Chapter 2

THE CAUSES OF URBAN STORMWATER POLLUTION

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 report, 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 cities and suburbs. The oily sheen on rainwater in roadside gutters is but one common example of urban runoff pollution.

This chapter discusses some of the causes of stormwater runoff and pollution, which are important to understand before adopting management strategies.

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. 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, 29 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 waterbodies. The storm-sewer system merely collects the urban runoff and discharges it directly to the nearest river, lake, or bay.

Over the past 29 years, 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, new efforts are now needed to address the remaining sources of water pollution, including urban runoff pollution.

Comprehensive stormwater regulation has been slow to develop (see box: "History of Stormwater Regulation in the United States"). 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. As of May 1999, states and the EPA have issued more than 260 permits affecting some 850 operators, including larger cities operating separate storm sewer systems, which require 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. In addition to stormwater runoff, which is the focus of this study, there are two other significant sources of urban wet weather pollution: sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs). SSOs occur when sanitary sewers, often because of leaks and cracks, become surcharged in wet weather and overflow, often through manholes or into basements. CSOs occur when flows into combined sewer system (systems that receive stormwater, sanitary sewer discharges from residences and businesses, and wastewater discharges from industrial facilities and transport it all through a single pipe) exceed the treatment and storage capacity of the sewer system and waste treatment facility. At that point, this combined waste stream overflows into creeks, rivers, lakes or estuaries through designated outfalls usually without treatment. CSOs and SSOs are more of a problem with older systems while stormwater is an issue for all metropolitan areas, especially growing areas. Moreover, while prevention programs can be very important to efforts to reduce CSOs and SSOs, structural changes are usually necessary. By contrast, much stormwater pollution can be prevented with proper planning in growing or redevelopment areas.

Remarkably, studies have shown that stormwater alone can be almost as contaminated as these sewage/stormwater mixtures. Yet stormwater runoff remains to be regulated in most of the nation's populated areas. While many CSO and SSO control measures may overlap with stormwater pollution control measures, strategies that deal with stormwater specifically must be implemented if the quality of America's waterbodies is to improve. These strategies are the focus of this report.

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### HISTORY OF STORMWATER REGULATION IN THE UNITED STATES

The history of stormwater regulation began over 25 years ago. It has been in and out of the courts, Congress, EPA and is now in the hands of states and local governments.

**1972:** EPA issues exemptions from the federal Clean Water Act NPDES permit program for most sources of stormwater. NRDC sues EPA to require permits for all point sources, including urban storm sewers (applications by 1973 and permits by 1974).

**1975–1977:** The U.S. District Court finds that EPA exemptions are contrary to the Clean Water Act (NRDC v. Train). This decision is upheld by U.S. Court of Appeals in 1977 (NRDC v. Costle).

**1980:** EPA issues rules responding to the court's decision that exempt cities outside "urbanized areas from needing NPDES permits for their storm sewers." NRDC and industry sue EPA over the rules (NRDC v. EPA).

**1980–1990:** During this period, EPA struggled with developing stormwater rules, and extends the stormwater permit deadlines for large cities until 1987 and 1989. EPA also issues "nonenforcement letters" informing cities that EPA would not take enforcement actions against cities with permit applications and proposes narrowing the definition of stormwater discharges. In 1983, EPA issues a final report on the Nationwide Urban Runoff Program. In 1984, NRDC and the states negotiated with EPA to reject narrowing coverage and revoke letters.
1987: In Clean Water Act amendments, Congress requires EPA to issue by 1989 "Phase I" rules addressing stormwater from cities with a population over 100,000 and from industrial sites, and to issue by 1992 "Phase II" rules for other significant sources of stormwater pollution.

1990: EPA promulgates "Phase I" NPDES stormwater regulations and extends compliance beyond those dates in the 1987 law. NRDC sues EPA for illegally extending deadlines and excluding certain sources from regulations (NRDC v. EPA).[d]

1992: A U.S. Court of Appeals ruling prohibits further stormwater dead-line extensions (NRDC v. EPA)[e] and invalidates certain provisions of the Phase I rule. EPA and the states issued initial general permits for storm-water discharges.

1992: Congress provides an additional extension to small cities for storm-water permit applications.

1995: EPA is sued for its failure to conduct study, file report, and issue regulations concerning Phase II stormwater pollutant sources (NRDC v. Browner).[f] EPA issues Report to Congress on "Storm Water Discharges Potentially Addressed by Phase II of the NPDES Storm Water Program." NRDC and EPA enter into consent decree requiring EPA to issue a final rule by March 1999 (later extended to October 1999) addressing both Phase II stormwater and Phase I issues remanded by the court. In 1996, EPA convenes a federal advisory committee.

1997: EPA issues draft Phase II stormwater rules.

b 568 F.2d 1369 (D.C. Cir. 1972).
c 673 F.2d 392 (D.C. Cir. 1980) (per curiam).
d 915 F.2d 1314 (9th Cir. 1990).
e 966 F.2d 1292 (9th Cir. 1992).
f No. 95-634 PLF (D.D.C.) (consent order signed April 6, 1995).

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, as illustrated in Figure 2-1 (print report only).

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 Midwestern 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. These consequences will be discussed in Chapter 3; the following is a discussion of the sources of these problems.

<table>
<thead>
<tr>
<th>Table 2-1</th>
<th>Impacts from Increases in Impervious Surfaces</th>
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<tbody>
<tr>
<td>Resulting Impacts</td>
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<tr>
<td>Increased Imperviousness Leads to:</td>
<td>Flooding</td>
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<tr>
<td>Increased Volume</td>
<td>•</td>
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<tr>
<td>Increased Peak Flow</td>
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<tr>
<td>Increased Peak Flow Duration</td>
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<tr>
<td>Increased Stream Temperature</td>
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<tr>
<td>Decreased Base Flow</td>
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<tr>
<td>Changes in Sediment Loadings</td>
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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, worldwide, 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; in Los Angeles the figure approaches two thirds. The city of Olympia, Washington, also found that transport imperviousness constituted approximately two-thirds of total imperviousness in several 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. Research has also found 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. In one study, conversion of forest to impervious cover resulted 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. Figure 2-3 (print report only) shows that as the amount of impervious surface in a watershed increases infiltration and evapotranspiration both drop substantially. 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, 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. In a 620-square-mile portion of the watershed of the Des Plaines River in Illinois, in 1886, 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, as illustrated in Figure 1-5 (print report only). 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 as discussed in Chapter 3.

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. Studies have shown that 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. One riparian forest in the Chesapeake Bay region removed 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 from runoff to coastal waters. 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. Feedlots are a large source of pathogens, nutrients, and BOD. Agricultural and timber operations discharge high quantities of sediment. This report focuses on those activities in urbanized and urbanizing areas, practices of homeowners, businesses, and government agencies that also contribute many of these contaminants.

<table>
<thead>
<tr>
<th>TABLE 2-2</th>
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<tbody>
<tr>
<td>Categories of Principal Contaminants in Stormwater</td>
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<tr>
<td>Category</td>
</tr>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>Organic chemicals</td>
</tr>
<tr>
<td>Pathogens</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Biochemical oxygen demand (BOD)</td>
</tr>
<tr>
<td>Sediment</td>
</tr>
<tr>
<td>Salts</td>
</tr>
</tbody>
</table>

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. One landmark study estimated that cars and other vehicles contributed 75 percent of the total copper load to the lower San Francisco Bay through runoff. 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 wear 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 the metropolitan Washington, DC, area. In general, fossil fuel combustion is the largest contributor of nitrogen to the waters of the northeastern United States, and is a very large contributor elsewhere.

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.

<table>
<thead>
<tr>
<th>Table 2-3</th>
<th>Sources of Heavy Metals from Transportation</th>
</tr>
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<tbody>
<tr>
<td>Source</td>
<td>Cd</td>
</tr>
<tr>
<td>Gasoline</td>
<td>•</td>
</tr>
<tr>
<td>Exhaust</td>
<td></td>
</tr>
<tr>
<td>Motor Oil &amp; Grease</td>
<td>•</td>
</tr>
<tr>
<td>Antifreeze</td>
<td></td>
</tr>
<tr>
<td>Undercoating</td>
<td></td>
</tr>
<tr>
<td>Brake Linings</td>
<td></td>
</tr>
<tr>
<td>Rubber</td>
<td>•</td>
</tr>
<tr>
<td>Asphalt</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Diesel Oil</td>
<td>•</td>
</tr>
<tr>
<td>Engine Wear</td>
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</tbody>
</table>

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 Sarasota Bay watershed in southwest Florida. 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, such as chloropyrifos, 2,4-D, and diazinon come from golf courses, municipal parks, highway medians and roadsides, and residential lawns and gardens. The percentage of pesticide lost in runoff can be large; one study found up to 90 percent of the herbicide 2,4-D was lost in runoff 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.

<table>
<thead>
<tr>
<th>Table 2-4</th>
<th>Six Pesticides Found Frequently in Stormwater Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pesticide Name</strong></td>
<td><strong>Human Health and/or Environmental Effects</strong></td>
</tr>
<tr>
<td>2,4-D</td>
<td>Associated with lymphoma in humans; testicular toxicant in animals.</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>Moderately toxic to humans; neurotoxicant; can be highly toxic to birds, aquatic organisms, and wildlife.</td>
</tr>
<tr>
<td>Diazinon</td>
<td>Moderately toxic to humans; neurotoxicant; can be highly toxic to birds, aquatic organisms, and wildlife.</td>
</tr>
<tr>
<td>Dicamba</td>
<td>Neurotoxicant; reproductive toxicity in animals; association with lymphoma in some human studies.</td>
</tr>
<tr>
<td>MCPA (Methoxane)</td>
<td>Low toxicity to non-toxic in test animals, birds, and fish; suspected gastrointestinal, liver, and kidney toxicant.</td>
</tr>
<tr>
<td>MCPP (Mecoprop)</td>
<td>Slightly to moderately toxic; some reproductive effects in dogs; suspected cardiovascular, blood, gastrointestinal, liver, kidney, and neurotoxicant.</td>
</tr>
</tbody>
</table>

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 shellfish bed closures are frequently the result of septic system effluent. One study found that 74 percent of the nitrogen entering the Buttermilk Bay estuary in Massachusetts originated from septic systems. 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. In Seattle, one industrial facility's discharge of lead to the storm sewer system resulted in sediment so contaminated that it could be sent to a smelter to be refined. 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 near Los Angeles frequently exceeded EPA benchmark figures, for biochemical oxygen demand, nitrogen, oil and grease, phosphorus, and sediment.
Street, Sidewalk, and Airport De-icing

In colder parts of the country, 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. The Northern Virginia Soil and Water Conservation District estimates that each day, dogs leave 180,000 pounds of waste on the ground in Fairfax County, Virginia, 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. The case studies presented in this report demonstrate a wide variety of effective and efficient strategies for addressing stormwater runoff at the source.

Notes


29. AbTech Industries, *Introducing OARS(tm)*, promotional flyer, undated (calculation based on 1995 King County study that found that concentration of oil in stormwater from arterial roads and parking lots was 30 mg./L; assumed annual rainfall of forty inches).


41. 63 Federal Register 1540 (January 9, 1998).


Chapter 3

THE CONSEQUENCES OF URBAN STORMWATER POLLUTION

The degradation caused by urban stormwater pollution is serious, and affects a significant proportion of the nation's population. Changes in land use that increase impervious cover lead to flooding, erosion, habitat degradation, and water quality impairment. Everyday activities such as driving, maintaining vehicles and lawns, disposing of waste, and even walking pets often cover impervious surfaces with a coating of various harmful materials. Construction sites, power plants, failed septic systems, illegal discharges, and improper sewer connections also contribute substantial amounts of contaminants to runoff. When these contaminants enter lakes, streams, and estuaries they result in stormwater pollution. This pollution, in turn, impacts important natural resources as well as other, equally important activities such as commercial and recreational fishing, swimming, and boating. While urban stormwater runoff is not alone in causing these impacts (industrial and agricultural runoff are equal or greater contributors to water quality impairment on a national scale), the environmental, aesthetic, and public health impacts outlined in this chapter will not be eliminated until urban stormwater pollution is controlled.

Flooding and Property Damage

The most dramatic consequence of increases in the volume and rate of stormwater runoff is flooding and property damage. As discussed in the preceding chapter, undeveloped areas such as forests and wetlands serve as sponges for excess rainwater, so when these areas are eradicated, filled in, or replaced with impervious cover such as asphalt, the volume of water entering streams and rivers increases. One study estimated that because of the increase in impervious cover in a watershed a flood event that should be expected once in 100 years could occur once every 5 years when the impervious cover reaches 25 percent, and could become an annual event when impervious cover reaches 65 percent.

Conventional urban stormwater management, with its emphasis on engineered flood control measures such as dams, dikes and levees, and detention facilities, has in many areas helped to mitigate some of the worst flood damage. But it has been vastly outstripped by the pace of flood-producing urbanization. Furthermore, by quickly channeling stormwater away from certain areas via paved channels, stormwater pipes, and stream bank stabilization techniques (e.g., riprap, cutbacks, plantings, and bulkheads) rather than providing for retention or infiltration, conventional stormwater management can simply transfer hydrologic impacts downstream. At times, downstream areas experience greater habitat loss, increased channel widening and erosion, and worse flooding due to the reduced storage and facilitated runoff upstream.
An Announcement from the Experts: "No One Safe From Flooding," FEMA Says

WASHINGTON April 1, 1997 -- Destructive floods can -- and do -- occur in -- every state in the nation, according to recent statistics issued by the Federal Emergency Management Agency (FEMA).

While some communities are less likely to experience flooding than others, nowadays very few, if any, are entirely safe from this threat, which is by far the most common type of natural disaster in the United States. "About 90% of our natural disasters involve flooding in one way or another," FEMA Director James Lee Witt said, "and the impression many people have that floods seem to happen more frequently now than they used to is quite accurate."

"As more and more land is cleared for development and paved over, there is less and less available to soak up excess water," Witt said. "The runoff has to go somewhere, and places that never flooded before are now at risk."

The records of the Federal Insurance Administration indicate that approximately $1.1 billion in claims under the National Flood Insurance Program were paid in each of fiscal years 1995 and 1996. Those same records indicate that the Federal Insurance Administration paid flood insurance claims in every state of the union during that two-year period.


Streambank and Streambed Erosion

The increased volume and rate of urban stormwater runoff erodes streambanks and streambeds, dislodging and suspending sediment that might otherwise have remained in place. Erosion can be gradual, or can occur rapidly through a sudden collapse of a streambank. Changes in hydrology also affect the shape and dimension of river channels, thereby altering aquatic habitat and channel stability.

Siltation and Sedimentation

Rapidly flushing stormwater can increase erosion from all land, not just streambanks and streambeds. Stormwater then transports the eroded sediment downstream into the receiving waters. Eventually, when sediment-laden water is stilled, that sediment settles to the bottom of the stream, river, lake, or estuary. When sediments settle out, they may cover or destroy important habitat such as spawning beds or submerged aquatic vegetation. Pollutants such as phosphorus attach to sediment particles and become suspended or dissolved in receiving waters. The magnitude of the sedimentation problem is staggering: one study estimates that each year erosion from construction sites puts 80 million tons of sediment into receiving waters.

Siltation and sedimentation has economic impacts as well. These excess deposits of sediment clog harbors and other water transport routes and reduce the storage capacity of reservoirs, obliging governments to spend billions of dollars each year to dredge and maintain those channels and facilities. The U.S. Army Corps of Engineers dredges 83 million cubic yards of sediment linked to pollution sources each year at an annual cost of $180 million. In many cases, these dredged sediments are laden with nutrients, heavy metals, and toxic chemicals -- making disposal expensive. Siltation can also affect commercial and recreational fishing by degrading necessary habitat and can impede recreational boating by creating obstructions.
Increased Water Temperature

Aquatic organisms have specific water temperature preferences and tolerance limits. Changes in water temperature can have a serious impact on aquatic ecosystems. Water that infiltrates the ground and flows beneath the surface is usually much cooler than surface runoff. Not only do impervious surfaces prevent infiltration, they often warm stormwater as it runs off. Unshaded rooftops, parking lots, and other impervious areas can be 10–12°F warmer than fields and forests and consequently can heat the stormwater passing over them, often to 90°F or more, even before it reaches a stream or lake. Research has found that the average stream temperature increases directly with the percentage of impervious cover in the watershed. One study documented a temperature difference of almost 20°F between a wooded section of a Maryland stream and an open section of the same stream 7/10ths of a mile downstream. Furthermore, trees shade waterbodies keeping them cool, while development often replaces tress with impervious surfaces.

Harm to Aquatic Life

Urban runoff can harm aquatic life in many ways due to changes in water chemistry and habitat loss. The metals and organics that stormwater carries are toxic to fish and other forms of aquatic life. For example, untreated urban runoff collected from an auto recycling facility near Los Angeles over several years repeatedly killed 20 percent or more of the minnows exposed to it. Urban stormwater is also often toxic to several species of aquatic insects, on which fish, frogs and other higher life forms feed. For example, organic chemicals may have effects on the immune systems and early development of aquatic life. Stormwater can also bring toxic levels of road salt to urban waters. In certain streams draining roadway areas, studies have measured concentrations of chloride at levels 25 or even 60 times the level harmful to trout. Even the trash that stormwater carries harms wildlife. The plastic loops that hold six-packs of beer or soda together can strangle gulls.

Sediment in stormwater has a number of harmful effects on aquatic life. Sediment still suspended in water increases infection and disease among fish by irritating their gills. A number of fish species, including endangered species such as the log perch or blue shiner, cannot tolerate sediment levels in the water above certain threshold levels, and thus disappear from waterbodies under those conditions. Suspended sediment scour submerged plants attached to rocks, as well as blocks sunlight that aquatic plants use to produce growth through photosynthesis.

When sediment settles, it can bury and smother bottom-dwelling insects and reduce the survival rate of fish eggs. At the same time, sediment deposition fills in the spaces between the gravel in stream beds that fish use to spawn and raise their young and in which invertebrate food sources live. Furthermore, sediment may carry nutrients, bacteria, toxic metals and organic chemicals to the water.

The increase in surface runoff associated with land development also dramatically increases runoff of the nutrients phosphorus and nitrogen, causing receiving waters to suffer. Many nutrients, which cling to soil particles in natural settings, are dislodged by development and other activities making them free to run off with stormwater. For example, in a comparison between two Maine watersheds, phosphorus export was 10 times greater in a developed watershed than a forested watershed. In highly developed areas these increases are usually permanent.

The enrichment of waters with nutrients is termed eutrophication and is a concern for several reasons. Excess phosphorus causes elevated growth of algae and aquatic vegetation in lakes and streams. Excess nitrogen can have a similar effect in marine waters. The excessive plant growth interferes with the use of waterbodies for recreation, fisheries, industry, agriculture, and drinking water supply. It can also lead to foul odors, noxious gas, and poor aesthetic quality of the receiving water. In marine systems, nutrient enrichment can lead to red and brown tides that are a threat to marine organisms and human health. Perhaps most dramatically, eutrophication can cause fish kills. When the vegetation dies and decomposes, it consumes oxygen dissolved in the water. Fish and other aquatic organisms cannot
tolerate dissolved oxygen concentration below certain thresholds. As a result, eutrophic waters are typically devoid of most life.

Organic material discharged to a lake or stream also consumes oxygen when decomposing thereby reducing the dissolved oxygen content of the receiving water. As with nutrient enrichment, sudden additions of such material, perhaps in a storm or through illicit dumping, frequently causes fish kills. Longer term impacts include changes in fish populations and reductions in shellfish.

The increase in water temperature compounds the oxygen-depletion problem. The warmer the water, the less dissolved oxygen it can carry. Research indicates that the thermal changes caused by urban runoff can increase visible algae blooms and have severe impacts on cold-water fish and other aquatic life.

Changes in hydrologic patterns also have a significant effect on aquatic life. Urbanization increases both the magnitude and frequency of extreme low and high flow events. It also leads to a decrease in infiltration resulting from decreased base flow, an increase in water temperature, and declines in upland, riparian, and instream habitat quality. Research indicates that larger flood events significantly reduce populations of young fish such as trout and salmon as well as invertebrate populations.

These impacts -- sedimentation, contaminant loadings, hydrologic instability, oxygen depletion and temperature increases -- not only threaten individual animals, but also reduce the diversity of life living in these waterbodies. Studies have shown a sharp drop in the diversity of insect populations, which serve as food for higher life forms such as frogs and fish, as the amount of impervious cover in an urbanizing watershed passes 10 or 15 percent. Other research has shown that the variety of fish species drops as well, with the disappearance of sensitive fish such as trout and salmon. In short, stream biological health declines as watershed imperviousness increases.

**Harm to Coastal Shellfisheries**

Pathogens in stormwater also contaminate shellfish beds, and this contamination, along with pollution from other sources, causes closure of shellfish beds nationwide. Data collected from five coastal states indicate that urban runoff and storm sewers are the most pervasive source of shellfish harvesting restrictions, contaminating over 30 percent of the area reported as subject to such restrictions in those states. A key contributing factor is the fact that levels of bacteria and viruses are usually much greater -- 100 to 1,000 times greater -- in the bottom sediment, where shellfish live, than in the water above.

**Harm to Sport Fishing**

The harm to fish leads quickly to harm to fisheries. Sport fishing is a big business in the United States, and many of the species that are most sensitive to degraded water conditions, such as brown trout and salmon, are the species anglers prize most. Quality fisheries can be an important economic asset to the surrounding communities. The U.S. Fish & Wildlife Service estimates that over 35 million anglers spent over $38 billion dollars in pursuit of their pastime in 1996, money that would not be spent if there were no fish to be caught.

**Human Illness**

Stormwater carries disease-causing bacteria, viruses, and protozoa. Swimming in polluted waters can make you sick. A study in Santa Monica Bay found that swimming in the ocean near a flowing storm sewer drain during dry weather conditions significantly increased the swimmer's risk of contracting a broad range of health effects. Comparing swimming near flowing storm-drain outlets to swimming at a distance of 400 yards from the outlet, the study found a 66 percent increase in an group of symptoms indicative of respiratory disease and a 111 percent increase in a group of symptoms indicative of gastrointestinal illness within the next 9 to 14 days. Increased sediment in receiving water is also related to human illness: sediment prolongs life of pathogens and makes it easier for them to reproduce.
Impacts to Drinking Water Supply

In urbanized areas, runoff pollution is a serious concern for water supply agencies. Over 90 percent of the people in the United States rely on public supplies of drinking water. Of that 90 percent, 19 percent are served by systems with reported health violations. A nationwide survey of surface drinking water supply utilities found that with an increase in urbanization there arose an increased concern among managers over runoff pollutants, particularly nutrients, bacteria, and toxic organic chemicals. The costs can be astronomical. For example, runoff pollution from suburban and agricultural sources is one of the largest threats to New York City's currently unfiltered drinking water supply. If this pollution cannot be prevented, New York City may need to filter its water supply at a capital cost of perhaps $5 billion or more.

Aesthetic Losses

Even if stormwater does not cause illness in humans from direct exposure or through dining on contaminated shellfish, it can cause other annoyances or intrusions. The cigarette butts, polystyrene cups, and other trash that storm sewers dump in neighborhood waters are an obvious eyesore. Sediment loads reduce the clarity of water, which not only reduces its attractiveness but can also increase the likelihood of boating, swimming, and diving accidents. Excess nutrient loads can cause severe algal blooms, which coat the surface of water with an unpleasant scum, cloud the water, and add unpleasant odors and taste to water used for swimming or drinking. The fish kills that urban stormwater pollution can cause are also community nuisances.

Harm to tourism and recreation. The combination of potential human illness and aesthetic losses can cause loss of revenues from tourism and recreational activities. Urban stormwater runoff was a documented contributing factor to approximately 25 percent of the approximately 1,651 beach closings reported in 1997, and was probably a factor in many more beach closings for which the contaminant sources were undocumented. Coastal tourism is a major component of local economic activity across the nation, adding, for example, some $54 billion dollars and more than 320,000 jobs to the economies of nine California counties alone. Inland, along rivers and lakes, tourism and recreational activities dependent on clean water provide municipalities with tax revenues and employment opportunities. Each year, water-based recreation adds $26 million to $31 million and a minimum of 650 to 750 jobs to the economies of 13 New Hampshire towns along the Connecticut River, and over $13 million and 290 jobs to the economy of the upper Delaware Valley between New York and Pennsylvania.

Notes


an estimate of $2.1 billion to $6.5 billion in annual dredging and construction costs for water storage facilities. The total annual cost of dredging material from navigational channels is $180 million.


8. R. Klein, *Preventing Damage to 600 Miles of Maryland Streams, Wetlands, Rivers, and Tidal Waters: Why Improvements to Maryland's Stormwater Management Program are Urgently Needed*, Community and Environmental Defense Services, Freeland, Maryland, 1999. According to Klein, Warmwater fish, such as smallmouth bass and darters begin dying at 86° F and suffer stress at 78° F; trout begin dying at 72° F and suffer stress above 88° F.


38. Santa Monica Bay Restoration Project. *An Epidemiological Study of Possible Adverse Health Effects of Swimming in Santa Monica Bay*, pp. iv, v, 122.


Chapter 12

LOW IMPACT DEVELOPMENT

Introduction

Low Impact Development (LID) has emerged as a highly effective and attractive approach to controlling stormwater pollution and protecting developing watersheds and already urbanized communities throughout the country. Several LID practices and principles, particularly the source control approach and the use of micro-scale integrated management practices have the potential to work effectively as stormwater quality retrofits in existing ultra urban areas as well. Developments in and application of LID techniques that have occurred since the original publication of Stormwater Strategies motivated this new section, which is an addendum to the discussion of strategies for addressing stormwater in new development and redevelopment covered in Chapters 5 through 11.

LID stands apart from other approaches through its emphasis on cost-effective, lot-level strategies that replicate predevelopment hydrology and reduce the impacts of development. By addressing runoff close to the source, LID can enhance the local environment and protect public health while saving developers and local governments money.

Below is a discussion of LID, its principles, practices, and benefits followed by 13 new case studies. The case studies provide examples of several LID practices and describe how they are being applied throughout the country. These practices are the building blocks of LID design and, when integrated in a systematic way, provide substantial benefits to the developer and community.

What is Low Impact Development?

LID is simple and effective. Instead of large investments in complex and costly engineering strategies for stormwater management, LID strategies integrate green space, native landscaping, natural hydrologic functions, and various other techniques to generate less runoff from developed land. LID is different from conventional engineering. While most engineering plans pipes water to low spots as quickly as possible, LID uses micro-scale techniques to manage precipitation as close to where it hits the ground as possible. This involves strategic placement of linked lot-level controls that are "customized" to address specific pollutant load and stormwater timing, flow rate, and volume issues. One of the primary goals of LID design is to reduce runoff volume by infiltrating rainfall water to groundwater, evaporating rain water back to the atmosphere after a storm, and finding beneficial uses for water rather than exporting it as a waste product down storm sewers. The result is a landscape functionally equivalent to predevelopment hydrologic conditions, which means less surface runoff and less pollution damage to lakes, streams, and coastal waters.
LID is economical. It costs less than conventional stormwater management systems to install and maintain, in part, because of fewer pipe and below-ground infrastructure requirements. But the benefits do not stop here. The associated vegetation also offers human “quality of life” opportunities by greening the neighborhood, and thus contributing to livability, value, sense of place, and aesthetics. This myriad of benefits include enhanced property values and re-development potential, greater marketability, improved wildlife habitat, thermal pollution reduction, energy savings, smog reduction, enhanced wetlands protection, and decreased flooding. LID is not one-dimensional; it is a simple approach with multifunctional benefits.

LID is flexible. It offers a wide variety of structural and nonstructural techniques to reduce runoff speed and volume and improve runoff quality. LID works in constrained or freely open lands, in urban infill or retrofit projects, and in new developments. In a combined sewer system, LID can reduce both the number and the volume of sewer overflows. Opportunities to apply LID principles and practices are infinite -- almost any feature of the landscape can be modified to control runoff (e.g., buildings, roads, walkways, yards, open space). When integrated and distributed throughout a development, watershed, or urban drainage area, these practices substantially reduce the impacts of development.

As urbanization continues to degrade our lakes, rivers, and coastal waters LID is increasingly being used to reverse this trend, resulting in cleaner bodies of water, greener urban neighborhoods, and better quality of life. LID offers a strong alternative to the use of centralized stormwater treatment. It aims to work within the developed and developing environment to find opportunities to reduce runoff and prevent pollution. LID controls stormwater runoff at the lot level, using a series of integrated strategies that mimic and rely on natural processes. By working to keep rainwater on site, slowly releasing it, and allowing for natural physical, chemical, and biological process to do their job, LID avoids environmental impacts and expensive treatment systems.

Low Impact Development Principles and Practices

LID is grounded in a core set of principles based on the paradigm that stormwater management should not be seen as stormwater disposal and that numerous opportunities exist within the developed landscape to control stormwater runoff close to the source. Underlying these principles is an understanding of natural systems and a commitment to work within their limits whenever possible. Doing so creates an opportunity for development to occur with low environmental impact. The principles are:

- integrate stormwater management early in site planning activities
- use natural hydrologic functions as the integrating framework
- focus on prevention rather than mitigation
- emphasize simple, nonstructural, low-tech, and low cost methods
- manage as close to the source as possible
- distribute small-scale practices throughout the landscape
- rely on natural features and processes
- create a multifunctional landscape
LID uses a systems approach that emulates natural landscape functions. A near limitless universe of runoff control strategies, combined with common sense and good housekeeping practices, are the essence of a LID strategy.

These basic strategies, also known as integrated management practices, rely on the earth's natural cycles, predominantly the water cycle, to reduce land development impacts on hydrology, water quality, and ecology. Integrated management practices combine a variety of physical, chemical, and biological processes to capture runoff and remove pollutants at the lot level (See Insert).

Several strategies focus on disconnecting roofs and paved areas from traditional drainage infrastructure and conveying runoff instead to bioretention areas, swales, and vegetated open spaces. LID also strives to prevent the generation of runoff by reducing the impervious footprint of a site, thereby reducing the amount of water that needs treatment. The end hydrological results are a reduction in runoff volume, an increased time of concentration, reduced peak flow and duration, and improved water quality.

Developers apply most LID strategies on the micro-scale, distributed throughout the site near the source of runoff. They customize strategies according to site conditions in order to reduce specific pollutants and to control runoff, a technique known as site-foot-printing. LID is particularly effective when practices are integrated into a series of linked, strategically placed and designed elements that each contribute to the management of stormwater.

Bioretention, a core LID practice, provides a good example of how LID management practices work. What looks like a nicely landscaped area is in fact an engineered system that facilitates depression storage, infiltration, and biological removal of pollutants. Developers usually place bioretention areas in parking lot islands, at the edge of paved areas, at the base of buildings, or in open space areas. Runoff is directed to these low-tech treatment systems instead of conventional stormwater infrastructure. Bioretention areas use plants and soil to trap and treat petroleum products, metals, nutrients, and sediments. Bioretention areas, also known as "rain gardens," are relatively inexpensive to build, easy to maintain, and can add aesthetic value to a site, without consuming large amounts of valuable land area.10

LID includes integrating land and infrastructure management. Activities such as street sweeping, toxic-free and low-impact landscaping, frequent cleaning of catch basins, sediment control, and downspout disconnection all reduce runoff contamination. LID works equally well in new development and redevelopment projects and is easily customized to complement local growth management, community revitalization, and watershed protection goals.11

LID is much more than the management of stormwater -- it is rethinking the way we plan, design, implement, and maintain projects. Comprehensive programs usually complement LID practices with broader issues such as: considering where growth disturbance should occur; increasing awareness of the cumulative impacts of development; involving the community and raising watershed awareness; developing direct social marketing of LID retrofit actions to households, institutions and commercial

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**Ten Common LID Practices**

1. Rain Gardens and Bioretention
2. Rooftop Gardens
3. Sidewalk Storage
4. Vegetated Swales, Buffers, and Strips; Tree Preservation
5. Roof Leader Disconnection
6. Rain Barrels and Cisterns
7. Permeable Pavers
8. Soil Amendments
9. Impervious Surface Reduction and Disconnection
10. Pollution Prevention and Good Housekeeping

**LID Practices Use Natural Functions to Trap and Treat Runoff:**

**Physical:** increases interception, infiltration, and evapotranspiration; facilitates sediment removal, filtration, and volatilization; stabilizes soils to reduce sedimentation and erosion.

**Chemical:** facilitates adsorption, chelation, ion exchange, and organic complexing.

**Biological:** increases transpiration, nutrient cycling, direct uptake, and microbial decomposition.
establishments; creating a rational institutional framework for implementing stormwater management, and establishing an authority to guide and administer stormwater management activities.

**LID and Retrofitting the Ultra Urban Environment**

The fundamental approach of using micro-scale management practices and source control has great potential to generate substantial benefits in existing urbanized watersheds. LID principles and practices are particularly well-suited to ultra urban areas because most LID techniques, like rain gardens and tree planter boxes, use only a small amount of land on any given site. Many LID practices, including bioretention, are good for urban retrofit projects since they are easily integrated into existing infrastructure, like roads, parking areas, buildings, and open space.

LID practices can be applied to all elements of the urban environment. For example, bioretention technology can effectively turn parking lot islands, street medians, tree planter boxes, and landscaped areas near buildings into specialized stormwater treatment systems. Developers can redesign parking lots to reduce impervious cover and increase stormwater infiltration while optimizing parking needs and opportunities. Innovative designs for urban areas may also include roof gardens, methods for capturing and using rainwater, and use of permeable pavement in low traffic areas, parking areas, and walking paths. Furthermore, LID strategies can help beautify the urban environment and create desirable public open space.

**Seven Benefits of Low Impact Development**

**Effective.** Research has demonstrated LID to be a simple, practical, and universally applicable approach for treating urban runoff. By reproducing predevelopment hydrology, LID effectively reduces runoff and pollutant loads. Researchers have shown the practices to be successful at removing common urban pollutants including nutrients, metals, and sediment. Furthermore, since many LID practices infiltrate runoff into groundwater, they help to maintain lower surface water temperatures. LID improves environmental quality, protects public health, and provides a multitude of benefits to the community.

**Economical.** Because of its emphasis on natural processes and micro-scale management practices, LID is often less costly than conventional stormwater controls. LID practices can be cheaper to construct and maintain and have a longer life cycle cost than centralized stormwater strategies. The need to build and maintain stormwater ponds and other conventional treatment practices will be reduced and in some cases eliminated. Developers benefit by spending less on pavement, curbs, gutters, piping, and inlet structures. LID creates a desirable product that often sells faster and at a higher price than equivalent conventional developments.

**Flexible.** Working at a small scale allows volume and water quality control to be tailored to specific site characteristics. Since pollutants vary across land uses and from site to site, the ability to customize stormwater management techniques and degree of treatment is a significant advantage over conventional management methods. Almost every site and every building can apply some level of LID and integrated management practices that contribute to the improvement of urban and suburban water quality.

**Adds value to the landscape.** It makes efficient use of land for stormwater management and therefore interferes less than conventional techniques with other uses of the site. It promotes less disturbance of the landscape and conservation of natural features, thereby enhancing the aesthetic value of a property and thus its desirability to home buyers, property users, and commercial customers. Developers may even realize greater lot yields when applying LID techniques. Other benefits include habitat enhancement, flood control, improved recreational opportunities, drought impact prevention, and urban heat island effect reduction.

**Achieves multiple objectives.** Practitioners can integrate LID into other urban infrastructure components and save money. For example, there is a direct overlap between stormwater management and Combined Sewer Overflow (CSO) control such that municipalities can use LID to help remedy both
Lot level LID applications and integrated stormwater management practices combine to provide substantial reductions in peak flows and improvements in water quality for both combined and separated systems.

**Follows a systems approach.** LID integrates numerous strategies, each performing different stormwater management functions, to maximize effectiveness and save money. By emulating natural systems and functions, LID offers a simple and effective approach to watershed sensitive development.

**Makes sense.** New environmental regulations geared toward protecting water quality and stabilizing our now degraded streams, rivers, lakes, and estuaries are encouraging a broader thinking than centralized stormwater management. Developers and local governments continue to find that LID saves them money, contributes to public relations and marketing benefits, and improves regulatory expediencies. LID connects people, ecological systems, and economic interests in a desirable way.