Chapter 2 – Stormwater Impacts

Stormwater and Land Development Impacts

> **What's New in this Chapter?**
> - Advances in scientific understanding of the water quality impacts of stormwater runoff
> - Concepts of Directly Connected Impervious Area (DCIA) and DCIA disconnection from the CT DEEP MS4 General Permit
> - Discussion of climate change impacts and stormwater management

Stormwater is from rain or snowmelt that runs off land surfaces such as rooftops, streets, highways, parking lots, and lawns. Along the way, the stormwater may pick up and transport contaminants. These contaminants might include motor oils, gasoline, antifreeze, and brake dust (commonly found on pavements), deposition from atmospheric sources, fertilizers and pesticides (found on landscaped areas), heavy metals and pathogens (commonly found on roofs)[2] and soil sediments (from farms and construction sites). Stormwater eventually flows into a local stream, river or lake, or into a storm drain and continues through storm pipes until it is discharged into a local waterbody. Stormwater that seeps into the ground receives some treatment by natural soil processes and eventually replenishes groundwater aquifers and surface waters such as lakes, streams, and oceans.

Stormwater is one component of the hydrologic cycle, which is the distribution and movement of water between the earth's atmosphere, land, and water bodies (Figure 2-1). While stormwater itself is a natural process, the development of the landscape with impervious surfaces such as buildings, roads, and parking lots, as well as storm sewer systems and other man-made features, alters the stormwater flow and composition, and even other parts of the hydrologic cycle, which can adversely impact water quality and aquatic habitat of a site or watershed. Even conversion of natural vegetation (wooded areas and meadows) to lawn can significantly alter the infiltration and water holding capacity of native soils by eliminating vegetation with deep root systems and compacting soils during construction. In addition, natural pollutant removal mechanisms provided by on-site vegetation and soils have less opportunity to remove pollutants from stormwater runoff in developed areas. This transformation increases the amount of stormwater runoff from a site, decreases infiltration and groundwater recharge, and alters natural drainage patterns.

Stormwater runoff can be considered both a point source and a nonpoint source of pollution. Stormwater runoff that flows into a conveyance system and is discharged through a pipe, ditch, channel, or other structure is considered a point source discharge under EPA's National Pollutant Discharge Elimination System (NPDES) permit program, as administered by CT DEEP.

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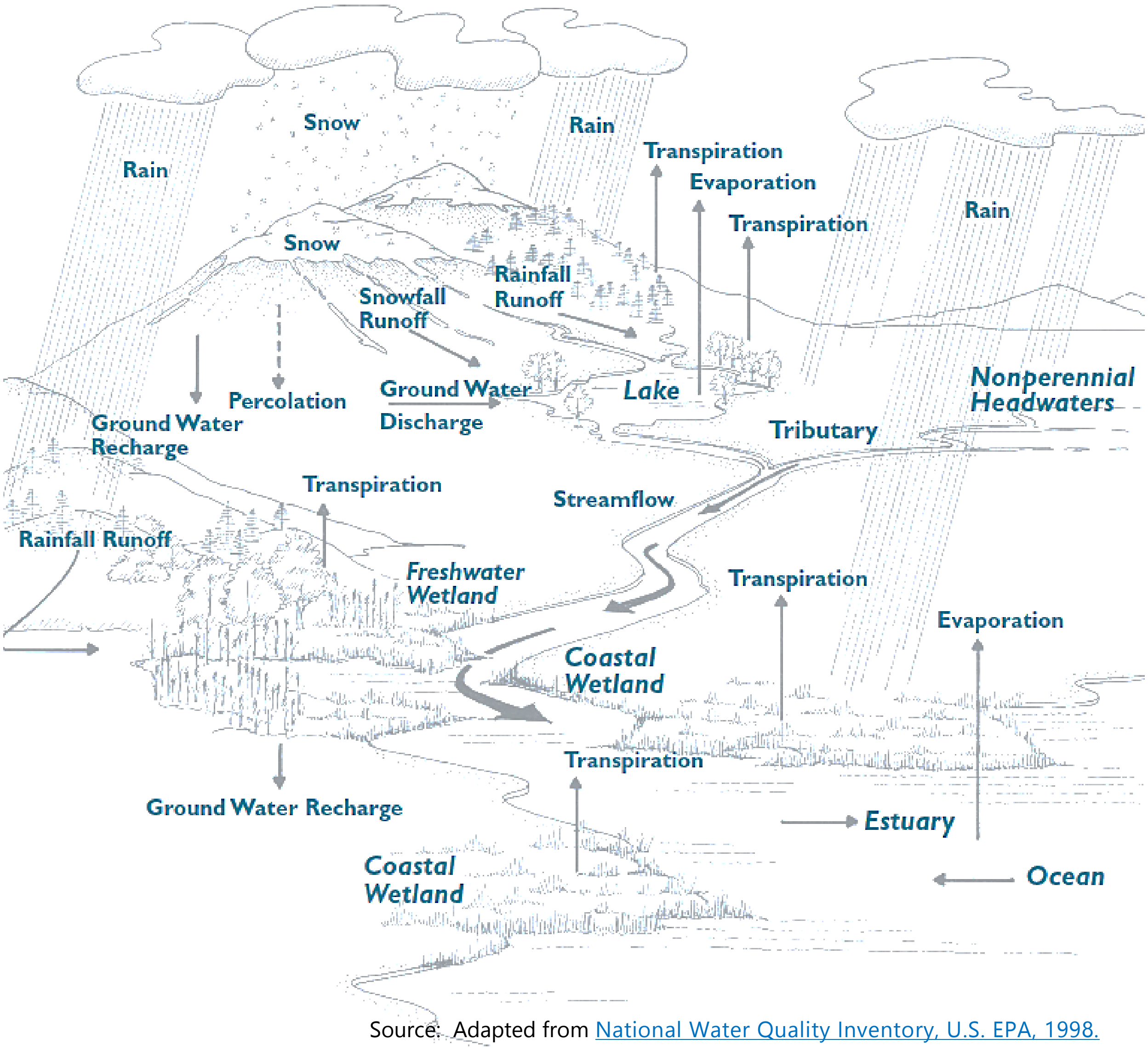
[2] Lye DJ. Rooftop runoff as a source of contamination: a review. Sci Total Environ. 2009 Oct 15;407(21):5429-34. doi: 10.1016/j.scitotenv.2009.07.011. Epub 2009 Jul 31. PMID: 19647287.

Stormwater runoff that flows over the land surface and is not concentrated in a defined channel is considered a type of nonpoint source pollution. In most cases stormwater runoff begins as a nonpoint source (i.e., sheet flow) and becomes a point source discharge (i.e., shallow concentrated flow or flow conveyed by a gutter, ditch, drainpipe, etc.).

Figure 2-1. Hydrologic Cycle



Source: Adapted from [National Water Quality Inventory, U.S. EPA, 1998.]

The stormwater-related impacts of land development on rivers, streams, and other receiving waters can be grouped into four categories, which are described further in the following sections:

1. Hydrologic Impacts
2. Stream Channel and Floodplain Impacts
3. Water Quality Impacts
4. Habitat and Ecological Impacts

Hydrologic Impacts

Development can dramatically alter the hydrologic regime of a site or watershed as a result of increases in impervious surfaces. The impacts of development on hydrology may include:

- Increased runoff volume
- Increased peak discharges
- Decreased runoff travel time
- Reduced groundwater recharge
- Reduced stream baseflow
- Increased frequency of bankfull and overbank flow
- Increased flow velocity during storms
- Increased frequency and duration of high stream flow

Figure 2-2 depicts typical pre-development and post-development streamflow hydrographs for a developed watershed.

Stream Channel and Floodplain Impacts

Stream channels in developed areas respond to and adjust to the altered hydrologic regime that accompanies urbanization. The severity and extent of stream adjustment is a function of the degree of watershed imperviousness.[3] The impacts of development on stream channels and floodplains may include:

- Channel scour, widening, and downcutting
- Streambank erosion and increased sediment loads
- Shifting bars of coarse sediment
- Burying of stream substrate and increase in embeddedness
- Loss of pool/riffle structure and sequence
- Man-made stream enclosure or channelization
- Floodplain expansion

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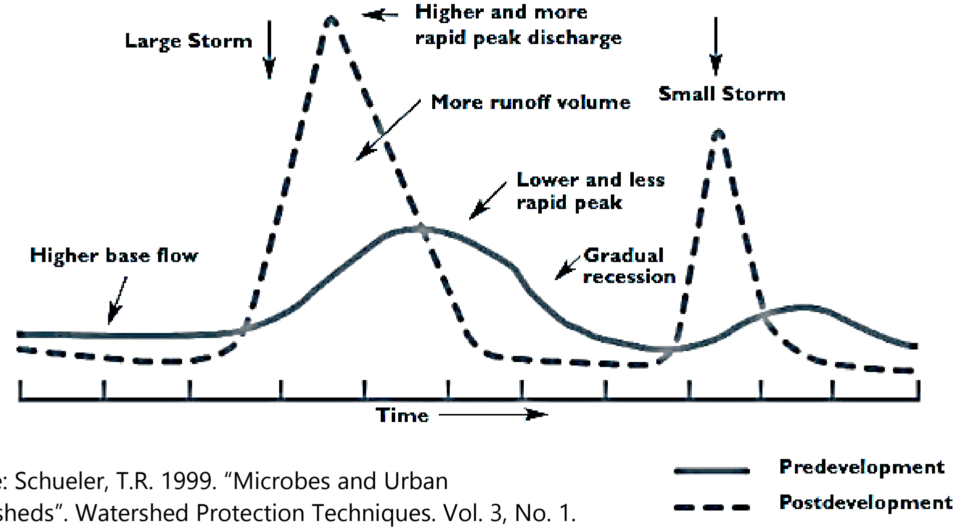
[3] Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE). 1998. Urban Runoff Quality Management (WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87).

Figure 2-2. Changes in Stream Hydrology as a Result of Land Development



Source: Schueler, T.R. 1999. "Microbes and Urban Watersheds". Watershed Protection Techniques. Vol. 3, No. 1.

Water Quality Impacts

Land development and urbanization of the landscape increases the discharge of pollutants in stormwater runoff. Development introduces new sources of stormwater pollutants and provides impervious surfaces that accumulate pollutants between storms. Structural stormwater collection and conveyance systems allow stormwater pollutants to quickly wash off during storm or snowmelt events and discharge to downstream receiving waters. By contrast, most undeveloped areas have better depression storage and pervious surfaces. Natural processes, such as infiltration, interception, depression storage, filtration by vegetation, and evaporation, can reduce the quantity of stormwater runoff and remove pollutants. Impervious areas decrease the natural stormwater purification functions of watersheds and increase the potential for water quality impacts in receiving waters.

In Connecticut, stormwater is a major source of pollution to surface waters throughout the State. This pollution can limit the use of impacted waterbodies, which may include primary contact recreation, such as swimming and boating, and the ability to support healthy aquatic life. Stormwater runoff is also a contributor to excessive nutrient enrichment in lakes and ponds, as well as a continued threat to estuarine waters and Long Island Sound.[4] In urban communities with combined storm and sanitary sewer systems, stormwater runoff also contributes to combined sewer overflows (CSOs), which can have significant surface water quality and public health impacts during and after storm events.

Waterbodies in Connecticut that are impacted by pollutants may be determined to be impaired (i.e., not meeting water quality standards for certain uses) as a result of stormwater or other

[4] United States Environmental Protection Agency (EPA). 2001. National Water Quality Inventory: 1998 Report to Congress. EPA620-R-01-005. Office of Water, Washington, D.C.

related stressors related to urbanization. Impaired waters are identified in the Connecticut Integrated Water Quality Report, which is updated by CT DEEP approximately every two years. This information is also available through an interactive map viewer maintained by UConn at: https://nemo.uconn.edu/ms4/tools/ms4map.html.

Stormwater runoff from developed areas can also degrade groundwater quality if stormwater with high pollutant loads is directed into the soil without adequate treatment. Certain land uses and activities, sometimes referred to as stormwater "hotspots" (e.g., commercial parking lots, vehicle service and maintenance facilities, and industrial rooftops), are known to produce higher loads of pollutants such as metals and toxic chemicals. Soluble pollutants can migrate into groundwater and potentially contaminate wells in groundwater supply aquifer areas.

Table 2-1 lists the principal pollutants found in stormwater runoff, typical pollutant sources, related impacts to receiving waters, and factors that promote pollutant removal. Table 2-1 also identifies those pollutants that commonly occur in a dissolved or soluble form, which has important implications for the selection and design of stormwater management practices described later in this Manual. Chapter 3 - Preventing and Mitigating Stormwater Impacts contains additional information on pollutant removal mechanisms for various stormwater pollutants.

Table 2-1. Summary of Stormwater Pollutants

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Excess Nutrients - Nitrogen, Phosphorus (soluble)	Animal waste, fertilizers, failing septic systems, landfills, atmospheric deposition, erosion and sedimentation, illicit sanitary connections	Algal growth, nuisance plants, ammonia toxicity, reduced clarity, oxygen deficit (hypoxia), pollutant recycling from sediments, decrease in submerged aquatic vegetation (SAV)	Phosphorus: High soil exchangeable aluminum and/or iron content, vegetation, presence of carbon in the filtration medium and aquatic plants Nitrogen: Alternating aerobic and anaerobic conditions, low levels of toxicants, near neutral pH (7)
Sediments - Suspended, Dissolved, Deposited, Sorbed Pollutants	Construction sites, streambank erosion, wash off from impervious surfaces, winter sand application	Increased turbidity, lower dissolved oxygen, deposition of sediments, aquatic habitat alteration, sediment and benthic toxicity	Lowering turbulence, increasing residence time
Pathogens - Bacteria, Viruses	Animal waste, failing septic systems, illicit sanitary connections	Human health risk via drinking water supplies, contaminated swimming beaches, and contaminated shellfish consumption	High light (ultraviolet radiation), increasing residence time, filtration by media/soil filtration, disinfection
Organic Materials - Biochemical Oxygen Demand, Chemical Oxygen Demand	Leaves, grass clippings, brush, failing septic systems	Lower dissolved oxygen, odors, fish kills, algal growth, reduced clarity	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7)

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Hydrocarbons - Oil and Grease	Industrial processes; commercial processes; automobile wear, emissions, and fluid leaks; improper oil disposal	Toxicity of water column and sediments, bioaccumulation in food chain organisms	Lowering turbulence, increasing residence time, physical separation or capture techniques
Metals - Copper, Lead, Zinc, Mercury, Chromium, Aluminum (soluble)	Industrial processes, normal wear of automobile brake linings and tires, automobile emissions and fluid leaks, metal roofs	Toxicity of water column and sediments, bioaccumulation in food chain organisms	High soil organic content, high soil cation exchange capacity, near neutral pH (7)
Synthetic Organic Chemicals - Pesticides, VOCs, SVOCs, PCBs, PAHs, PFAS, other contaminants of emerging concern (soluble)	Residential, commercial, and industrial application of herbicides, insecticides, fungicides, rodenticides; industrial processes; commercial processes; food packaging, commercial household products, industry (PFAS); residues of tire wear most often in urban runoff (6-PPD Quinone) [5]	Toxicity of water column and sediments, bioaccumulation in food chain organisms, health effects of drinking water contamination (PFAS)	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7), high temperature and air movement for volatilization of VOCs; treatability for PFAS and 6-PPD Quinone in stormwater is an evolving area of research.

[5] Markus Brinkmann, David Montgomery, Summer Selinger, Justin G. P. Miller, Eric Stock, Alper James Alcaraz, Jonathan K. Challis, Lynn Weber, David Janz, Markus Hecker, Steve Wiseman. Acute Toxicity of the Tire Rubber-Derived Chemical 6PPD-quinone to Four Fishes of Commercial, Cultural, and Ecological Importance. Environmental Science & Technology Letters, 2022; DOI: 10.1021/acs.estlett.2c00050

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Deicing Constituents - Sodium, Calcium, Potassium, Chloride, Ethylene Glycol, Other Pollutants (soluble)	Road salting and uncovered salt storage. Snowmelt runoff from snow piles in parking lots and roads during the spring snowmelt season or during winter rain on snow events.	Toxicity of water column and sediments, contamination of drinking water, harmful to salt intolerant plants. Concentrated loadings of other pollutants as a result of snowmelt.	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7)
Trash and Debris	Litter washed through storm drain network	Degradation of aesthetics, threat to wildlife, potential clogging of storm drainage system	Lowering turbulence, physical straining/capture
Freshwater Impacts	Stormwater discharges to tidal wetlands and estuarine environments	Dilution of the high marsh salinity and encouragement of the invasion of brackish or upland wetland species such as *Phragmites*	Stormwater retention and volume reduction
Thermal Impacts	Runoff with elevated temperatures from contact with impervious surfaces (pavement)	Adverse impacts to aquatic organisms that require cold and cool water conditions	Retention/infiltration of runoff, use of vegetation and trees for shading of impervious surfaces, increased pool depths in stormwater ponds/wetlands

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
[1]Factors that promote removal of most stormwater pollutants include: ○ Increasing hydraulic residence time ○ Lowering turbulence ○ Flow through fine, dense herbaceous plants ○ Filtration through medium-fine textured soil ○ Presence of carbon in the filtration medium			

Table above is developed from a compilation of sources.[6, 7, 8, 9, 10, 11]

[6] Ali, W.; Takaijudin, H.; Yusof, K.W.; Osman, M.; Abdurrasheed, A.S. The Common Approaches of Nitrogen Removal in Bioretention System. Sustainability 2021, 13, 2575. https://doi.org/ 10.3390/su13052575

[7] Watershed Management Institute, Inc. 1997. Operation, Maintenance, and Management of Stormwater Management Systems. In cooperation with U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

[8] Metropolitan Council. 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates, prepared by Barr Engineering Company, St. Paul, Minnesota

[9] Ismail W. Almanassra, Viktor Kochkodan, Gordon Mckay, Muataz Ali Atieh, Tareq Al-Ansari, Review of phosphate removal from water by carbonaceous sorbents, Journal of Environmental Management, Volume 287, 2021, 112245, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2021.112245.

[10] Bettina Seiwert, Maolida Nihemaiti, Mareva Troussier, Steffen Weyrauch, Thorsten Reemtsma, Abiotic oxidative transformation of 6-PPD and 6-PPD quinone from tires and occurrence of their products in snow from urban roads and in municipal wastewater, Water Research, Volume 212, 2022, 118122, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2022.118122.

[11] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

Excess Nutrients

Urban stormwater runoff typically contains elevated concentrations of nitrogen and phosphorus that are mostly derived from lawn fertilizer, detergents, animal waste, atmospheric deposition, organic matter, and improperly installed or failing septic systems. Nutrient concentrations in urban runoff are like those found in secondary wastewater effluents (American Public Works Association and Texas Natural Resource Conservation Commission). Elevated nutrient concentrations in stormwater runoff can result in excessive growth of vegetation or algae in streams, lakes, reservoirs, and estuaries, a process known as accelerated eutrophication. Phosphorus is typically the growth-limiting nutrient in freshwater systems, while nitrogen is growth-limiting in estuarine and marine systems. This means that in marine waters algal growth usually responds to the level of nitrogen in the water, and in fresh waters algal growth is usually stimulated by the level of available or soluble phosphorus.[12]

Nutrients are a major source of degradation in many of Connecticut's water bodies. Excessive nitrogen loadings have led to hypoxia, a condition of low dissolved oxygen, in Long Island Sound. A Total Maximum Daily Load (TMDL) for nitrogen has been developed for Long Island Sound, which will restrict nitrogen loadings from point and non-point sources throughout Connecticut. Phosphorus in runoff has impacted the quality of many of Connecticut's lakes and ponds, which are susceptible to eutrophication from phosphorus loadings. Nutrients are also detrimental to submerged aquatic vegetation (SAV). Nutrient enrichment can favor the growth of epiphytes (small plants that grow attached to other things, such as blades of eelgrass) and increase amounts of phytoplankton and zooplankton in the water column, thereby decreasing available light. Excess nutrients can also favor the growth of macroalgae, which can dominate and displace eelgrass beds and dramatically change the food web.[13]

Sediment

Sediment loading to waterbodies occurs from washed off particles that are deposited on impervious surfaces such as roads and parking lots (through winter sand application or vehicle tracking), soil erosion associated with construction activities, and streambank erosion. Although some erosion and sedimentation is natural, excessive sediment loads can be detrimental to aquatic life including phytoplankton, algae, benthic invertebrates, and fish by interfering with photosynthesis, respiration, growth, and reproduction. Solids can either remain in suspension or settle to the bottom of the water body. Suspended solids can make the water cloudy or turbid, detract from the aesthetic and recreational value of a water body, and harm SAV, finfish, and

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[12] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

[13] Deegan, L., A. A. Wright, S. G. Ayvazian, J. T. Finn, H. Golden, R. R. Merson, and J. Harrison. 2002. Nitrogen loading alters seagrass ecosystem structure and support of higher trophic levels. Aquatic Conservation. 12(2): p. 193-212. March-April, 2002.

shellfish. Sediment transported in stormwater runoff can be deposited in a stream or other water body or wetland and can adversely impact fish and wildlife habitat by smothering bottom dwelling aquatic life (including increasing spawning failure)[14] and changing the bottom substrate. Sediment deposition in water bodies can result in the loss of deep-water habitat and can affect navigation, often necessitating dredging. Sediment, particularly finer particles, can also transport pollutants such as nutrients, toxics, organics, metals, and hydrocarbons. Pathogens, often measured with the surrogate fecal indicator bacteria (FIB), are known to attach to, and thereby transport with, sediment in stormwater. Sediment accumulation in stormwater BMPs has been noted to function as a reservoir to these microorganisms.[15]

Additionally, sediment accumulation can degrade or inhibit the effectiveness of stormwater BMPs and thereby, contribute to water quality impacts indirectly as well (see the Maintenance sections of Infiltration Trenches, Underground Infiltration Systems, Dry Water Quality Swales, Wet Water Quality Swales, and Underground Detentions). Each of these contributing factors that complicate or compound the impact of sediment on water quality further demonstrate the importance of BMP maintenance and ensuring preventative measures to control erosion are taken when disturbing sediment/soil (see the Soil Erosion and Sediment Control Guidelines).

Pathogens

Pathogens are bacteria, protozoa, and viruses that can cause disease in humans. The presence of FIB such as fecal coliform, Escherichia coli, and Enterococci are indicators of the potential presence of pathogenic organisms and potential risk to human health.[16] Fecal indicator bacteria levels in stormwater runoff routinely exceed public health standards for water contact during recreation and shell fishing. Sources of fecal indicator bacteria and pathogens in stormwater runoff include animal waste from pets, wildlife, and waterfowl; combined sewer overflows; failing septic systems; and illegal sanitary sewer cross-connections. High levels of fecal indicator bacteria in stormwater have commonly led to the closure of beaches and shell fishing beds along coastal areas of Connecticut.

Organic Materials

Oxygen-demanding organic substances such as grass clippings, leaves, animal waste, and street litter are commonly found in stormwater. The decomposition of such substances in waterbodies can deplete oxygen from the water, thereby causing similar effects to those caused by nutrient

[14] Krzysztof Kukuła, Aneta Bylak, Synergistic impacts of sediment generation and hydrotechnical structures related to forestry on stream fish communities, Science of The Total Environment, Volume 737, 2020, 139751, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139751.

[15] Urban Water Resources Research Council, Pathogens in Wet Weather Flows Technical Committee, Environmental and Water Resources Institute, American Society of Civil Engineers 2014 https://www.asce-pgh.org/Resources/EWRI/Pathogens%20Paper%20August%202014.pdf

[16] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

loading. Organic matter is of primary concern in waterbodies where oxygen is not easily replenished, such as slower moving streams, lakes, and estuaries. An additional concern for unfiltered water supplies is the formation of trihalomethane (THM), a carcinogenic disinfection byproduct generated by the mixing of chlorine with water high in organic carbon.[17]

Hydrocarbons

Stormwater runoff from developed areas contains a wide array of hydrocarbon compounds, some of which are toxic to aquatic organisms at low concentrations.[18] Vehicles are the primary sources of hydrocarbons in stormwater runoff. Source areas with higher concentrations of hydrocarbons in stormwater runoff include roads, parking lots, gas stations, vehicle service stations, residential parking areas, and bulk petroleum storage facilities.

Metals

Metals such as copper, lead, zinc, mercury, and cadmium are commonly found in stormwater runoff. Chromium and nickel are also frequently present.[19] The primary sources of these metals in stormwater runoff are vehicular exhaust residue, fossil fuel combustion, corrosion of galvanized and chrome-plated products, roof runoff, stormwater runoff from industrial sites, and the application of deicing agents. Architectural copper associated with building roofs, flashing, gutters, and downspouts has been shown to be a source of copper in stormwater runoff in Connecticut and other areas of the country.[20,21] Marinas have also been identified as a source of copper and, therefore, present aquatic toxicity to inland and marine waters.[22] Washing or sandblasting of boat hulls to remove salt and barnacles also removes some of the bottom paint, which contains copper and zinc additives to protect hulls from deterioration.

In Connecticut, discharge of metals to surface waters is of particular concern. Metals can be toxic to aquatic organisms, can bioaccumulate, and have the potential to contaminate drinking water supplies. Many major rivers in Connecticut have copper levels that exceed Connecticut's Copper Water Quality Criteria. Although metals generally attach themselves to the solids in stormwater runoff or receiving waters, studies have demonstrated that dissolved metals, particularly copper

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[17] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[18] Woodward-Clyde Consultants. 1990. Urban targeting and BMP Selection: An Information and Guidance Manual for State NPS Program Staff Engineers and Managers, Final Report.

[19] United States Environmental Protection Agency (EPA). 1983. Results of the Nationwide Urban Runoff Program, Volume 1, Final Report. Water Planning Division. Washington, D.C. NTIS No. PB 84-185 552.

[20] Barron, T. 2000. Architectural Uses of Copper: An Evaluation of Stormwater Pollution Loads and Best Management Practices. Prepared for the Palo Alto Regional Water Quality Control Plant.

[21] Tobiason, S. 2001. "Trickle Down Effect". *Industrial Wastewater.* Water Environment Federation. Vol. 9, No. 6.

[22] Sailer Environmental, Inc. 2000. Final Report on the Alternative Stormwater Sampling for CMTA Members. Prepared for Connecticut Marine Trades Association.

and zinc, are the primary toxicants in stormwater runoff from industrial facilities throughout Connecticut.[23, 24] Additionally, stormwater runoff can contribute to elevated metals in aquatic sediments by combining with road salts which then mobilize metals.[25] Many metals can become bioavailable where the bottom sediment is anaerobic (without oxygen) such as in a lake or estuary. Metal accumulation in sediments has resulted in impaired aquatic habitat and more difficult maintenance dredging operations in estuaries because of the special handling requirements for contaminated sediments.

Synthetic Organic Chemicals

Synthetic organic chemicals can also be present at low concentrations in urban stormwater. Pesticides, phenols, polychlorinated biphenyls (PCBs), and polynuclear or polycyclic aromatic hydrocarbons (PAHs) are the compounds most frequently found in stormwater runoff. Such chemicals can exert varying degrees of toxicity on aquatic organisms and can bioaccumulate in fish and shellfish. Toxic organic pollutants are most found in stormwater runoff from industrial areas. Pesticides are commonly found in runoff from urban lawns and rights-of-way.[26] A review of monitoring data on stormwater runoff quality from industrial facilities has shown that PAHs are the most common organic toxicants found in roof runoff, parking area runoff, and vehicle service area runoff.[27] Emerging contaminants such as per- and polyfluoroalkyl substances (PFAS), which is a group of man-made chemicals that have been manufactured and used in a variety of industries since the 1940s, are an increasing concern for public health in both drinking water supplies and in stormwater runoff.

Deicing Constituents

Salting of roads, parking lots, driveways, and sidewalks during winter months and snowmelt during the early spring result in the discharge of sodium, chloride, and other deicing compounds to surface waters via stormwater runoff. Excessive amounts of sodium and chloride may have harmful effects on water, soil, and vegetation, and can also accelerate corrosion of metal surfaces. Drinking water supplies, particularly groundwater wells, may be contaminated by runoff from roadways where deicing compounds have been applied or from highway facilities where salt mixes are improperly stored. In addition, sufficient concentrations of chlorides may prove toxic to certain aquatic species. Excess sodium in drinking water can lead to health

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[23] Mas, D.M.L., Curtis, M.D., and E.V. Mas. 2001. "Investigation of Toxicity Relationships in Industrial Stormwater Discharges", presented at New England Water Environment Association 2001 Annual Conference, Boston, MA.

[24] New England Bioassay, Inc. 2001. Final Report on Stormwater Toxicity Identification Evaluations (TIE) at Industrial Sites. Prepared for the Connecticut Department of Environmental Protection.

[25] https://stormwater.pca.state.mn.us/index.php/Environmental_impacts_of_road_salt_and_other_de-icing_chemicals

[26] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[27] Pitt, R., Field, R., Lalor, M., and M. Brown. 1995. "Urban Stormwater Toxic Pollutants: Assessment, Sources, and Treatability". Water Environment Research. Vol. 67, No. 3.

problems in individuals on low sodium diets. Other deicing compounds may contain nitrogen, phosphorus, and oxygen demanding substances. Antifreeze from automobiles is a source of phosphates, chromium, copper, nickel, and cadmium.

Other pollutants such as sediment, nutrients, and hydrocarbons are released from the snowpack during the spring snowmelt season and during winter rain-on-snow events. The pollutant loading during snowmelt can be significant and can vary considerably during the melt event.[28] For example, a majority of the hydrocarbon load from snowmelt occurs during the last 10 percent of the event and towards the end of the snowmelt season.[29] Similarly, PAHs, which are hydrophobic materials, remain in the snowpack until the end of the snowmelt season, resulting in highly concentrated loadings.[30]

Trash and Debris

Trash and debris are washed off the land surface by stormwater runoff and can accumulate in storm drainage systems and receiving waters. Litter detracts from the aesthetic value of waterbodies and can harm aquatic life either directly (by being mistaken for food) or indirectly (by habitat modification). Sources of trash and debris in urban stormwater runoff include residential yard waste, commercial parking lots, street refuse, combined sewers, illegal dumping, and industrial refuse.

Impacts of Freshwater Discharges

Discharge of freshwater, including stormwater, into brackish and tidal wetlands can alter the salinity and hydroperiod of these environments, which can encourage the invasion of brackish or freshwater wetland species such as Phragmites australis (common reed).

Thermal Impacts

Impervious surfaces may increase temperatures of stormwater runoff and receiving waters. Roads and other impervious surfaces heated by sunlight may transport thermal energy to a stream during storm events. Direct exposure of sunlight to shallow ponds and impoundments, as well as unshaded streams, may further elevate water temperatures. Elevated water temperatures can exceed fish and invertebrate tolerance limits, reducing survival and lowering resistance to disease. Coldwater fish such as trout may be eliminated, or the habitat may become marginally supportive of cold-water species. Elevated water temperatures also contribute to decreased oxygen levels in water bodies and dissolution of solutes.

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[28] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[29] Oberts, G. 1994. "Influence of Snowmelt Dynamics on Stormwater Runoff Quality". Watershed Protection Techniques. Vol. 1, No. 2.

[30] Metropolitan Council. 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates, prepared by Barr Engineering Company, St. Paul, Minnesota.

Additionally, increasing temperatures may compound the issues around harmful algal blooms. As noted by EPA, warming water temperatures may favor harmful algal blooms in several ways:[31]

- Toxic blue-green algae prefer warmer water.
- Warmer temperatures prevent water from mixing, allowing algae to grow thicker and faster.
- Warmer water is easier for small organisms to move through and allows algae to float to the surface faster.
- Algal blooms absorb sunlight, making water even warmer and promoting more blooms.

Habitat and Ecological Impacts

Changes in hydrology, stream morphology, and water quality that accompany the development process can also impact stream habitat and ecology. A large body of research has demonstrated the relationship between urbanization and impacts to aquatic habitat and organisms. Habitat and ecological impacts may include:

- A shift from external (leaf matter) to internal (algal organic matter) stream production
- Reduction in the diversity, richness, and abundance of the stream community (aquatic insects, fish, amphibians)
- Destruction of freshwater wetlands, riparian buffers, and springs
- Creation of barriers to fish migration

Impacts on Other Receiving Environments

Most of the research on the ecological impacts of urbanization has focused on streams. However, urban stormwater runoff has also been shown to adversely impact other types of receiving environments such as wetlands, lakes, and estuaries. Development alters the physical, geochemical, and biological characteristics of wetland systems. Lakes, ponds, wetlands, estuaries and SAV are impacted through deposition of sediment and particulate pollutant loads. Additionally, increased nutrient loads accelerate eutrophication and lower light penetration impacting the living organisms of these waterbodies. Estuaries also experience more extreme salinity swings caused by increased runoff and reduced baseflow. Table 2- 2 summarizes the effects of land development and urbanization on these receiving environments.

[31] https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms

Table 2- 2 Effects of Land Development and Urbanization on Other Receiving Environments

Receiving Environment	Impacts
Wetlands	➢ Changes in hydrology and hydrogeology ➢ Increased nutrient and other contaminant loads ➢ Compaction and destruction of wetland soil ➢ Changes in wetland vegetation ➢ Changes in or loss of habitat ➢ Changes in the community (diversity, richness, and abundance) of organisms ➢ Loss of biota ➢ Permanent loss of wetlands
Lakes and Ponds	➢ Impacts to biota on the lake bottom due to sedimentation ➢ Contamination of lake sediments ➢ Water column turbidity ➢ Aesthetic impairment due to floatables and trash ➢ Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity ➢ Contaminated drinking water supplies
Estuaries	➢ Sedimentation in estuarial streams and SAV beds ➢ Altered hydroperiod of brackish and tidal wetlands, which results from larger, more frequent pulses of fresh water and longer exposure to saline waters because of reduced baseflow ➢ Hypoxia ➢ Turbidity ➢ Bioaccumulation ➢ Loss of SAV due to nutrient enrichment ➢ Scour of tidal wetlands and SAV ➢ Short-term salinity swings in small estuaries caused by the increased volume of runoff which can impact key reproduction areas for aquatic organisms

Source: Adapted from WEF and ASCE, 1998.

Impervious Cover

Impervious cover is any impervious surface in the landscape that cannot effectively absorb and infiltrate rainfall. For the purpose of this Manual, impervious surfaces include, but are not limited to roads, parking lots, driveways, roofs, sidewalks, patios (i.e., solid or open-joint patios or decks with an underlying impervious surface), water surfaces of manmade impoundments (i.e., stormwater ponds and swimming pools) only if they are hydraulically connected to a storm drainage system, receiving waterbody, or wetland; compacted gravel surfaces and highly compacted soils. These surfaces disrupt the natural hydrologic cycle, increasing surface runoff and decreasing infiltration of rainfall into the soil.

Impervious cover is widely considered a key environmental indicator. A large body of scientific literature has shown that groundwater recharge, stream base flow, and water quality measurably change and can decrease as impervious cover increases. Studies have shown a direct relationship between the intensity of development, as indicated by the amount of impervious cover, and the degree of damage in a watershed. [32, 33, 34, 35, 36, 37, 38] Research nationwide has shown that when impervious cover in a watershed reaches approximately 10 percent, ecological stress becomes clearly apparent. Beyond 25 percent, stream stability is reduced, habitat is lost, water quality becomes degraded, and biological diversity decreases.[39] Figure 2-3 illustrates this effect.

Studies indicate that as the amount of impervious cover in a watershed exceeds 12 percent, unacceptable impacts to aquatic life can be predicted to occur in surface waters. The Connecticut Watershed Response Plan for Impervious Cover set a target of 11 percent impervious cover or less to be applied in Connecticut based on the observed water quality

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[32] Schueler T. R. Kumble P. A. Heraty M. A. Metropolitan Washington Council of Governments & United States. (1992). A current assessment of urban best management practices: techniques for reducing non-point source pollution in the coastal zone. Metropolitan Washington Council of Governments.

[33] Schueler, T.R. 1994. "The Importance of Imperviousness". Watershed Protection Techniques. Vol. 1, No. 3.

[34] Schueler, T.R. 1995. Site Planning for Urban Stream Protection. Metropolitan Washington Council of Governments. Washington, D.C.

[35] Booth, D.B. and L.E. Reinelt. 1993. "Consequences of Urbanization on Aquatic Systems - Measured Effects, Degradation Thresholds, and Corrective Strategies", in Proceedings of the Watershed '93 Conference. Alexandria, Virginia.

[36] Arnold, C.L., Jr., and C.J. Gibbons. 1996. "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator". Journal of the American Planning Association. Vol. 62, No. 2.

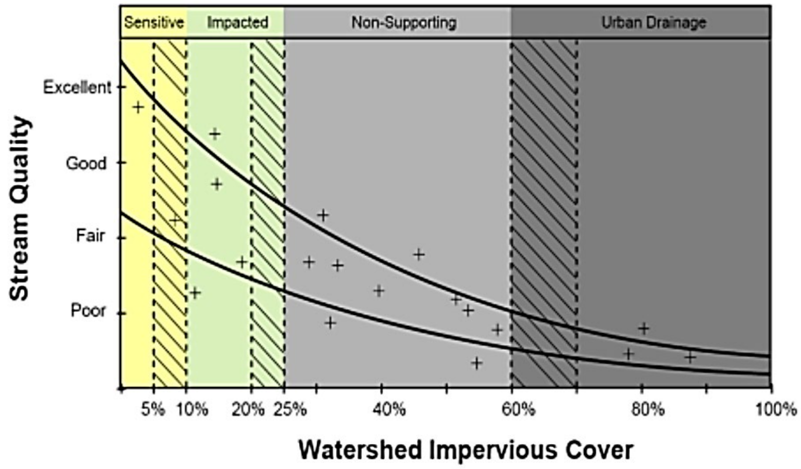
[37] Brant, T.R. 1999. "Community Perceptions of Water Quality and Management Measures in the Naamans Creek Watershed". Master's Thesis for the Degree of Master of Marine Policy

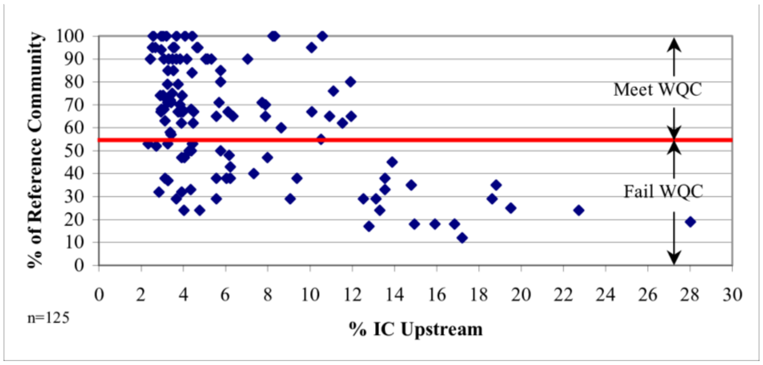
[38] Shaver, E.J. and J.R. Maxted. 1996. "Technical Note 72 Habitat and Biological Monitoring Reveals Headwater Stream Impairment in Delaware's Piedmont". Watershed Protection Techniques. Vol. 2, No. 2.

[39] Natural Resources Defense Council (NRDC). 1999. Stormwater Strategies: Community Responses to Runoff Pollution.

impairments at 12 percent IC and an application of a 1 percent margin of safety. Stormwater runoff has been identified as a probable contributing cause to the impairment. Municipalities and other stakeholders should therefore aim to mitigate stormwater impacts in areas with IC greater than 11 percent to reduce the amount of stormwater pollution reaching surface waters, to improve water quality.

Figure 2-3. Relationship Between Watershed Impervious Cover and Stream Health





National impervious cover model (top) and scatterplot of percent impervious cover and reference macroinvertebrate communities in Connecticut (bottom).

Image sources: Center for Watershed Protection[40] (top) and Chris Bellucci/CT DEEP (bottom).

[40] Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. March 2003.

Impervious Area and Directly Connected Impervious Area

Impervious area (IA) includes any impervious surface in a drainage area or watershed. Impervious area with a direct hydraulic connection to a storm drainage system or a waterbody via continuous paved surfaces, gutters, drainpipes, or other conventional conveyance and detention structures that do not reduce runoff volume is referred to as "Effective Impervious Area" or, for this manual, "Directly Connected Impervious Area (DCIA)". DCIA is considered a better predictor of watershed/ecosystem health than IA because it only includes impervious surfaces that contribute stormwater runoff to a stream, other waterbody, or wetland.

Impervious areas that are not directly connected to a storm drainage system, receiving waterbody, or wetland are considered "disconnected" and therefore not considered DCIA. The following types of impervious areas are considered disconnected:

- Impervious areas that drain as sheet flow onto and over an adjacent pervious area that, due to its size, slope, vegetation, and underlying soil characteristics, can retain the appropriate portion of the Water Quality Volume, as defined in Chapter 4. This non-structural LID site planning and design technique is called "simple disconnection," which is described further in Chapter 5 – Low Impact Development Site Planning and Design Strategies.
- Impervious areas that discharge runoff through structural stormwater BMPs designed to retain the appropriate portion of the Water Quality Volume.
- Isolated impervious areas that are not hydraulically connected to a storm drainage system, receiving waterbody, or wetland.
- Swimming pools or man-made impoundments, unless hydraulically connected to a storm drainage system, receiving waterbody, or wetland.
- The surface area of natural waterbodies (e.g., wetlands, ponds, lakes, streams, rivers).

The CT DEEP MS4 General Permit requires regulated municipalities to track and disconnect DCIA using simple disconnection and structural stormwater BMPs for redevelopment projects and retrofits, or by converting impervious surfaces to pervious surfaces. The existing DCIA of a site is also an important factor in determining the portion of the Water Quality Volume that must be retained, also referred to as the "Required Retention Volume" (see Chapter 4).

Stormwater Management and Climate Change Impacts

Water resources in Connecticut are affected by climate stressors, including increasing temperatures, changing precipitation patterns, extreme events (storms, floods, and drought), and rising sea levels. These changing conditions have implications for stormwater management as local and state decision makers look to implement appropriate maintenance plans, improve existing infrastructure, and build new stormwater systems that are more resilient to changes in the quantity and quality of stormwater runoff.[41] See Appendix G for additional details regarding climate change and stormwater impacts in Connecticut, including the basis for the approach selected to incorporate climate change considerations into this Manual.

This Manual incorporates climate change and resilience considerations for stormwater management design and implementation, including:

- Preserving pre-development site hydrology using LID site planning and design strategies (Chapter 5 – Low Impact Development Site Planning and Design Strategies) and structural stormwater BMPs (Chapters 7-13)
- Discussion of updated design storm precipitation for stormwater quantity and quality control (Chapter 4)
- Sea level rise and other considerations for stormwater BMP siting and design in coastal areas (Chapter 4, Chapter 8, and Chapter 10)
- Design considerations for mitigating the potential negative impacts of climate change on stream temperatures and nutrient loads (Chapter 4 and Chapter 8).

It is important to consider future conditions when designing and implementing stormwater BMPs (including long-term maintenance) to ensure the longevity of the investment. Appendix G contains additional resources that may be of use when evaluating climate change considerations for resilient stormwater management design and implementation, including long-term maintenance.

[41] EPA, 2021, https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff