excess nitrogen entering the watershed. Of particular concern is the application of fertilizers and pesticides just before an intense storm event, since they may not have had time to become fixed in the soil and thatch.

Similarly, harmful pesticides found in stormwater from golf courses, municipal parks, highway medians and roadsides, and residential lawns and gardens. The percentage of pesticide lost in runoff can be large after being applied a few hours before a storm event.

Since organic matter contains nutrients, raking autumn leaves or grass clippings into gutters or streets for municipal collection or otherwise facilitating the entry of these materials into the storm-sewer system also adds nutrient loads and oxygen-demanding substances to stormwater. Poorly maintained garden beds or lawns can be a source of sediment as well.

Six Pesticides Found Frequently in Stormwater Samples	
Pesticide Name	**Human Health and/or Environmental Effects**
2,4-D	Associated with lymphoma in humans; testicular toxicant in animals.
Chlorpyrifos	Moderately toxic to humans; neurotoxicant; can be highly toxic to birds, aquatic organisms, and wildlife.
Diazinon	Moderately toxic to humans; neurotoxicant; can be highly toxic to birds, aquatic organisms, and wildlife.
Dicamba	Neurotoxicant; reproductive toxicity in animals; association with lymphoma in some human studies.
MCPA (Methoxane)	Low toxicity to non-toxic in test animals, birds, and fish; suspected gastrointestinal, liver, and kidney toxicant.
MCPP (Mecoprop)	Slightly to moderately toxic; some reproductive effects in dogs; suspected cardiovascular, blood, gastrointestinal, liver, kidney, and neurotoxicant.
Sources: T.R. Schueler, quot;Urban Pesticides: From the Lawn to the Stream,quot; Watershed Protection Techniques, vol. 2, no. 1, Fall 1995, pp. 247, 250 and Extoxnet: Extension Toxicology Network Pesticide Information Profiles, http://ace/orst.edu/info/extoxnet, and Environmental Defense Fund, Scorecard Chemical Profiles, http://www.scorecard.org/chemical-profiles.	

Construction Sites

Construction activity is the largest direct source of human-made sediment loads. Results from both field studies and erosion models indicate that erosion rates from construction sites are typically an order of magnitude larger than row crops and several orders of magnitude greater than rates from well-vegetated areas, such as forest or pastures. Since erosion rates are much higher for construction sites relative to other land uses, the total yield of sediment and nutrients is higher. Studies indicate that poorly managed construction sites can release 7 to 1,000 tons of sediment per acre during a year, compared to 1 ton or less from undeveloped forest or prairie land. Construction activity can also result in soil compaction and increased runoff.

Like nutrients, soil and sediment are, to a certain degree, a naturally occurring and functional component of all waterbodies. Yet human activities usually increase the amount of sediment entering our waterbodies to such an extent as to turn sediment into a water quality problem.

Illicit Sanitary Connections to Storm Sewers From Homes and Businesses

Illicit connections from toilets to storm sewer pipes can add pathogens to stormwater. Pathogens are viruses, bacteria, and protozoa harmful to human health. Coliform bacteria, which come from human waste, is commonly used as an indicator that harmful pathogens may be present in the water. Studies have found high levels of coliform bacterial in stormwater.

Illicit sanitary connections can also add nutrients such as nitrogen and phosphorus to stormwater. Human waste also contributes to BOD. Leaking sanitary sewer lines located near storm sewer lines can pose the same problems as illicit connections.

Septic Systems

Effluent from poorly maintained or failing septic systems can rise to the surface and contaminate stormwater. Septic systems can be important sources of pathogens and nutrients, especially nitrogen, that are not effectively removed from the waste stream. Bathing beach and fishing area closures are frequently the result of septic system effluent. Fecal coliform and BOD can be present in stormwater if the system is improperly sited, designed, installed, or maintained.

Illicit Industrial Connections to Storm Sewers

Businesses that illicitly connect pipes containing wastewater from industrial processes to the storm sewer system rather than to the sanitary sewers can add metals, solvents or other contaminants to stormwater. Floor drains, dry wells, and cesspools are also frequent sources of illicit industrial discharges and connections.

Uncovered Materials Stored Outside

Rain or melting snow can erode piles of bulk material, such as sand, loose topsoil, or road salt if left uncovered, adding sediment, salts or other pollutants to nearby waterbodies. Likewise, precipitation can wash contaminants off leaking or dirty objects left outdoors. For example, water quality monitoring showed that untreated runoff collected from auto recycling facilities frequently exceeded EPA benchmark figures, for biochemical oxygen demand, nitrogen, oil and grease, phosphorus, and sediment.

Street, Sidewalk, and Airport De-icing

Salts used to keep roads, parking lots and sidewalks free of ice often drain into our waterbodies as snow and ice melt and spring rain falls. While some salt and ice treatment is necessary to keep roads safe in winter, measures can be taken to reduce or prevent the impacts from de-icing. The principal salts used are sodium chloride and calcium chloride, although materials such as calcium magnesium acetate and other commercial products are also used. Some municipalities spread sand to maintain road traction on snow and ice, and this sand eventually may increase sediment loads. Airports de-ice runways and planes, usually with glycol mixtures that can be both toxic to fish, wildlife, and humans and exert high BOD on receiving streams.

Landfills

Because the soil cover on landfills is not stabilized with vegetation or other retaining cover while the landfill is operational, soil can erode from landfills as it does from construction sites. Additionally, improperly maintained hazardous-waste landfills can allow toxic contaminants to reach or stay on the surface of the landfill, allowing stormwater to carry these pollutants to nearby waterbodies.

Pets and Wild Animals

Waste from domestic and wild animals is a source of pathogens, nutrients and BOD in stormwater. A study estimated that each day, dogs leave 180,000 pounds of waste on the ground in one county alone. Waste from birds such as pigeons, geese, and gulls that are attracted to human activity can also be a problem. Wild geese that congregate in large numbers on cultivated turf adjacent to bodies of water also contribute to pathogen, nutrient and BOD loadings.

Littering

Not only does stormwater frequently receive no treatment, it also often does not even have the benefit of simple filtering or screening for visible objects. As a result, paper cups, cigarette butts, virtually anything made of styrofoam, newspaper, and other materials that people toss on the ground are carried into storm sewer systems -- and eventually into lakes, streams, and oceans.

This list, exhaustive as it is, is incomplete. Galvanized roofs, unpaved roads, the dust that collects on paved streets, and countless other aspects of daily life in urban areas contribute to polluted runoff. The first step in stormwater management is not to memorize any particular list, but rather to recognize the breadth of opportunities for pollution prevention and the need to think holistically about the entire chain of human activities that affect runoff quantity and quality. As you can see, the above demonstrates a wide variety of effective and efficient strategies for addressing stormwater runoff at the source.

NOTE: modified from material obtained from the U.S. EPA