New Jersey Stormwater Best Management Practices Manual

February 2004

C H A P T E R 1

Impacts of Development on Runoff

This chapter describes the adverse impacts unmanaged land development can have on groundwater recharge and stormwater runoff quality and quantity both at and downstream of a development site. The chapter also reviews the fundamental physical, chemical, and biological aspects of the rainfall-runoff process and how they can be altered by development. In doing so, the chapter demonstrates the need for the NJDEP Stormwater Management Rules at N.J.A.C. 7:8, which have been developed to directly address these adverse impacts. In addition, the chapter seeks to increase understanding of these physical, chemical, and biological processes in order to improve the design of structural and non-structural measures mandated by the Rules' groundwater recharge, stormwater quality, and stormwater quantity requirements.

Runoff Quantity

Development can dramatically alter the hydrologic response of an area and, ultimately, an entire watershed. Prior to development, native vegetation can either directly intercept precipitation or evapotranspirate that portion that has infiltrated into the ground back into the atmosphere. Development can remove this beneficial vegetation and replace it with turf grass lawns and impervious roofs, driveways, parking lots, and roads, thereby reducing the site's pre-developed evapotranspiration and infiltration rates. In addition, clearing and grading can remove surface depressions that store rainfall. Construction activities may also compact the soil and diminish its infiltration rate, resulting in increased rates and volumes of stormwater runoff from the development site.

Impervious areas directly connected to gutters, channels, and storm sewers can transport runoff more quickly than natural, vegetated conveyances. This shortening of the transport or travel time quickens the rainfall-runoff response of the site, causing flow in downstream waterways to peak faster and higher than under natural or predeveloped site conditions. These increases can create new and aggravate existing downstream flooding and erosion problems and can increase the quantity of sediment and other pollutants in the waterways.

Filtration of runoff and removal of pollutants by natural surface and channel vegetation is eliminated by storm sewers that discharge runoff directly into waterways. Increases in impervious area can also decrease opportunities for infiltration and reduce stream base flow and groundwater recharge. Reduced base flows and increased peak flows produce greater fluctuations between normal and storm flow rates, which can increase channel erosion and adversely impact aquatic organisms and habitats. Reduced base flows can negatively impact the hydrology of adjacent wetlands and the health of biological communities that depend on these base flows.

To address these impacts, planners, engineers, reviewers, and other participants in the design of stormwater management measures must rethink traditional approaches to both land development itself and the environmental problems it can cause. New approaches such as those described in this manual must be taken. For example, nonstructural stormwater management principles provide a prevent-minimize-mitigate approach that is preferred by the NJDEP Stormwater Management Rules. Under these Rules, nonstructural stormwater management techniques are a requirement for new land development projects. Nonstructural stormwater management measures, also known as Low Impact Development Best Management Practices (LID-BMPs), include reduction of impervious cover, maintenance of natural vegetation, and reduction of nutrient inputs. LID-BMP techniques can significantly reduce and even prevent the negative effects of land development on stormwater runoff described above. Nonstructural stormwater management practices are covered in detail in *Chapter 2: Low Impact Development Techniques.*

During heavy rainfall, many land developments increase the rate or volume of stormwater runoff, even those with well-designed LID techniques. Historically, this increased runoff was managed through state and/or local regulations that required peak runoff rates leaving a site after development to be equal to those that existed prior to development. It was believed that if the peak rate of runoff was maintained, the downstream waterways could assimilate the runoff in the same manner as before development. This control was accomplished using detention and retention basins that store and then gradually release the runoff.

However, this control methodology failed to account for the increased volume of runoff caused by land development. Watershed studies in New Jersey have demonstrated that this additional volume resulted in extended peak rates and increases in non-peak flows that increased flooding and erosion problems downstream. These same watershed studies determined that, by reducing peak post-development site runoff to rates less than pre-developed site conditions throughout the watershed, the volume of post-development runoff was redistributed and pre-development peaks were maintained or reduced throughout the watershed.

The Stormwater Management Rules incorporate these peak flow reduction requirements, which are similar to those previously published in the NJDEP Flood Hazard Area Control Act Rules and the New Jersey Department of Community Affairs (NJDCA) Residential Site Improvement Standards (RSIS).

Runoff Quality

In addition to increases in runoff volume, land development often results in the accumulation of pollutants on the land surface that runoff can mobilize and transport to streams. New impervious surfaces and cleared areas created by development can accumulate a variety of pollutants from the atmosphere, fertilizers, animal wastes, and leakage and wear from vehicles. Pollutants can include metals, suspended solids, hydrocarbons, pathogens, and nutrients. Common pollutants found in stormwater runoff are shown in Table 1-1.

In addition to increased pollutant loading, land development can adversely affect water quality and stream biota in more subtle ways. For example, stormwater falling on impervious surfaces or stored in detention or retention basins can become heated and raise the temperature of the downstream waterway, adversely affecting cold water fish species such as trout. Development can remove trees along streambanks that normally provide shading, stabilization, and leaf litter that falls into streams and becomes food for the aquatic community.

Table 1-1: Typical Stormwater Pollutants

Pollutant	Typical Concentration
Total suspended solids [a]	80 mg/l
Total phosphorus [b]	0.30 mg/l
Total nitrogen [a]	2.0 mg/l
Total organic carbon [d]	12.7 mg/l
Fecal coliform bacteria [c]	3600 MPN/100ml
E. Coli bacteria [c]	1450 MPN/100ml
Petroleum hydrocarbons [d]	3.5 mg/l
Cadmium [e]	2 ug/l
Copper [a]	10 ug/l
Lead [a]	18 ug/l
Zinc [e]	140 ug/l
Chlorides [f] (winter only)	230 mg/l
Insecticides [g]	0.1 to 2.0 ug/l
Herbicides [g]	to 5.0 ug/l

Notes

1. Data sources: [a] Schueler (1987), [b] Schueler (1995), [c] Schueler (1997), [d] Rabanal and Grizzard (1996), [e] USEPA (1983), [f] Oberts (1995), [g] Schueler (1996).
2. Concentrations represent mean or median storm concentrations measured at typical sites and may be greater during individual storms. Mean or median runoff concentrations from stormwater hotspots are higher than those shown.
3. Units: mg/l = milligrams/liter ug/l = micrograms/liter MPN = Most Probable Number

The following sections provide basic information on the most common pollutants associated with stormwater runoff from a broad range of land uses.

1. Solids/Floatables

Solids/floatables are primarily a surface water pollution concern. They are defined by the NJDEP as wastes or debris floating, suspended or otherwise contained in wastewater or waters of the state (N.J.A.C. 7:22A-1.4 et seq.). These materials include debris such as bottles, jars, cans, cardboard boxes, paper bags, newspapers, plastic containers and wrappings, condoms, hypodermic needles, leaves, and branches.

Solid/floatable materials are wastes that are inadvertently or purposefully disposed of either on land or directly into stormwater conveyances. Runoff transports this material to receiving waters where it can disperse, float, wash ashore onto beaches or embankments, or settle onto waterway bottoms. Solid/floatable material can create odors, aesthetic problems, and even toxic or corrosive gases that can emanate from bottom mud deposits.

2. Sediment

Sediment is one of the most significant pollutants created by development and transferred by its runoff. Sediments consist largely of soil materials eroded from uplands as a result of natural processes and human activities.

The greatest sediment loads are exported during the construction phase of land development. Adequate sediment and erosion control must be installed and maintained at the site to prevent the delivery of large quantities of sediment into downstream waterways and water bodies. Other pollutants such as nutrients and organic matter attached to the sediment can also be delivered. Requirements for appropriate erosion controls are available in the Standards for Soil Erosion and Sediment Control in New Jersey available from the State Soil Conservation Committee (SSCC) or local Soil Conservation Districts.

Sediment and other nonpoint source pollution from agricultural sources is also a major contributor to water quality problems in the state. Sediment from croplands clogs lakes, road ditches, canals, and culverts, particularly during and just after active tilling.

High concentrations of suspended sediment in streams and lakes cause many adverse consequences including increased turbidity, reduced light penetration, reduced prey capture for sight-feeding predators, clogged fish gills/filters, and reduced angling success. Additional impacts can result after sediment is deposited in slower moving waters. These include the smothering of benthic communities, alterations in the composition of the bottom substrate, and the rapid filling-in of small impoundments that create the need for costly dredging and reductions in the overall aesthetic value of the water resource. Sediment is also an efficient carrier of toxins and trace metals. Once deposited, pollutants in these enriched sediments can be remobilized under suitable environmental conditions and threaten benthic life.

3. Nutrients

Phosphorus and nitrogen are nutrients used by plants during photosynthesis. Phosphorus in natural waters occurs as phosphate in three classifications: orthophosphates (P04), polyphosphates (polymers of phosphoric acid), and organically bound phosphates. The most common forms of nitrogen are gaseous (N2), ammonia (NH3 or NH4), nitrite (NO2), nitrate (NO3), and nitrogen bound in organic compounds. Pollution from inorganic phosphorus (orthophosphates) and inorganic nitrogen (nitrates and ammonia) are of chief concern in New Jersey.

In general, undeveloped land produces relatively few nutrients; agricultural, residential, industrial, and commercial areas produce more nutrient loadings. In rural and residential areas, substantial amounts of nutrients originate from commercial fertilizers, manure from livestock feeding operations, or dairy farming. Fertilizer spread on lawns and farmland during the winter can contribute nutrients to runoff in the springtime. Pet wastes contribute nutrients to runoff in residential areas. Detergents and raw sanitary waste also contribute to nutrient loading.

The action of phosphates and nitrates can be quite different. Although both can be transported by groundwater, phosphorus often combines with fine soil particles and remains locked in the soil until it is either utilized by plant life or eroded away with the soil. In the latter case, the phosphorus will flow along with the soil particles as suspended sediment. Nitrates in the soil remain much more soluble. During the late winter and occasionally in midseason following exceptionally heavy rainfall, nitrates may pass below the root zone into the groundwater. This movement of nitrates into groundwater may cause a public health hazard because high nitrate concentrations in drinking water can cause infant methemoglobinemia (Blue Baby Syndrome).

Under normal conditions, phosphorus and nitrogen are not generally regarded as problem chemicals. However, in excessive amounts, phosphorus and nitrogen present a problem by over-stimulating plant growth within the aquatic environment. When excessive concentrations (especially phosphorus) pass into surface fresh waters, they can contribute to eutrophication in slower moving water bodies and to dense algal growths on substrates within flowing water systems.

The greatest risk of eutrophication is in small agricultural ponds, urban lakes, and impoundments that have retention times of two weeks or more. Under optimal growing conditions, these lake systems can experience chronic and severe eutrophic symptoms such as surface algal scums, water discoloration, strong odors, depressed oxygen levels (as the bloom decomposes), release of toxins, and reduced palatability of fishery resources. High nutrient levels also promote the growth of dense mats of green algae that attach to rocks and cobbles in shallow, unshaded headwater streams. This phenomenon is present in many residential areas with recreational water bodies bordered by extensive, improperly fertilized lawn.

Coastal waters and estuaries in New Jersey also suffer from increased incidences of phytoplankton blooms, e.g., Barnegat Bay has been the site of several algal bloom problems including brown tide. Concern exists that this problem is caused, in part, by inputs from nutrient-enriched fresh waters; however, the relationship between high nutrient levels and algal production is extremely complex and is not fully understood.

4. Pesticides

Pesticides, which include insecticides, herbicides, rodenticides, and fungicides, are among the few toxic substances deliberately introduced to the environment. These substances are used routinely for agricultural purposes and in residential and commercial property maintenance to biochemically affect specific unwanted organisms. However, these substances can produce unintended toxic effects on ecosystems and human life by contaminating soil, water, and air. Numerous acute and chronic effects on humans and other organisms are associated with pesticide exposure. Pesticides can enter an organism through inhalation, ingestion, or skin contact. They have caused decreases in aquatic populations either directly, through damage to the food chain by decreasing reproductive success, or indirectly, by reducing oxygen levels in the water through a reduction in the populations of higher plants and phytoplankton. Some pesticides, such as DDT, dieldrin, and chlordane, are no longer in use but persist in the food chain and in the human body. Other commonly used pesticides, such as malathion, are suspected carcinogens and are hazardous more through direct contact than indirect contact via the food chain.

Pesticides are carried in stormwater from application sites by becoming dissolved or suspended in runoff or by binding to particulate matter carried in runoff. These pesticides can contaminate surface or groundwater through infiltration devices or overflow. The fate and transport of pesticides are dependent on their physical and chemical properties and their chemical interactions with the environment. Processes that determine the path of pesticides in the environment are primarily photolysis (degradation in light), hydrolysis (degradation in the presence of water), and sorption reactions that are dependent on the chemical nature and solubility of the pesticide and the percentage of particulate and organic matter present in the sediment. Some pesticides, such as aldicarb, are highly soluble in water and are easily flushed into aquatic ecosystems or groundwater. Pesticides with low solubility may accumulate in sediments by adhering to particulate matter. Adsorption and absorption increase with the amount of organic matter present. These factors and the resistance to degradation of certain pesticides (expressed as the half-life) increase the persistence of these substances in the environment.

5. Metals

The permissible concentrations of metals in water are established directly by numerical criteria under the surface and groundwater quality standards and indirectly by standards under the Safe Drinking Water Act. Concentrations of metals found in water can have adverse effects upon public health as well as upon aquatic biota. Lead, arsenic, copper, cadmium, mercury, and some forms of chromium are all metals of concern.

Metals can occur naturally in soil or result from human activity. The quantities of metals leaching into water from natural sources are influenced largely by the water's pH. Acid rain and the low pH water often found in swamps may increase the solution of metals into water. Although mercury and copper have been shown to cause serious health problems, lead is of primary public health concern. It has a cumulative, toxic neurological effect and may be particularly harmful to children. One of the principal sources of lead in stormwater runoff has been the tetraethyl lead in gasoline, but pollution from this source is rapidly declining due to stringent federal controls over lead in gasoline.

6. Road Salt

Road salt, primarily composed of sodium chloride (common salt), has the potential to impair land vegetation, water quality, and aquatic ecosystems. This material is commonly used throughout the state as a low-cost substance for melting snow and ice. Road salt entering stormwater runoff generally originates from salt stockpiles or from salt application to roadways and other impervious surfaces. Precipitation falling on salted surfaces creates runoff containing dissolved salt. The increasing amount of urban and suburban development in New Jersey has resulted in increased roadways and other impervious surfaces such as parking lots, which has increased the use of road salt.

The primary problem with road salt is the contamination of ground and surface waters, which may render them unusable or require expensive treatment procedures. Increased sodium chloride concentrations in water create aesthetically displeasing drinking water and interfere with pristine manufacturing processes. High levels of sodium consumed in drinking water can elevate blood pressure and impair kidney function in susceptible individuals.

Because of salt's long residence time, salt water often tends to build up concentration in groundwater. Due to a seasonal effect, the highest levels of chloride ions appear in the summer months. This effect is attributed to the slow movement of groundwater (reacting to winter applications) and high summer evapotranspiration rates.

Excessive salt or saline input to fresh surface waters can cause significant use impairment. The input of highly concentrated saline water into fresh water lakes can retard springtime mixing. The density of the bottom layer of water increases, thereby overriding the normal thermal density gradients responsible for vertical mixing. This saline buildup can decrease oxygen levels and cause high mortality among bottom-dwelling organisms. Increased salt loading to bays and estuaries can alter natural saline concentrations and disrupt shellfish reproduction and fish spawning. Surface water effects are dependent on the concentrations of sodium chloride entering the system, the amount of dilution, and the sensitivity of the aquatic ecosystem.

Aside from contaminating surface and groundwater, high levels of sodium chloride can kill roadside vegetation and corrode infrastructure such as bridges, roads, and stormwater management devices. In addition, some industrial operations can be impaired by an increase in the salinity of intake water.

7. Petroleum Hydrocarbons

Petroleum hydrocarbons in water are considered very harmful to natural biota. In addition, some constituents are carcinogenic and toxic to humans. No numerical criteria exist for petroleum hydrocarbons in ground or surface water quality standards. In both cases and in most waters, the basic criterion is "none noticeable."

Additional requirements for surface water prohibit hydrocarbons on aquatic substrata, along the shore in quantities detrimental to the natural biota, and where they would render waters unsuitable for their designated uses. The same standards are generally applicable to oil and grease, which, except for petroleum hydrocarbons, are not considered especially dangerous. Control efforts are mainly directed toward hydrocarbons.

Although the hydrocarbons harmful to water quality are mostly liquid at ambient temperatures, they are absorbed and adsorbed onto solid particles of sediment so rapidly that they are found mainly as particulates in runoff. Only considerable masses of oil will remain in liquid form in the larger storm drains. Petroleum hydrocarbons are also biodegradable in an aerobic environment, although at a relatively slow rate.

8. Pathogens

Pathogens (viral and bacterial) and non-pathogenic bacteria are found in the intestinal tracts of humans and other warm-blooded animals and are excreted with fecal wastes. A number of human diseases can be transmitted by runoff contaminated by fecal sources. Some well-documented bacterial agents include the *Salmonella* group responsible for typhoid fever, paratyphoid fever, and intestinal fever; the *Shigella* group causing bacillary dysentery; *Vibrio cholerae* responsible for cholera; and *Escherichia coli (E. coli)* causing gastroenteritis. In humans, gastroenteritis is the leading waterborne infectious disease in the United States. Deficient water treatment and groundwater contamination of wells are responsible for most of the outbreaks (65 percent) and cases (63 percent). The ingestion of shellfish harvested from contaminated waters can lead to disease as well.

Human fecal contamination is primarily a sewage treatment problem complicated by cross-connections or interconnections between sanitary and storm sewers, where combined sewer overflows degrade surface waters and where faulty, improperly sized, or improperly located septic systems contaminate groundwater. Animal fecal material from livestock operations, domestic pet populations, and concentrated wildlife populations contaminate surface waters via overland runoff and stormwater sewer discharges. Groundwater contamination occurs in areas with very permeable soils and/or high groundwater tables and where sinkholes, fractured rock, and well casings provide possible entry routes.

It is generally accepted that urban runoff will exceed desired bacterial limits. When considering stormwater contributions to the flow in a combined sewer system, the importance of stormwater control for bacterial water quality should be considered.

While not directly responsible for disease, fecal coliform bacteria have traditionally served as the microbiological indicators for the potential presence of waterborne pathogens. Enterococci appear to be a more accurate indicator than coliform bacteria, especially in saltwater where their resistance time and survival rate is similar to that of pathogenic bacteria. Research is being conducted on the use of bacteriophages as viral indicators. Until regulations are revised, however, the state will continue to rely on traditional indicators (total and fecal coliforms) as well as enterococci.

Compared to other pollutants, bacteria and pathogens have relatively low residence times in the environment. Survival in surface waters varies with environmental factors such as temperature, light intensity, salinity, nutrient levels, bacteriophages and predation, absorption, sedimentation, and the presence of toxic substances.

Bacteria and viruses, when introduced to the subsurface environment, can undergo a natural die-off, be retained in the soil, or be transported to groundwater. Survival rates of both bacteria and viruses decrease with increasing temperature, decreasing soil moisture, and increasing competition with native soil microflora. Bacteria can be effectively retained in soils by the filtering action of fine particle soils with small pore size. The finer the soil grain, the greater its capability to filter out microorganisms. Adsorption, however, is the principal mechanism by which viruses are retained in the soil, and it can be a factor for retaining bacteria. Adsorption may be temporary; viruses may remain on the soil particle and be returned to subsurface flow during intense rainfall.

Groundwater is less likely to be contaminated by bacteria than surface waters. Bacteria and pathogens are generally filtered, adsorbed by soil, or dead before reaching the groundwater.

There is presently limited information that specifically addresses the survivability and transport of bacteria in stormwater runoff. The exact distances bacteria would be transported vary with soil properties, climate, and vegetation.

Parasites are an additional concern under this general category of pollutants. A number of infectious diseases are transmissible to humans via ordinary parasites. Common causes of these diseases are dog and cat parasites such as roundworms and hookworms shed in animal feces. The intimate relationships that household pets have with people, combined with the large pet population, greatly increase the potential for transmission of pathogens. This also appears to be true for bacteria and viruses, many of which have long survival times when infected pet waste is washed into receiving waters via stormwater.

Two relatively common protozoa that cause intestinal disorders in humans are also of great concern. The first is *Cryptosporidium Spp.,* which often causes diarrhea and may be accompanied by fever, abdominal pain, nausea, constipation, and/or weight loss. Most infections occur after contact with infected people. The other is *Giardia Spp.,* which causes many of the same symptoms as cryptosporidiosis. Its major reservoirs appear to be water and food contaminated by infected animals and people. A worrisome feature of these organisms is their resistance to environmental influences and disinfectants.