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Attention: **Steve Pichette, P.Eng.**

Subject: **TSS Loading to Granular Trenches of Etobicoke Drainage Systems**

Introduction

This report Memo was prepared to provide background information that can be used to estimate the amount of total suspended sediment (TSS) that may accumulate in the granular trenches of Etobicoke drainage systems or any other granular infiltration/ filtration trenches that may be used to capture sediment laden surface runoff. The collected information is then used to estimate the time (years) that it would take to fill the void space (storage) of the trench. The same information can also be used to estimate the cleaning frequency of catch basins.

Background Data

A useful document from the USA EPA for "*sediment loads from urban surface areas*" is provide in Attachment A and can be found at the following link (https://www.epa.gov/sites/production/files/2015-10/documents/usw_b.pdf). From this document, the following table can be used to estimate TSS loadings in runoff from different types of land uses. Attachment B presents a summary of the two types of Etobicoke Drainage Systems while Attachment C presents the details of the proposed system for the BCDC Developments.

Table 4-3. Typical Pollutant Loadings from Runoff by Urban Land Use (lbs/acre-yr)

Land Use	TSS	TP	TKN	NH_3-N	NO_2+NO_3-N	BOD	COD	Pb	Zn	Cu
Commercial	1000	1.5	6.7	1.9	3.1	62	420	2.7	2.1	0.4
Parking Lot	400	0.7	5.1	2	2.9	47	270	0.8	0.8	0.04
HDR	420	1	4.2	0.8	2	27	170	0.8	0.7	0.03
MDR	190	0.5	2.5	0.5	1.4	13	72	0.2	0.2	0.14
LDR	10	0.04	0.03	0.02	0.1	NA	NA	0.01	0.04	0.01
Freeway	880	0.9	7.9	1.5	4.2	NA	NA	4.5	2.1	0.37
Industrial	860	1.3	3.8	0.2	1.3	NA	NA	2.4	7.3	0.5
Park	3	0.03	1.5	NA	0.3	NA	2	0	NA	NA
Construction	6000	80	NA	NA	NA	NA	NA	NA	NA	NA

HDR: High Density Residential, MDR: Medium Density Residential, LDR: Low Density Residential
NA: Not available; insufficient data to characterize loadings
Source: Horner et al, 1994

Estimating TSS Loads to Granular Trench

To estimate the TSS loads to a granular infiltration/ filtration trench, the following data needs to be determined.

1- Drainage area (ha/m) contributing runoff to granular trench,
2- Storage volume within the trench (m^3/m or L/m) where TSS may accumulate,
3- Land use of drainage area and associated annual TSS loads (kg/ha/yr),
4- Number of years of use and total TSS load (kg/ha),
5- Pre-treatment (% TSS removal) of runoff before it reaches granular trench,
6- TSS loads to granular trench (kg/ha),
7- TSS retention within granular trench (kg/ha),
8- Estimate volume of TSS retained within the trench (L/m) and compare with available storage volume in trench.

Based on the proposed modified Etobicoke drainage system for the Barrhaven Conservancy subdivisions, with a ROW width of 16.5 m and typical lot depths of 21 m, the total drainage area to the granular trench can be calculated to be 58.5 m^2/m or 0.00585 ha/m. With a typical trench width of 2 m and a depth of 0.2 m below the lowest perforated pipe within the trench, the storage volume for sediment retention can be calculated as 2 m x 0.2 m x 40% (void space), or 0.16 m3/s (160 L/m). These computations were performed in the spreadsheet shown in Table 1 below, where the green cells are user inputs, and the yellow cells show the results of calculations.

Table 1: Computation of Drainage Area and Effective Trench Volume

Trench Volume and Contributing Area					
Width(m)=	2.0		ROW (m)=	16.5	
Depth(m)=	0.20		Lot1 Depth (m)=	21	
Void Space(%)=	40%		Lot2 Depth (m)=	21	
	=======			=======	
Storage=	0.16	m3/m	Area=	58.5	(m2/m)
	160	L/m	Area=	0.00585	ha/m
	27350	L/ha			

To assess the longevity of the available sediment storage within the granular trench of the Etobicoke system, two scenarios are considered; i) system treats stormwater during and post construction; and ii) system only treats stormwater once construction is completed. In both scenarios, only the storage below the lowest perforated pipe is considered.

As per the US EPA's "table 4-3", annual TSS loads of 6000 lbs/acre are expected during construction and 190 lbs/acre once construction is completed for a Medium Density Residential land use. These sediment loads can be transformed to kg/ha/yr by dividing the "lbs" by 2.2 lbs/kg and multiply the results by 2.471 ac/ha, such that the 6000 lbs/acre load becomes 6739 kg/ha/yr and the 190 lbs/acre load becomes 213 kg/ha/yr.

Longevity of Etobicoke System if Pre and Post Construction Runoff Treated

Assuming a three (3) year construction period, the total TSS load from this activity can be determined by multiplying the 6739 kg/ha/yr by 3 years for a total yield of 20,217 kg/ha, has shown in Figure 2. Before this TSS load reaches the granular trenches within the Etobicoke system, the runoff will be pre-treated by the deep sump catch basins where it is expected that 25% of the sediments will be retained. This will leave a residual load of 15,163 kg/ha [(1-25%) x 20,217] kg/ha to reach the granular trenches. Given that granular trenches are expected to remove at least 80% of TSS, we can conclude that 80% of the 15,163 kg/ha will be retained within the trench, that is 12,130 kg/ha.

As per Table 1, the drainage area to the Etobicoke system is 0.00585 ha/m. The TSS to be retained within the trench, after three years of construction activities, can be estimated at 0.00585 ha/m x 12,130 kg/ha = 70.96 kg/m. Using a conservative specific gravity of 2.3 for TSS, this 70.96 kg/m represents a volume of 30.9 L/m. The available storage volume within the portion of the trench that is below the lowest perforated pipe is 160 L/m, as per Table 1. Therefore, after three years of construction the available storage will be reduced from 160 L/m to 129 L/m. As per Table 2a, with a TSS Loading of 213 kg/ha/yr, associated with the selected Medium Density Residential land use, it would take over 399 years to fill up the remaining 129 L/m of storage. If it is assumed that 100% of the sediments are retained within the granular trench below the lowest perforated pipe, it would still take just over 300 years for the system to fill up with sediments, refer to Table 2b.

Table 2a: Longevity of Etobicoke System if Construction Runoff Treated
(with 80% TSS retained within trench)

Sediment Loading to Granular Trenches and Storage Longevity								
								Volume
Landuse:	TSS Load	Number of	Total Load	Pre-treatment	Load to ESS	TSS retained	Mass Retained	Retained
	(kg/ha/yr)	(years)	(kg/ha)	(%)	(kg/ha)	in ESS	(kg/ha)	(L/m)
Construction	6739	3	20217	25%	15163	80%	12130	30.9
MDR	213	396.6	84626	25%	63470	80%	50776	129.1
		============	=======		=======		=======	=======
		399.6	104843		78632		62906	160
Specific Gravity of TSS								
2.3								

Table 2b: Longevity of Etobicoke System if Construction Runoff Treated
(with 100% TSS retained within trench)

Sediment Loading to Granular Trenches and Storage Longevity								
								Volume
Landuse:	TSS Load	Number of	Total Load	Pre-treatment	Load to ESS	TSS retained	Mass Retained	Retained
	(kg/ha/yr)	(years)	(kg/ha)	(%)	(kg/ha)	in ESS	(kg/ha)	(L/m)
Construction	6739	3	20217	25%	15163	100%	15163	38.6
MDR	213	298.3	63657	25%	47743	100%	47743	121.4
		============	=======		=======		=======	=======
		301.3	83875		62906		62906	160
Specific Gravity of TSS								
2.3								

Longevity of Etobicoke System if only Post Construction Runoff Treated

As shown in Table 3a, and based on the same calculations, if the runoff during construction was diverted away from the Etobicoke system and treated by some other means, the longevity of the system would increase by almost 100 years, from 399 yrs to 491 yrs if 80% of the post construction TSS is retained in the trench below the lowest perforated pipe. The longevity is reduced to 393 years if 100% of the TSS is retained (see Table 3b).

Table 3a: Longevity of Etobicoke System if Only Post Construction Runoff Treated
(with 80% TSS retained within trench)

Sediment Loading to Granular Trenches and Storage Longevity								
								Volume
Landuse:	TSS Load	Number of	Total Load	Pre-treatment	Load to ESS	TSS retained	Mass Retained	Retained
	(kg/ha/yr)	(years)	(kg/ha)	(%)	(kg/ha)	in ESS	(kg/ha)	(L/m)
Construction	6739	0	0	25%	0	80%	0	0.0
MDR	213	491.3	104843	25%	78632	80%	62906	160.0
		============	=======		=======		=======	=======
		491.3	104843		78632		62906	160
Specific Gravity of TSS								
2.3								

Table 3b: Longevity of Etobicoke System if Only Post Construction Runoff Treated
(with 100% TSS retained within trench)

Sediment Loading to Granular Trenches and Storage Longevity								
								Volume
Landuse:	TSS Load	Number of	Total Load	Pre-treatment	Load to ESS	TSS retained	Mass Retained	Retained
	(kg/ha/yr)	(years)	(kg/ha)	(%)	(kg/ha)	in ESS	(kg/ha)	(L/m)
Construction	6739	0	0	25%	0	80%	0	0.0
MDR	213	393.0	83875	25%	62906	100%	62906	160.0
		============	=======		=======		=======	=======
		393.0	83875		62906		62906	160
Specific Gravity of TSS								
2.3								

Frequency of Catch Basin Cleaning

In this section we will evaluate the frequency of catch basin clean out, on the basis that the 1 m deep sumps will retain 25% of the TSS loadings. We will also consider that only 0.7 m of the 1 m deep sump can be filled with sediments, leaving a 0.3 m scour depth below the invert of the lead pipe. As such and using a 0.6 m by 0.6 m catch basin, the useable storage volume can be calculated as 0.6m x 0.6m x 0.7m = 0.252 m3 or 252 L per catch basin.

The drainage area to each catch basin can be determined by the spacing between them. Using a typical catch basin spacing of 80 m, we can determine, based on the information provided in Table 1, that the drainage area to a set of catch basins is 80m x 0.00585ha/m = 0.468 ha or 0.234 ha per catch basin.

Using the annual TSS loadings provided in Table 2a, it can be determined that catch basin cleaning should take place once a year during construction and significantly less (theoretically every 46 years) once the construction activities are completed, see Table 4. Notwithstanding the theoretical 46 year catch basin clean out for a Medium Density Residential land use, it recommended that the sumps be cleaned out at least once every 2 to 5 years.

Table 4: Catch Basin TSS Loadings and Clean Out Frequency

TSS Loading to Catch Basins and Required Clean Out			
CB spacing (m)=	80	CB width/length (m)=	0.6
Drainage Area (m2/CB)=	2340	CB Sump depth (m)=	1
Drainage Area (ha/CB)=	0.234	Scour depth (m)=	0.3
		Effective volume (m3/CB)=	0.252
		Effective volume (L/CB)=	252
Annual TSS to each CB		**Required clean out frequency (yrs)**	
During Construction (L)=	171	1.47	
During MDR(L)=	5	46.43	

Conclusions

Based on the data available from the US EPA on pollutant loadings from urban runoff, the proposed development characteristics (ROW widths and lot sizes), the proposed dimensions of the Modified Etobicoke drainage system with deep sump catch basins, the analysis presented in this report Memo demonstrates that the sediment retention capacity of the granular trenches within the system could last almost 400 years if the runoff from both the construction period and post construction conditions were treated by the Etobicoke system. If the runoff from the construction period was treated by some other means, the longevity of the system would be increased by approximately 100 years. During construction activities, the removal of sediments from the catch basin sumps should be done once a year. Once all construction activities are completed the catch basin cleaning frequency can return to the City's regular frequency.

Yours truly,
J.F Sabourin and Associates Inc.

J.F Sabourin, M.Eng, P.Eng
Director of Water Resources Projects

Attachments

Attachment A: US EPA Reference with Pollutant Loadings from Urban Runoff
Attachment B: Excerpts from "Evaluation of Roadside Ditches and Other Related Stormwater Management Practices
Attachment C: Proposed Modified Etobicoke Filtration System for BCDC Developments

Ottawa. ON
Paris. ON
Gatineau. QC
Montréal. QC
Québec. QC

Attachment A

US EPA Reference with Pollutant Loadings from Urban Runoff

4.0 Environmental Assessment

Waterways and receiving waters near urban and suburban areas are often adversely affected by urban storm water runoff. The degree and type of impact varies from location to location, but it is often significant relative to other sources of pollution and environmental degradation. Urban storm water runoff affects water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of urban waterways. As reported in the National Water Quality Inventory 1996 Report to Congress (US EPA, 1998d), urban runoff was the leading source of pollutants causing water quality impairment related to human activities in ocean shoreline waters and the second leading cause in estuaries across the nation. Urban runoff was also a significant source of impairment in rivers and lakes. The percent of total impairment attributed to urban runoff is substantial. This impairment constitutes approximately 5,000 square miles of estuaries, 1.4 million acres of lakes, and 30,000 miles of rivers. Seven states also reported in the Inventory that urban runoff contributes to wetland degradation.

Adverse impacts on receiving waters associated with storm water discharges have been discussed by EPA (1995b) in terms of three general classes. These are:

- Short-term changes in water quality during and after storm events including temporary increases in the concentration of one or more pollutants, toxics or bacteria levels.

- Long-term water quality impacts caused by the cumulative effects associated with repeated storm water discharges from a number of sources.

- Physical impacts due to erosion, scour, and deposition associated with increased frequency and volume of runoff that alters aquatic habitat.

As described in the Terrene Institute's *Fundamentals of Urban Runoff Management* (Horner et al, 1994), pollutants associated with urban runoff potentially harmful to receiving waters fall into the categories listed below:

- Solids
- Oxygen-demanding substances
- Nitrogen and phosphorus
- Pathogens
- Petroleum hydrocarbons
- Metals
- Synthetic organics.

These pollutants degrade water quality in receiving waters near urban areas, and often contribute to the impairment of use and exceedences of criteria included in State water quality standards. The quantity of these pollutants per unit area delivered to receiving waters tends to increase with the degree of development in urban areas.

While water quality impacts are often unobserved by the general public, other storm water impacts are more visible. Stream channel erosion and channel bank scour provide direct evidence of water quantity impacts caused by urban storm water. Urban runoff increases directly with imperviousness and the degree of watershed development. As urban areas grow, urban streams are forced to accommodate larger volumes of storm water runoff that recur on a more frequent basis. This leads to stream channel instability. The change in watershed hydrology associated with urban development also causes channel widening and scour, and the introduction of larger amounts of sediment to urban streams. Visible impacts include eroded and exposed stream banks, fallen trees, sedimentation, and recognizably turbid conditions. The increased frequency of flooding in urban areas also poses a threat to public safety and property.

Both water quality and water quantity impacts associated with urban storm water combine to impact aquatic and riparian habitat in urban streams. Higher levels of pollutants, increased flow velocities and erosion, alteration of riparian corridors, and sedimentation associated with storm water runoff negatively impact the integrity of aquatic ecosystems. These impacts include the degradation and loss of aquatic habitat, and reduction in the numbers and diversity of fish and macroinvertebrates.

Public health impacts are for the most part related to bacteria and disease causing organisms carried by urban storm water runoff into waters used for water supplies, fishing and recreation. Water supplies can potentially be contaminated by urban runoff, posing a public health threat. Bathers and others coming in contact with contaminated water at beaches and other recreational sites can become seriously ill. Beach closures caused by urban runoff have a negative impact on the quality of life, and can impede economic development as well. Similarly, the bacterial contamination of shellfish beds poses a public health threat to consumers, and shellfish bed closures negatively impact the fishing industry and local economies.

Aesthetic impacts in the form of debris and litter floating in urban waterways and concentrated on stream banks and beaches are quite visible to the general public. Storm water is a major source of floatables that include paper and plastic bags and packaging materials, bottles, cans, and wood. The presence of floatables and other debris in receiving waters during and following storm events reduces visual attractiveness of the waters and detracts from their recreational value. Nuisance algal conditions including surface scum and odor problems can also be attributed to urban storm water in many instances.

Based on available information and data, the following general statements can be made about urban storm water impacts.

- Impacts to water quality in terms of water column chemistry tend to be transient and elusive, particularly in rivers.
- Impacts to habitat and aquatic life are generally more profound, and are easier to see and quantify than changes in water column chemistry.

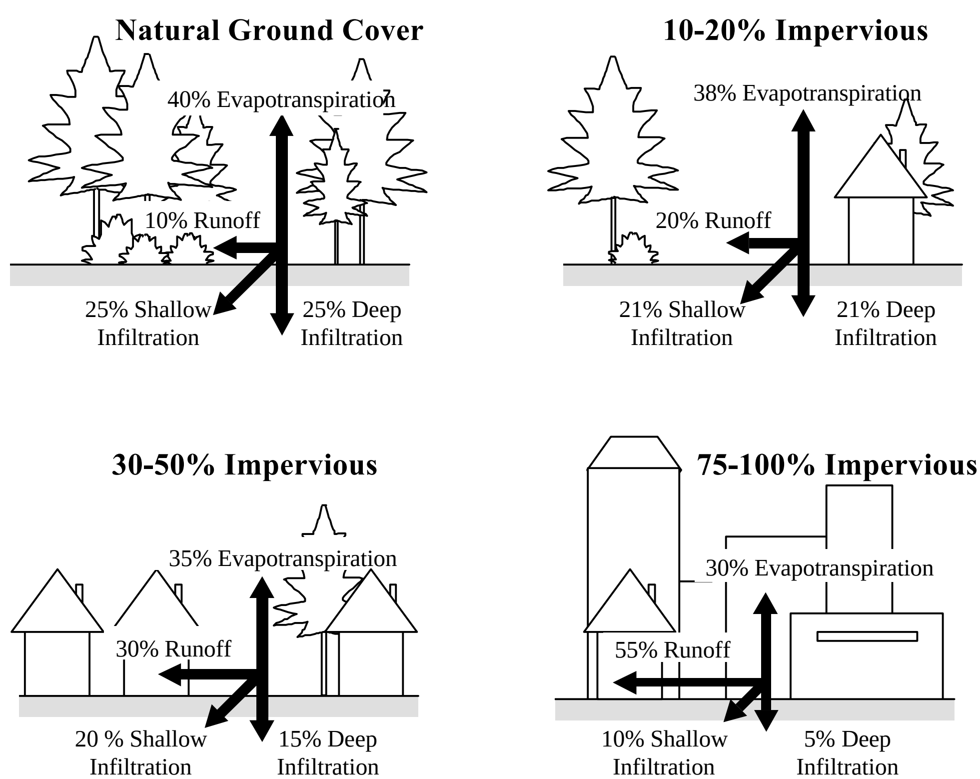
- Impacts are typically complex because urban storm water is often one of several sources including municipal discharges and diffuse runoff from agricultural and rural areas that affect urban waterways.
- Impacts are often interrelated and cumulative. For example, both degraded water quality and increased water quantity join to impact habitat and biological resources.

The following sections describe the sources of urban storm water runoff, the pollutants contained in urban runoff and the impacts attributable to urban storm water discharges. Examples supported by field observation and data have been used extensively to show storm water impacts. The impacts described include water quality impacts, water quantity impacts, public health impacts, habitat impacts, and aesthetic impacts.

4.1 Overview of Storm Water Discharges

Storm water runoff from urbanized areas is generated from a number of sources including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially, any surface which does not have the capability to pond and infiltrate water will produce runoff during storm events. When a land area is altered from a natural forested ecosystem to an urbanized land use consisting of rooftops, streets and parking lots, the hydrology of the system is significantly altered. Water which was previously ponded on the forest floor, infiltrated into the soil and converted to groundwater, utilized by plants and evaporated or transpired into the atmosphere is now converted directly into surface runoff. An important measure of the degree of urbanization in a watershed is the level of impervious surfaces. As the level of imperviousness increases in a watershed, more rainfall is converted to runoff. Figure 4-1 illustrates this transformation.

Figure 4-1. Effects of Imperviousness on Runoff and Infiltration



Source: Adapted from Arnold and Gibbons, 1996

The traditional means of managing storm water runoff in urban areas has been to construct a vast curb-and-gutter, catch basin, and storm drain network to transport this runoff volume quickly and efficiently away from the urbanized area and discharge the water to receiving streams. Two types of sewer systems are used to convey storm water runoff: separate storm sewers and combined sewers.

- *Separate storm sewer systems* convey only storm water runoff. Water conveyed in separate storm sewers is frequently discharged directly to receiving streams without receiving any intentional form of treatment. (In a municipality with a separate storm sewer system, sanitary sewer flows are conveyed in a distinct sanitary sewer system to municipal wastewater treatment plants.)

- In a *combined sewer system*, storm water runoff is combined with sanitary sewer flows for conveyance. Flows from combined sewers are treated by municipal wastewater treatment plants prior to discharge to receiving streams. During large rainfall events however, the volume of water conveyed in combined sewers can exceed the storage and treatment capacity of the wastewater treatment system. As a result, discharges of untreated storm water and sanitary wastewater directly to receiving streams can frequently occur in these systems. These types of discharges are known as combined sewer overflows (CSOs).

Historically, as urbanization occurred and storm drainage infrastructure systems were developed in this country, the primary concern was to limit nuisance and potentially damaging flooding due to the large volumes of storm water runoff that are generated. Little, if any, thought was given to the environmental impacts of such practices. As a result, streams that receive storm water runoff frequently cannot convey the large volumes of water generated during runoff events without significant degradation of the receiving stream. In addition to the problems associated with excess water volume, the levels of toxic or otherwise harmful pollutants in storm water runoff and CSOs can cause significant water quality problems in receiving streams.

In addition to point sources such as municipal separate storm sewers and combined sewer overflows, storm water runoff can enter receiving streams as a non-point source. Storm water runoff from a variety of sources such as parking lots, highways, open land, rangeland, residential areas and commercial areas can enter waterways directly as sheet flow or as a series of diffuse, discrete flows. Due to the diffuse nature of many storm water discharges, it is difficult to quantify the range of pollutant loadings to receiving streams that are attributable to storm water discharges. It is much easier, however, to measure the increased stream flows during rainfall events that occur in urbanized areas and to document impacts to streams that receive storm water runoff.

Awareness of the damaging effects storm water runoff is causing to the water quality and aquatic life of receiving streams is a relatively recent development. Storm water management traditionally was, and still is in many cases, a flood control rather than a quality control program. Local governments intending to improve the quality of their runoff-impacted streams are incorporating best management practices (BMPs) into their drainage programs. BMPs which reduce the volume of runoff discharged to receiving streams, such as minimizing directly connected impervious surfaces, providing on-site storage and infiltration and implementing stream buffers and restoring riparian cover along urban streams can help to prevent further degradation and even result in improvements of streams which receive storm water discharges. However, in many existing urbanized areas, the cost of infrastructure changes necessary to retrofit existing storm water drainage systems with structural BMPs--to provide for storm water quality as well as quantity control--can be prohibitively expensive. In these cases, non-structural BMPs can be implemented to reduce pollutant sources and to reduce the transfer of urban pollutants to runoff, before more expensive, structural controls are instituted.

The climate of a region can have a significant impact on the quantity and quality of storm water runoff. Factors such as the length of the antecedent dry periods between storms, the average rainfall intensity, the storm duration and the amount of snowmelt present can have significant impacts on the characteristics of runoff from an area. In areas where there is a significant amount of atmospheric deposition of particulates, storm water runoff can contain high concentrations of suspended solids, metals and nutrients. Areas that have infrequent rainfall such as the southwest U.S. can have runoff with significant concentrations of pollutants, especially from “hot spots” such as roads, parking lots and industrial areas. These areas, which typically have high-intensity, short-duration rainfall events, can generate significant loadings of suspended solids in storm water runoff. Many specific geographic factors can influence the nature and constituents contained in storm water runoff. Factors such as the soil types, slopes, land use patterns and the amount of imperviousness of a watershed can greatly affect the quality and quantity of runoff that is produced from an area.

4.2 Pollutants in Urban Storm Water

Storm water runoff from urban areas can contain significant concentrations of harmful pollutants that can contribute to adverse water quality impacts in receiving streams. Effects can include such things as beach closures, shellfish bed closures, limits on fishing and limits on recreational contact in waters that receive storm water discharges. Contaminants enter storm water from a variety of sources in the urban landscape.

Urban storm water runoff has been the subject of intensive research since the inception of the Water Quality Act of 1965. There have been numerous studies conducted to characterize the nature of urban storm water runoff and the performance of storm water BMPs. Data sources include the "208 Studies," the area-wide waste treatment management plans conducted by states under section 208 of the 1972 CWA; EPA's Nationwide Urban Runoff Program (NURP); the U.S. Geological Survey (USGS) Urban Stormwater Database; and the Federal Highway Administration (FHWA) study of storm water runoff loadings from highways. In addition to these federal sources, there is a great deal of information in the technical literature, as well as data collected by states, counties and municipalities. A recent data source is storm water monitoring data collected by municipalities regulated by the Phase I NPDES storm water regulations. As part of the Phase I permit application, regulated municipalities were required to collect data from five representative sites during a minimum of three storm events.

The most comprehensive study of urban runoff was NURP, conducted by EPA between 1978 and 1983. NURP was conducted in order to examine the characteristics of urban runoff and similarities or differences between urban land uses, the extent to which urban runoff is a significant contributor to water quality problems nationwide, and the performance characteristics and effectiveness of management practices to control pollution loads from urban runoff (US EPA, 1983). Sampling was conducted for 28 NURP projects which included 81 specific sites and more than 2,300 separate storm events. NURP focused on the following ten constituents:

- Total Suspended Solids (TSS)

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Phosphorus (TP)
- Soluble Phosphorus (SP)
- Total Kjeldahl Nitrogen (TKN)
- Nitrate + Nitrite (N)
- Total Copper (Cu)
- Total Lead (Pb)
- Total Zinc (Zn).

NURP examined both the soluble and the particulate fraction of pollutants, since the water quality impacts can depend greatly on the form that the contaminant is present. NURP also examined coliform bacteria and priority pollutants at a subset of sites. Median event mean concentrations (EMCs) for the ten general NURP pollutants for various urban land use categories are presented in Table 4-1.

Table 4-1. Median Event Mean Concentrations for Urban Land Uses

Pollutant	Units	Residential		Mixed		Commercial		Open/ Non-Urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	--	--
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/l	33	0.99	27	1.32	29	0.81	--	--
Total Zinc	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/l	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

COV: Coefficient of variation
Source: Nationwide Urban Runoff Program (US EPA 1983)

Results from NURP indicate that there is not a significant difference in pollutant concentrations in runoff from different urban land use categories. There is a significant difference, however, in pollutant concentrations in runoff from urban sources than that produced from non-urban areas.

The pollutants that are found in urban storm water runoff originate from a variety of sources. The major sources include contaminants from residential and commercial areas, industrial activities, construction, streets and parking lots, and atmospheric deposition. Contaminants commonly found in storm water runoff and their likely sources are summarized in Table 4-2.

Table 4-2. Sources of Contaminants in Urban Storm Water Runoff

Contaminant	Contaminant Sources
Sediment and Floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas, soil wash-off
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes
Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes
Oil and Grease/ Hydrocarbons	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

The concentrations of pollutants found in urban runoff are directly related to degree of development within the watershed. This trend is shown in Table 4-3, a compilation of typical pollutant loadings from different urban land uses.

Table 4-3. Typical Pollutant Loadings from Runoff by Urban Land Use (lbs/acre-yr)

Land Use	TSS	TP	TKN	NH_3-N	NO_2+NO_3-N	BOD	COD	Pb	Zn	Cu
Commercial	1000	1.5	6.7	1.9	3.1	62	420	2.7	2.1	0.4
Parking Lot	400	0.7	5.1	2	2.9	47	270	0.8	0.8	0.04
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MDR	190	0.5	2.5	0.5	1.4	13	72	0.2	0.2	0.14
LDR	10	0.04	0.03	0.02	0.1	NA	NA	0.01	0.04	0.01
Freeway	880	0.9	7.9	1.5	4.2	NA	NA	4.5	2.1	0.37
Industrial	860	1.3	3.8	0.2	1.3	NA	NA	2.4	7.3	0.5
Park	3	0.03	1.5	NA	0.3	NA	2	0	NA	NA
Construction	6000	80	NA	NA	NA	NA	NA	NA	NA	NA

HDR: High Density Residential, MDR: Medium Density Residential, LDR: Low Density Residential
NA: Not available; insufficient data to characterize loadings
Source: Horner et al, 1994

As indicated in Table 4-3, urban storm water runoff can contain significant concentrations of solids, nutrients, organics and metals. A comparison of the concentration of water quality parameters in urban runoff with the concentrations in domestic wastewater is shown in Table 4-4.

Table 4-4. Comparison of Water Quality Parameters in Urban Runoff with Domestic Wastewater (mg/l)

Constituent	Urban Runoff		Domestic Wastewater		
	Separate Sewers		Before Treatment		After Secondary
	Range	Typical	Range	Typical	Typical
COD	200-275	75	250-1,000	500	80
TSS	20-2,890	150	100-350	200	20
Total P	0.02-4.30	0.36	4-15	8	2
Total N	0.4-20.0	2	20-85	40	30
Lead	0.01-1.20	0.18	0.02-0.94	0.10	0.05
Copper	0.01-0.40	0.05	0.03-1.19	0.22	0.03
Zinc	0.01-2.90	0.02	0.02-7.68	0.28	0.08
Fecal Coliform per 100 ml	400-50,000		10^6-10^8		200

Source: Bastian, 1997

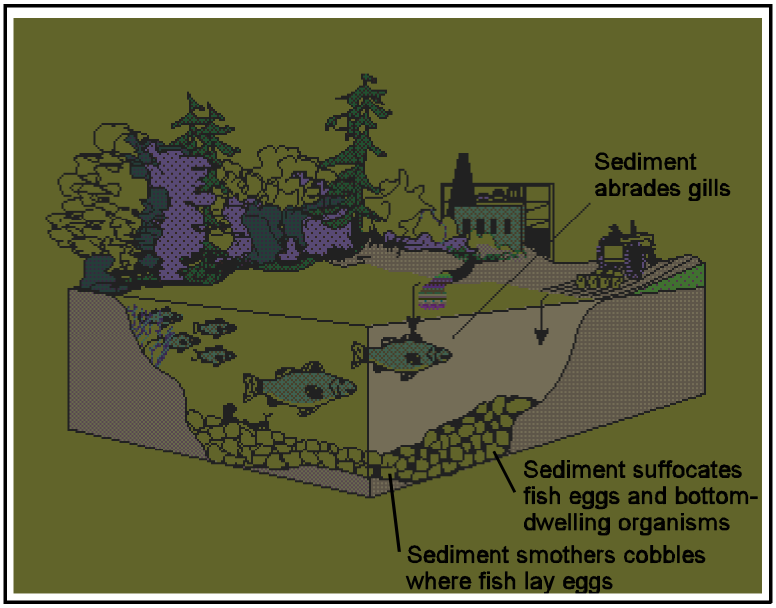
As indicated in Table 4-4, the concentrations of select water quality parameters in urban runoff is comparable to that found in untreated domestic wastewater. When untreated urban runoff is discharged directly to receiving streams, the loadings of pollutants can be much higher than the loadings attributable to treated domestic wastewater.

The following paragraphs summarize the major pollutants which are commonly found in urban storm water runoff.

4.2.1 Solids, Sediment and Floatables

Solids are one of the most common contaminants found in urban storm water. Solids originate from many sources including the erosion of pervious surfaces and dust, litter and other particles deposited on impervious surfaces from human activities and the atmosphere. Stream bank erosion and erosion at construction sites are also major sources of solids. Solids contribute to many water quality, habitat and aesthetic problems in urban waterways. Elevated levels of solids increase turbidity, reduce the penetration of light at depth within the water column, and limit the growth of desirable aquatic plants. Solids that settle out as bottom deposits contribute to sedimentation and can alter and eventually destroy habitat for fish and bottom-dwelling organisms (see Figure 4-2). Solids also provide a medium for the accumulation, transport and storage of other pollutants including nutrients and metals. Sediment bound pollutants often have a long history of interaction with the water column through cycles of deposition, re-suspension, and re-deposition. Impaired navigation due to sedimentation represents another impact affecting recreation and commerce. The relative contribution of TSS in urban storm water from different land uses is presented in Table 4-3. As shown in Table 4-4, the typical concentration of TSS in urban runoff is substantially higher than that in treated wastewater (Bastian, 1997). Construction produces the highest loading of TSS over other urban land use categories evaluated.

Figure 4-2. Effects of Siltation on Rivers and Streams



Source: US EPA, 1998d.

<u>4.2.2 Oxygen-Demanding Substances and Dissolved Oxygen</u>

The oxygen-demanding substances found in urban storm water can be measured by Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). Maintaining appropriate levels of dissolved oxygen in receiving waters is one of the most important considerations for the protection of fish and aquatic life. The amount of dissolved oxygen in urban runoff is typically 5.0 mg/l or greater, and it rarely poses a direct threat to in-stream conditions. As shown in Table 4-4, the level of COD associated with urban runoff is comparable to treated wastewater. The direct impact of urban storm water runoff on dissolved oxygen conditions in receiving waters is not thought to be substantial. However, the secondary impacts on the dissolved oxygen balance in receiving waters due to nutrient enrichment, eutrophication, and resulting sediment oxygen demand may be important.

4.2.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are the principal nutrients of concern in urban storm water. The major sources of nutrients in urban storm water are urban landscape runoff (fertilizers, detergents, plant debris), atmospheric deposition, and improperly functioning septic systems (Terrene Institute, 1996). Animal waste can also be an important source. There are a number of parameters used to measure the various forms of nitrogen and phosphorus found in runoff. Ammonia (NH_3) nitrogen is the nitrogen form that is usually the most readily toxic to aquatic life. Nitrate (NO_3) and nitrite (NO_2) are the inorganic fractions of nitrogen. Very little nitrite is usually found in storm water. Total Kjeldahl nitrogen (TKN) measures the organic and ammonia nitrogen forms. By subtraction, the organic fraction can be determined. Total phosphorus measures the total amount of phosphorus in both the organic and inorganic forms. Ortho-phosphate measures phosphorus that is most immediately biologically available. Most of the soluble phosphorus in storm water is usually present in the ortho-phosphate form.

The degree to which nitrogen and phosphorus are present in a river, lake or estuary can determine the trophic status and amount of algal biomass produced. Excess nutrients tend to increase primary biological productivity. The major impact associated with nutrient over-enrichment is excessive growth of algae that leads to nuisance algal blooms and eutrophic conditions. A secondary impact is the residual negative effect of decomposing algae in the form of sediment oxygen demand that depletes dissolved oxygen concentrations, particularly in bottom waters. The NURP study reported that nutrient levels in urban runoff appear not to be high in comparison with other possible discharges. However, more recent studies and programs have recognized that the amount of nitrogen and phosphorus present in urban storm water can be substantial, and becomes increasingly important as other point sources of nutrients are brought under control. Walker (1987) reported that “cause-effect relationships linking urban development to lake and reservoir eutrophication are well established,” and that “urban watersheds typically export 5 to 20 times as much phosphorus per unit per year, as compared to undeveloped watersheds in a given region.” The nutrient loadings from different urban and suburban land uses are presented in Table 4-3. As shown in Table 4-4, the total phosphorus and total nitrogen concentrations in urban runoff are substantially less than treated wastewater concentrations, but storm water volumes can be greater during wet weather events.

4.2.4 Pathogens

Pathogens are disease-producing organisms that present a potential public health threat when they are present in contact waters. Since storm water runoff typically does not come into contact with domestic wastewaters, and direct exposure to runoff is usually limited, there is generally little threat of pathogens in storm water runoff causing a public health risk. However, where runoff is discharged to recreational waters such as beaches and lakes, or where runoff comes into contact with shellfish beds, there is a potential public health risk associated with pathogen contamination.

There are a number of indicator organisms that have been used to evaluate the presence of harmful pathogens in storm water runoff. Several strains of bacteria are present naturally in the soil and can be transported by runoff. In addition, BMPs with standing water can be breeding grounds for naturally occurring bacteria. Therefore, interpretation of bacteriological sampling results can be difficult. Nevertheless, indicator organisms can provide useful insight into the public health risk associated with runoff. Fecal coliform has been widely used as an indicator for the presence of harmful pathogens in domestic wastewaters, and therefore studies characterizing storm water runoff have frequently used this indicator as well. Other bacterial indicators that have been used to evaluate the presence of harmful pathogens in storm water runoff include *Escherichia coli, streptococci* and *enterococci*. The presence of enteric viruses has also been evaluated in storm water runoff, as well as protozoans such as *Giardia lamblia* and *cryptosporidium*.

Fecal coliform concentrations in urban runoff were evaluated by NURP at 17 sites for 156 storm events. NURP reported that coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in many surface waters, even those providing high degrees of dilution. Concentrations of fecal coliform found by NURP exhibited a large degree of variability, and did not indicate any distinctions based on land use. Data from different sites did show a dramatic seasonal effect on coliform concentrations. Coliform counts in urban runoff during warmer periods of the year were found to be approximately 20 times greater that those found during colder periods. Based on this data, NURP concluded that coliform sources unrelated to those traditionally associated with human health risk may be significant.

The Terrene Institute (1996) reported that the primary sources of pathogens in urban storm water drains are animal wastes (including pets and birds), failing septic systems, illicit sewage connections, and boats and marinas. Field et al (1993) reported pathogens levels from storm water runoff and urban streams as shown in Table 4-5. Pathogens enumerated included bacteria (total and fecal coliform, fecal streptococci, enterococci, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Salmonella*) and enteroviruses (poliovirus, Coxsackie virus, and Echovirus).

Table 4-5. Densities of Selected Pathogens and Indicator Microorganisms in Storm Water in Baltimore, Maryland Area

Geometric Mean Densities								
Sampling Station	Entero-virus	*Salmon sp.*	*Pseudomon. aeruginosa*	*Staph. aureus*	Total Coliform	Fecal Coliform	Fecal Strep.	*Enterococci*
	PFU/ 10 L	MPN/ 10 L	MPN/ 10 L	MPN/ 100 mL	MPN/ 100 mL (10^4)	MPN/ 100 mL (10^3)	No./ 100 mL (10^4)	No./100 mL (10^4)
Bush St.	6.9	30	2000	120	38	83	56	12
Northwood	170	5.7	590	12	3.8	6.9	5	2.1

PFU: Plaque-forming units
MPN: Most Probable Number
Source: Field et al, 1993

As shown earlier in Table 4-4, typical fecal coliform concentrations for separate urban storm sewers varied widely, ranging between 400-50,000 mpn/100 ml. An example of fecal coliform concentrations measured in sheet flow associated with different impervious surfaces is presented in Table 4-6. The broad range in concentrations illustrates the highly variable nature of fecal coliform concentrations in storm water.

Table 4-6. Fecal Coliform Concentrations Collected in Sheetflow from Urban Land Uses

Land Use	Median (MPN/100 ml)	Range (MPN/100 ml)
Unpaved driveways and storage areas	26	0.02-300
Roof runoff	1.6	0.56-2.6
Sidewalks	55	19-90
Paved parking and driveways	2.8	0.03-66
Paved roads	19	1.8-430

MPN: Most Probable Number
Source: Field et al, 1993.

4.2.5 Petroleum Hydrocarbons

Petroleum hydrocarbons include oil and grease; the "BTEX" compounds: benzene, toluene, ethyl benzene, and xylene; and a variety of polynuclear aromatic hydrocarbons (PAHs). Sources of petroleum hydrocarbons include parking lots and roadways, leaking storage tanks, auto emissions, and improper disposal of waste oil. Petroleum hydrocarbons are typically concentrated along transportation corridors.

Petroleum hydrocarbons are known for their acute toxicity at low concentrations (Schueler, 1987). A study by Shepp (1996) measured the petroleum hydrocarbon concentrations in urban runoff from a variety of impervious areas in the District of Columbia and suburban Maryland. The amount of car traffic affects the concentration of hydrocarbons in runoff, with median concentrations ranging from 0.7 to 6.6 mg/l. Concentrations at these levels exceed the maximum concentrations recommended for the protection of drinking water supplies and fisheries protection. As pointed out by Shepp, the maximum concentration of petroleum hydrocarbons for protection of fisheries is 0.01 to 0.1 mg/l.

4.2.6 Metals

The primary sources of metals in urban storm water are industry and automobiles. Atmospheric deposition (both wet and dry) can make a substantial contribution in some parts of the country. A major finding of the NURP study is as follows:

> Heavy metals (especially copper, lead and zinc) are by far the most prevalent priority pollutant constituents found in urban runoff. End-of-pipe concentrations exceed EPA ambient water quality criteria and drinking water standards in many instances. Some of the metals are present often enough and in high enough concentrations to be potential threats to beneficial uses.

Metals in urban storm water have the potential to impact water supply and cause acute or chronic toxic impacts for aquatic life. Typical pollutant loading rates and urban runoff concentrations for lead, zinc and copper are presented in Tables 4-3 and 4-4. The frequency with which metals were detected as priority pollutants in the NURP study is presented in Table 4-7.

Table 4-7. Most Frequently Detected Priority Pollutants in Nationwide Urban Runoff Program Samples (1978-83)

Inorganics	Organics
Detected in 75% or more	
94% Lead 94% Zinc 91% Copper	None
Detected in 50-74%	
58% Chromium 52% Arsenic	None
Detected in 20-49%	
48% Cadmium 43% Nickel 23% Cyanides	22% Bis(2-ethylhexyl)phthalate 20% α-Hexachloro-cyclohexane
Detected in 10-19%	
13% Antimony 12% Beryllium 11% Selenium	19% α-Endosulfan 19% Pentachlorophenol* 17% Chlordane* 15% Lindane* 15% Pyrene** 14% Phenol 12% Phenanthrene** 11% Dichloromethane 10% 4-Nitrophenol 10% Chrysene** 10% Fluoranthene**

* Chlorinated hydrocarbon
** Polynuclear aromatic hydrocarbon
Source: US EPA, 1983

A major study of the quality of Wisconsin storm water (Bannerman et al, 1996) found that the probability of event mean concentrations for some metals (particularly copper and zinc) exceeding Wisconsin water quality criteria for cold water fish communities was high (Table 4-8). A study in Coyote Creek, California reported lead and zinc levels from urban runoff of 100 to 500 times the concentration in the ambient water column (Pitt, 1995).

Table 4-8. Probability of Event Mean Concentration of Constituents in Wisconsin Storm Water Exceeding Wisconsin Surface Water and Ground Water Quality Standards: Metals

Constituent	Probability of exceeding acute toxicity criteria for cold water fish communities (percent)	
	Storm Sewers	Streams
Cadmium, total recoverable	11	0
Copper, total recoverable	87	9
Lead, total recoverable	18	0
Silver, total recoverable	20	-
Zinc, total recoverable	91	7

Source: Bannerman et al, 1996.

4.2.7 Synthetic Organic Compounds

Synthetic organic compounds include a variety of manufactured compounds covering pesticides, solvents and household and industrial chemicals. The frequency that synthetic inorganics were detected as priority pollutants in the NURP study is presented in Table 4-7. In general, organic contaminants were found in less than 20 percent of samples. Nevertheless, synthetic organics do represent a threat. Even low concentrations of some synthetic organics over a long period of time have the potential to pose a severe health risks to humans and aquatic life though direct ingestion or bioaccumulation in the food chain. There is also some evidence that pesticides are found in higher concentrations in urban areas than agricultural areas (US EPA, 1995b). Further, Bannerman et al found that the probability for storm water and urban stream samples to exceed human cancer criteria for public water supply, and toxicity criteria for coldwater fish communities equaled or approached 100 percent for 10 compounds (Table 4-9).

Table 4-9. Probability of Event Mean Concentration of Constituents in Wisconsin Storm Water Exceeding Wisconsin Surface Water and Ground Water Quality Standards: Synthetic Organic Compounds

Constituent (Human cancer criteria for public water supply/ coldwater fish communities)	**Probability of exceedance (percent)**	
	Storm Sewers	**Streams**
Benzo[a]anthracene	98	100
Benzo[a]pyrene	99	100
Benzo[b]fluoranthene	100	100
Benzo[ghi]perylene	99	100
Benzo[k]fluoranthene	99	99
Chrysene	100	100
Indeno pyrene	100	99
Phenanthrene	100	99
Pyrene	100	100
DDT	98	100

Source: Bannerman et al, 1996

4.2.8 Temperature

Water temperature is an important measure of water quality. As described by Malina (1996), "the temperature of water affects some of the important physical properties and characteristics of water, such as… specific conductivity and conductance, salinity, and the solubility of dissolved gases (e.g., oxygen and carbon dioxide)." Specifically, water holds less oxygen as it becomes warmer, resulting in less oxygen being available for respiration by aquatic organisms. Furthermore, elevated temperatures increase the metabolism, respiration, and oxygen demand of fish and other aquatic life, approximately doubling the respiration for a 10°C (18°F) temperature rise; hence the demand for oxygen is increased under conditions where supply is lowered (California SWRCB, 1963).

Certain species of fish, such as salmon and trout, are particularly sensitive and require relatively low water temperatures. Even lower temperatures are required for spawning and egg hatching (US EPA, 1976). If the temperature of a stream reach is raised by 5 to 10°C (9 to 18°F), it is probable that such cold-water game fish will avoid this reach and that they will be replaced by "rougher," more tolerant fish (California SWRCB, 1963). Thus, even without direct mortality, the character of the fish life will change. Sudden changes in temperature directly stress the aquatic ecosystem. The states have adopted varying criteria to protect fisheries from such stresses. Typically, states limit in-stream temperature rises above natural ambient temperatures to 2.8°C (5°F). Allowable temperature rises in streams that support cold water fisheries may be lower, with some states adopting values as low as 1°C (1.8°F) and 0.6°C (1°F) (US EPA, 1988).

The temperature of urban waters is often affected directly by urban runoff. Urban runoff can be heated as it flows over rooftops, parking lots and roadways. When it reaches urban waterways it can cause a temporary fluctuation in the in-stream water temperature. Other factors that tend to increase summer water temperature in urban waters include the removal of vegetation from stream banks, reduced ground water baseflow, and discharges from storm water facilities with elevated water temperature. Frequent fluctuations in stream temperature stress the aquatic ecosystem, and make it difficult for temperature-sensitive species to survive.

Galli (1990a) undertook a major study of thermal impacts associated with urbanization and storm water management in Maryland. Temperature observations were taken at stream stations representing different levels of development, with impervious cover ranging from 1 percent to 60 percent. Results were compared with Maryland Class III standards for natural trout waters (68 °F) and Class IV standards for recreational trout waters (75 °F). As shown in Figure 4-3, streams in developed watersheds (Lower Whiteoak and Tanglewood Stations) have significantly higher spring and summer temperatures than streams in less developed watersheds. Galli also found that "imperviousness together with local meteorological conditions had the largest influence on urban stream temperatures." As shown in Figure 4-4, the rate of increase in baseflow water temperature in this study was determined to be 0.14 °F for each one percent increase in watershed imperviousness.

Figure 4-3. Relationship Between Increasing Imperviousness and Urban Stream Temperature

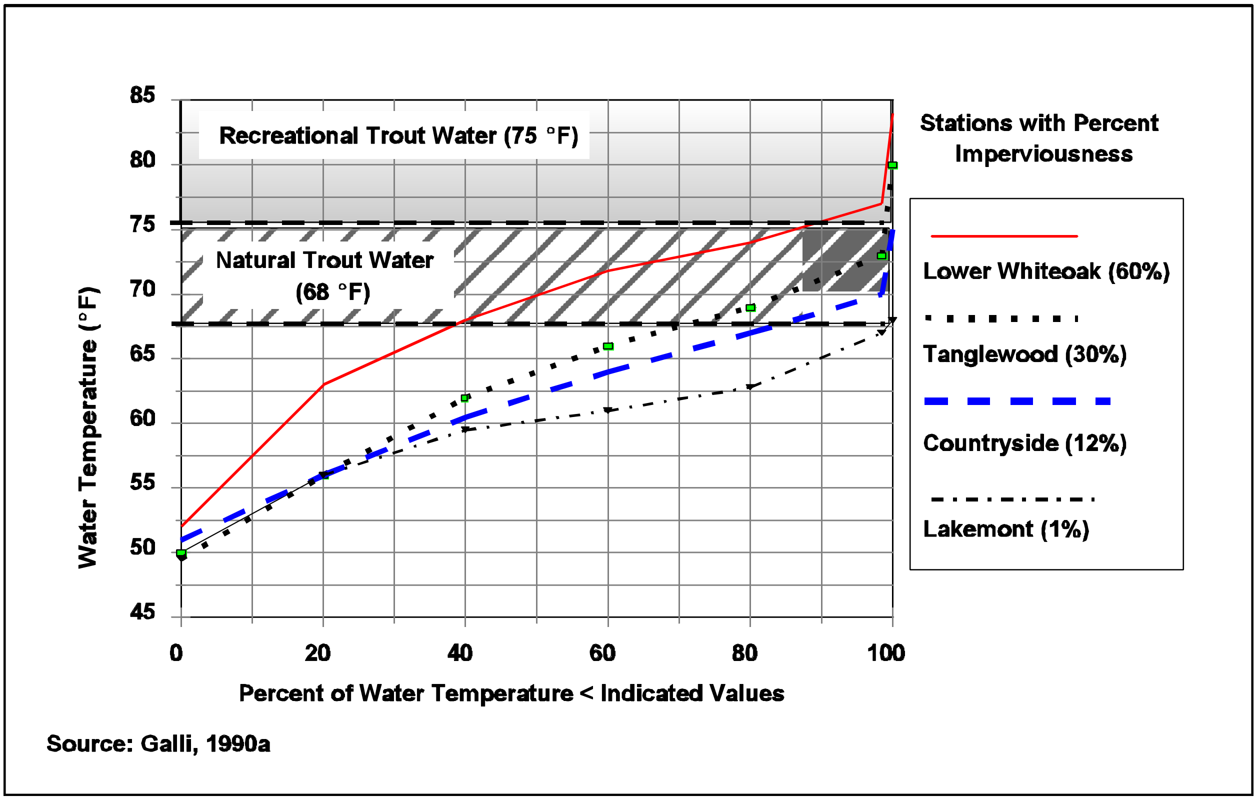
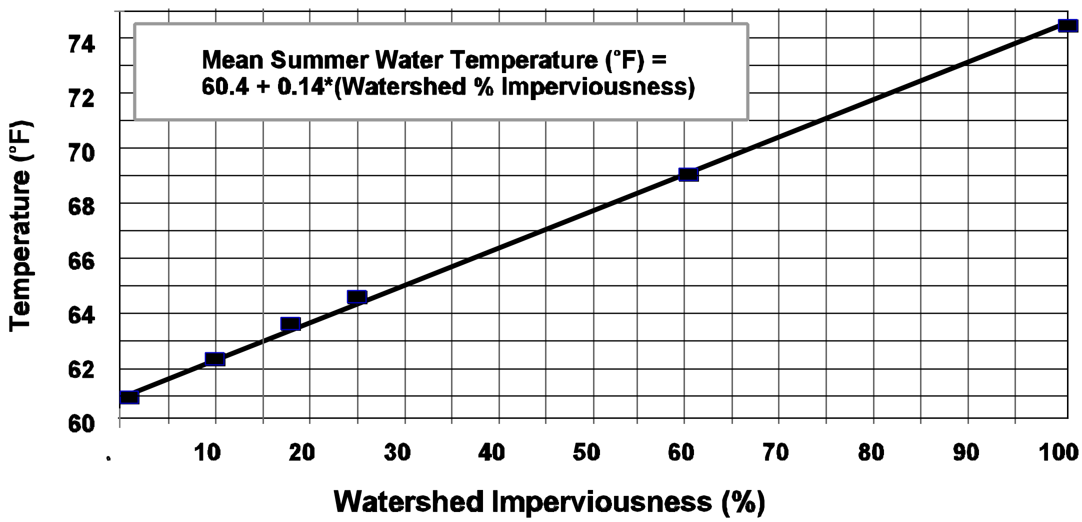


Figure 4-4. Relationship Between Watershed Imperviousness and Baseflow Water Temperature



Source: Galli, 1990a

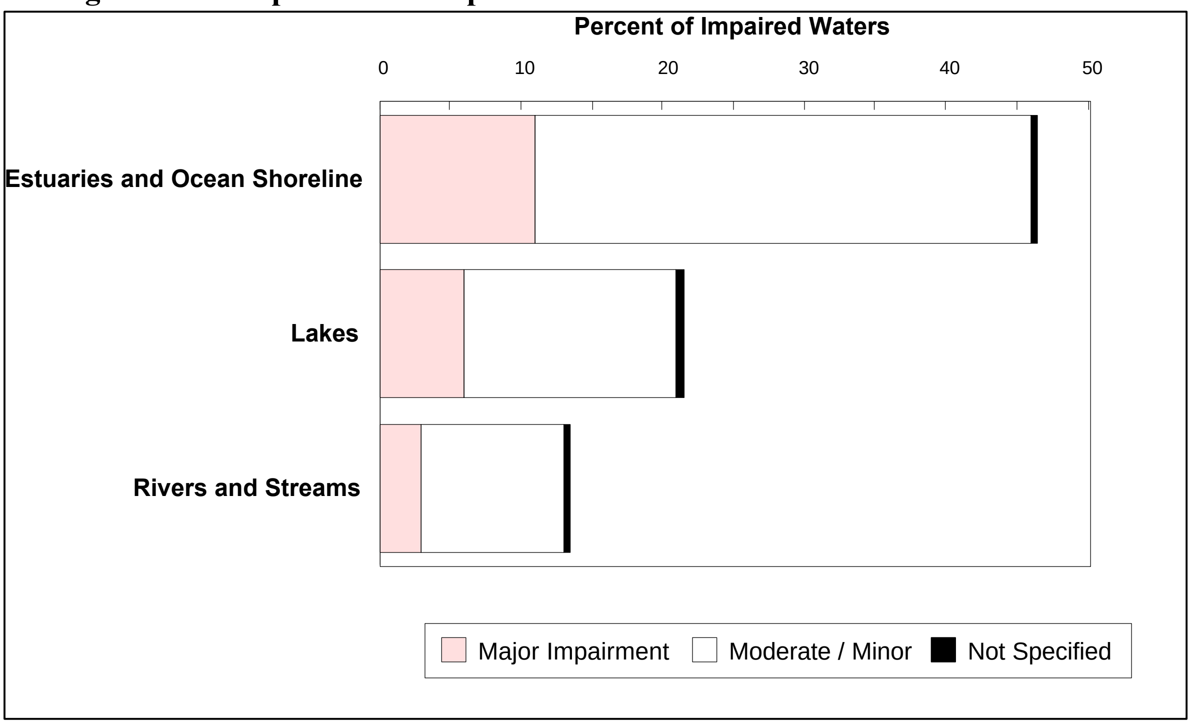
4.2.9 pH

As pointed out by Novotny and Olem (1994), "most aquatic biota are sensitive to pH variations," and "fish kills and reduction and change of other species result when the pH is altered outside their tolerance limits." Most pH impacts in urban waters are caused by runoff of rainwater with low pH levels (acid precipitation). In fact, urban areas tend to have more acidic rainfall than less developed areas. Some buffering of low pH rainwater occurs during contact with buildings, parking lots, roads and collection systems, and during overland flow. This is often very site specific. The alkalinity and thus the capacity of receiving waters to neutralize acidic storm water can also be important, and again is very site specific. Examples of pH impacts on fish populations are difficult to identify due to the cumulative, overlapping impacts from other factors. However, it is thought that the acidification problem in both the United States and Canada grows in magnitude when "episodic acidification" (brief periods of low pH levels from snow melt or heavy downpours) is taken into account (US EPA, 1992a). The spring snow melt can coincide with fish spawning periods.

4.3 Reported Impacts of Urban Storm Water

Urban runoff, which includes runoff from impervious surfaces such as streets, parking lots, buildings, lawns and other paved areas is one of the leading causes of water quality impairment in the United States. Based on the 1996 state Water Quality Inventory reports, siltation (sediment discharged from urban runoff, as well as construction sites, agriculture, mining and forests) is the leading cause of impaired water quality in rivers and streams. In the portion of the inventory identifying sources, urban runoff was listed as the leading source of pollutants causing water quality impairment related to human activities in ocean shoreline waters and the second leading cause in estuaries across the nation. Urban runoff was also a significant source of impairment in rivers and lakes. Urban runoff accounts for 47 percent of impaired miles of surveyed ocean shoreline, 46 percent of the impaired square miles of surveyed estuaries, 22 percent of the impaired acres of surveyed lakes and 14 percent of the impaired miles of surveyed rivers. Figure 4-5 illustrates the level of impairment attributable to urban storm water runoff based on states' Water Quality Inventory assessment reports.

Figure 4-5. Proportions of Impaired Water Bodies Attributed to Urban Runoff



Source: EPA, 1998d.

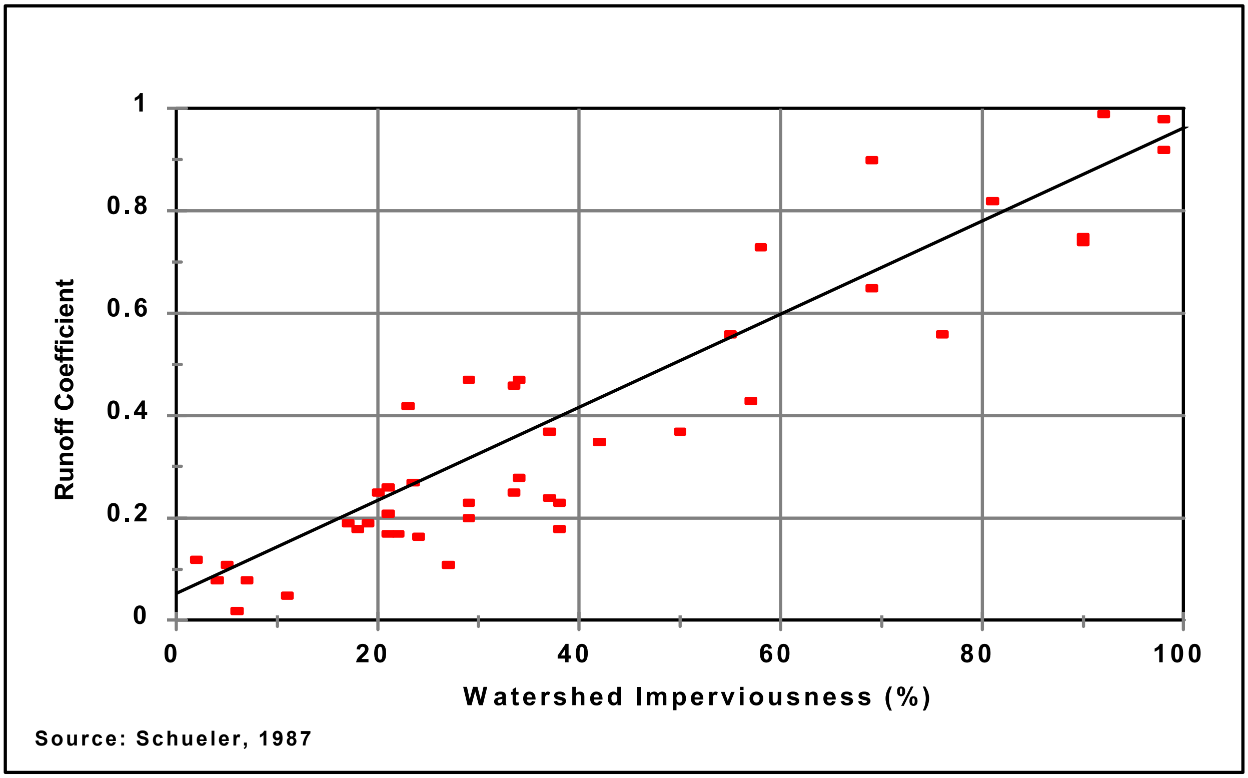
4.3.1 Flow Impacts

The volume and flow rate of storm water discharges can have significant impacts on receiving streams. In many cases, the impacts on receiving streams due to high storm water flow rates or volumes can be more significant than those attributable to the contaminants found in storm water discharges. While studies linking increased storm water flows due to urbanization to stream degradation are generally lacking in quantitative data, there are a number of studies that support this hypothesis. EPA summarized studies which contain documented evidence of impacts on steams due to urbanization (US EPA, 1997a). Impacts of urbanization and increased storm water discharges to receiving streams documented in this evaluation include:

- Increase in the number of bankfull events and increased peak flow rates
- Sedimentation and increased sediment transport
- Frequent flooding
- Stream bed scouring and habitat degradation
- Shoreline erosion and stream bank widening
- Decreased baseflow
- Loss of fish populations and loss of sensitive aquatic species
- Aesthetic degradation
- Changes in stream morphology
- Increased temperatures.

The amount of runoff generated within a watershed increases steadily with development. The presence of impervious areas such as roofs, parking lots and highways limits the volume of rain water infiltrated into the soil, and increases the amount of runoff generated. Urbanized areas also tend to have reduced storage capacities for runoff because of regrading, paving, and the removal of vegetative cover. Decreases in infiltration and evapotranspiration and an increase in runoff are the result of urbanization, with runoff volume linked to the percent of impervious area. The relationship between runoff coefficient and percent impervious area is illustrated in Figure 4-6.

Figure 4-6. Relationship of Watershed Imperviousness to Runoff Coefficient Levels



As shown in Table 4-10, the physical impacts to streams associated with increased imperviousness are substantial (US EPA, 1997a).

Table 4-10. Impacts from Increases in Impervious Surfaces

Increased Imperviousness Leads to:	Resulting Impacts				
	Flooding	Habitat loss	Erosion	Channel Widening	Stream bed Alteration
Increased Volume	✔	✔	✔	✔	✔
Increased Peak Flow	✔	✔	✔	✔	✔
Increased Peak Duration	✔	✔	✔	✔	✔
Increased Stream Temp.		✔			
Decreased Base Flow		✔			
Changes in Sediment Loading	✔	✔	✔	✔	✔

Source: EPA, 1997

The Delaware Department of Natural Resources and Environmental Control also identified a list of impacts on physical stream habitat attributed to urban storm water (DE DNREC, 1997). This list is as follows:

- Accelerated bank erosion
- Accelerated bank undercutting
- Increased siltation (burial of stable habitats)
- Elimination of meanders (channelization)
- Channel widening
- Reduced depth
- Reduced baseflow
- Loss of shade
- Increased temperature.

Specific impacts in the areas of flooding, stream bank erosion, and ground water recharge are described in the following subsections.

Flooding

Urbanization increases the frequency and severity of flooding due to increased runoff. Because of the decreased availability of pervious, permeable surfaces, and the related decrease in storage capacity, smaller more frequently occurring storms can create flooding problems. Hydrographs in urban streams peak higher and faster than streams in undeveloped areas. A comparison of estimated runoff volume and peak discharge for developed and undeveloped areas is presented in Table 4-11. As shown, both runoff volume and peak discharge are substantially increased under developed conditions.

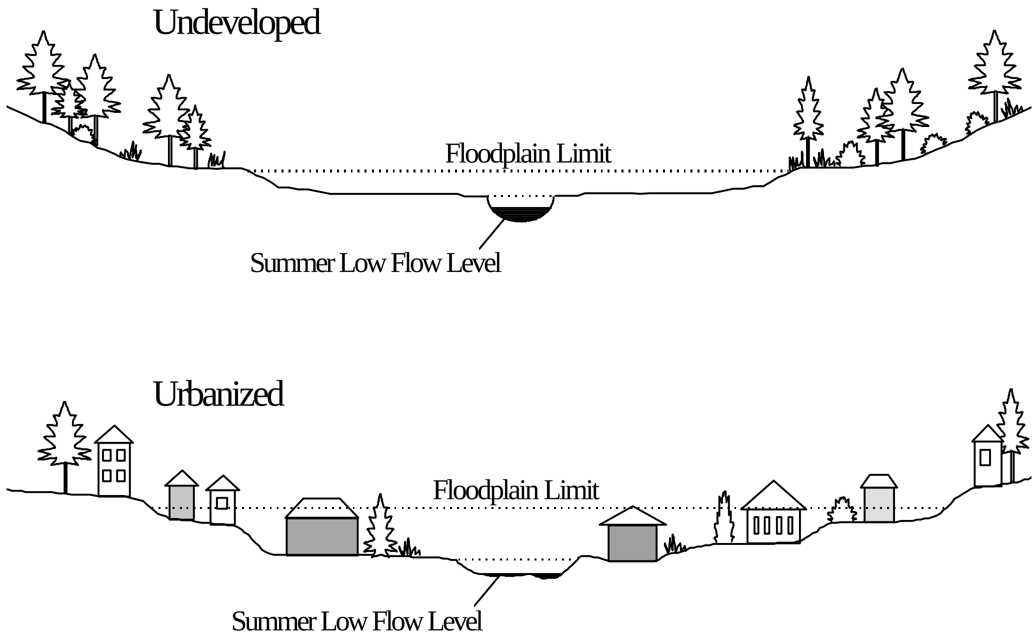
Table 4-11. Comparison of Estimated Runoff Volume and Peak Discharge for Developed and Undeveloped Areas

Storm Frequency (years)	Undeveloped Conditions (Woods in good condition)		Developed Conditions (Half-Acre Residential)	
	Estimated Runoff (in)	Estimated Peak Discharge (cfs)	Estimated Runoff (in)	Estimated Peak Discharge (cfs)
2	0.14	1.00	0.60	11.6
10	0.52	5.60	1.33	27.4
100	1.40	19.7	2.64	58.6

Source: Horner et al, 1994

The effects of urbanization on stream shape and the flood plain are illustrated in Figure 4-7. Increased peak discharge raises the flood plain level, flooding areas which were previously not at risk.

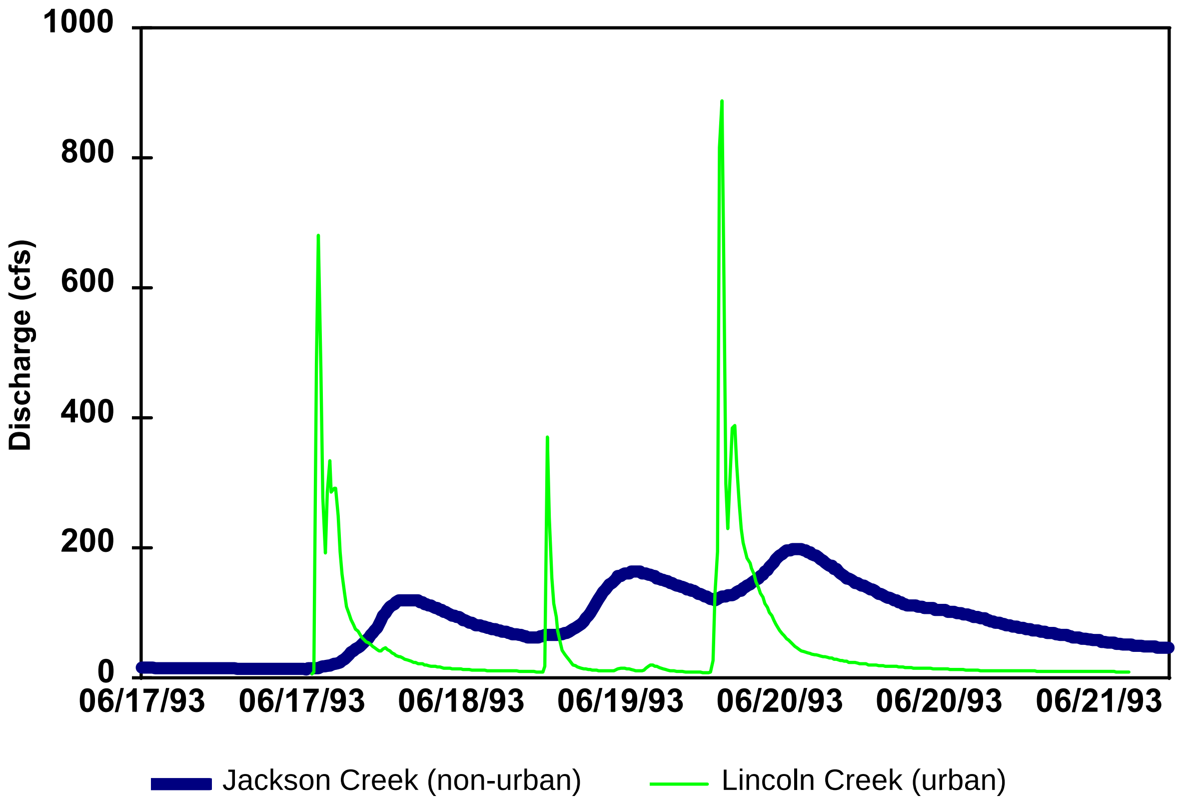
Figure 4-7. Effect of Urbanization on Stream Slope and Flooding



Source: Adapted from Schueler, 1987

A comparison of hydrographs from an urbanized stream (Lincoln Creek) and a non-urbanized stream (Jackson Creek) in Wisconsin are presented in Figure 4-8 (Masterson and Bannerman, 1994). As illustrated, the hydrograph for the urbanized stream exhibits a much higher peak flow rate that would correspond to a higher flood level.

Figure 4-8. Hydrographs for Urban and Non-Urban Streams



Source: Masterson and Bannerman, 1994

<u>Stream Bank Erosion</u>

Stream bank erosion is a natural phenomenon and source of both sediment and nutrients. However, urbanization can greatly accelerate the process of stream bank erosion. As the amount of impervious area increases, a greater volume of storm water is discharged directly to receiving waters, often at a much higher velocity. The increased volume and velocity of the runoff can overwhelm the natural carrying capacity of the stream network. In addition, streams in urbanized areas can experience an increase in bankfull flows. Since bankfull flows are highly erosive, substantial alterations in stream channel morphology can result.

Excessive bank erosion occurs as streams become wider and straighter to accommodate greater flows and an excess number of erosion-causing events. Signs of stream bank erosion attributable to increased storm water include undercut and fallen stream banks, felled bushes and trees along the banks, and exposed sewer and utility pipes. Sediments from eroding banks (and upland construction) are deposited in areas where the water slows, causing buildup, destruction of benthic habitat, and a decreased stream capacity for flood waters. This ultimately results in a greater potential for further erosion.

Krug and Goddard (1986) documented these phenomena in their study of Pheasant Branch, a developing watershed of 24.5 square miles near Middleton, Wisconsin. Local population grew markedly between 1970 to 1980, from 8,246 to 11,851, and is projected to reach 18,000 by the year 2000. Problems of stream channel erosion and suspended sediment developed in Pheasant Branch as a result of this growth. The increased erosion and sediment loadings have decreased the mean stream bed elevation by almost 2 feet, and increased the mean channel width by nearly 35 percent.

Table 4-12 shows the modeled percent increase at three sites for the volume of the 2-year flood, bankfull width, and bankfull depth under two development scenarios. These are the projected development levels in the year 2000 (projected urbanization), and complete urbanization of the watershed. The projected results are shown relative to pre-development conditions.

Table 4-12. Percent Increase of Two-Year Flood, Bankfull Width, and Bankfull Depth from Pre-Development Conditions to Urbanized Conditions (Based on Modeling Results)

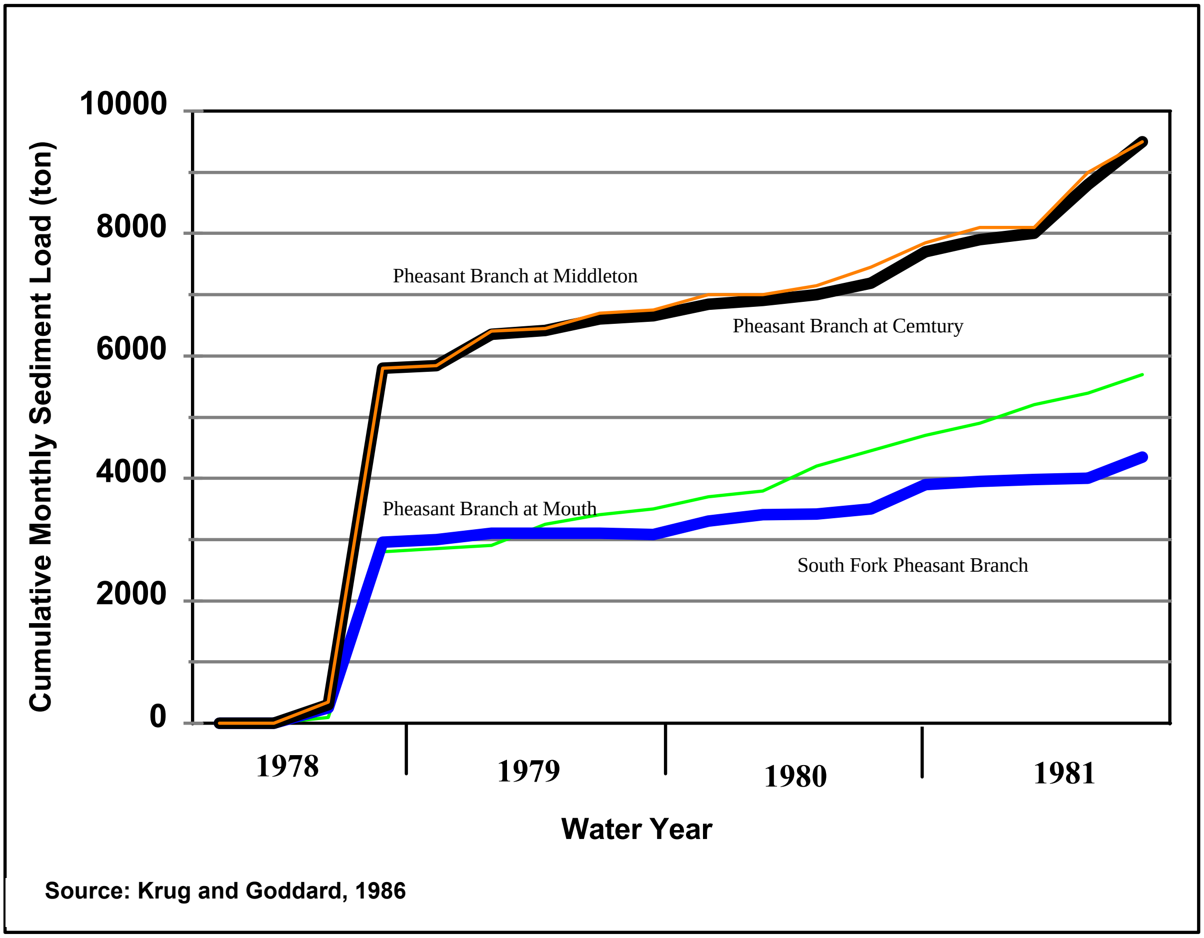
Site	Projected Urbanization			Complete Urbanization		
	2-year	Width	Depth	2-year	Width	Depth
	(Percent Increase from Pre-urbanization)			(Percent Increase from Pre-urbanization)		
Site 1	99	40	30	140	60	40
Site 2	324	110	80	361	110	80
Site 3	32	10	10	224	80	60

Source: EPA, 1997a

An example of the impact of urbanization on increased sediment loadings in several small streams in Wisconsin before, during and after development is illustrated in Figure 4-9 (Krug and Goddard, 1986). Sediment loads are greatest during construction, but remain elevated after construction relative to pre-development conditions.

Figure 4-9. Sediment Loadings on Small Streams in Wisconsin

Cumulative Monthly Sediment Load



Ground Water Recharge

Urbanization can have a major impact on ground water recharge. As shown earlier in Figure 4-1, both shallow and deep infiltration decrease as watersheds undergo development and urbanization. Ground water recharge is reduced along with a lowering of the water table. This change in watershed hydrology alters the baseflow contribution to stream flow, and it is most pronounced during dry periods. Ferguson (1990) points out that "base flows are of critical environmental and economic concern for several reasons. Base flows must be capable of absorbing pollution from sewage treatment plants and non-point sources, supporting aquatic life dependent on stream flow, and replenishing water-supply reservoirs for municipal use in the seasons when [water] levels tend to be lowest and water demands highest."

Base flows on Long Island, New York were substantially impacted by the construction of storm water conveyance systems during the period of rapid development between the 1940s and

1970s. As illustrated in Table 4-13, a steady decline in the average percent of baseflow was observed for streams in urbanized sewered areas relative to streams in un-sewered or rural areas (US EPA, 1997a).

Table 4-13. Average Percent Base Flow of Selected Streams on Long Island by Area

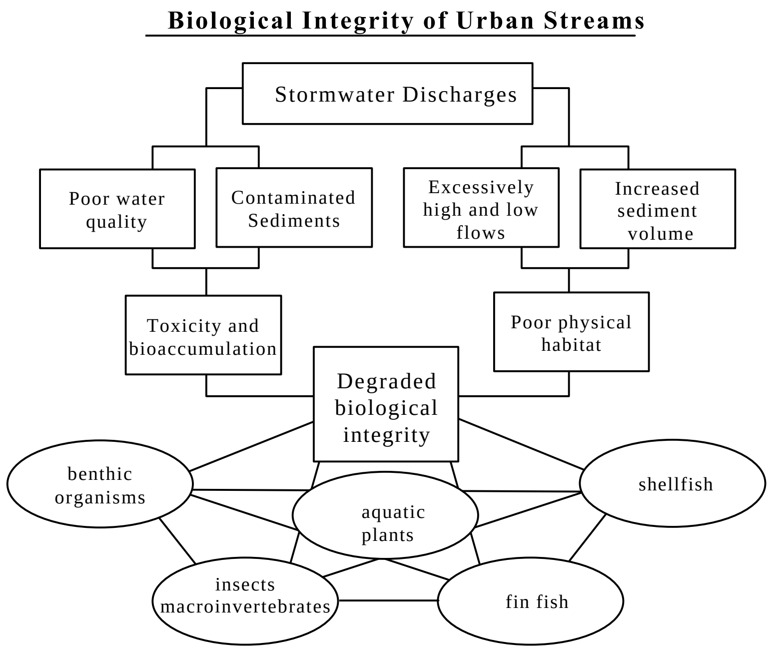
Years	Urbanized Sewered Area (% Flow from Base Flow)		Urbanized Un-sewered Area (% Flow from Base Flow)		Rural Un-sewered Area (% Flow from Base Flow)	
	Stream 1	Stream 2	Stream 1	Stream 2	Stream 1	Stream 2
1948-1953	(No data)	86	84	94	96	95
1953-1964	63	69	89	89	95	97
1964-1970	17	22	83	84	96	97

Source: US EPA, 1997a

4.3.2 Habitat Impacts

Natural ecosystems are a complex arrangement of interactions between the land, water, plants, and animals. The relationship between storm water discharge and the biological integrity of urban streams is illustrated in Figure 4-10 (Masterson and Bannerman, 1994). As shown, habitat is impacted by changes in both water quality and quantity, and the volume and quality of sediment. As reported by Schueler (1987), “no single factor is responsible for the progressive degradation of urban stream ecosystems. Rather, it is probably the cumulative impacts of many individual factors such as sedimentation, scouring, increased flooding, lower summer flows, higher water temperatures, and pollution.”

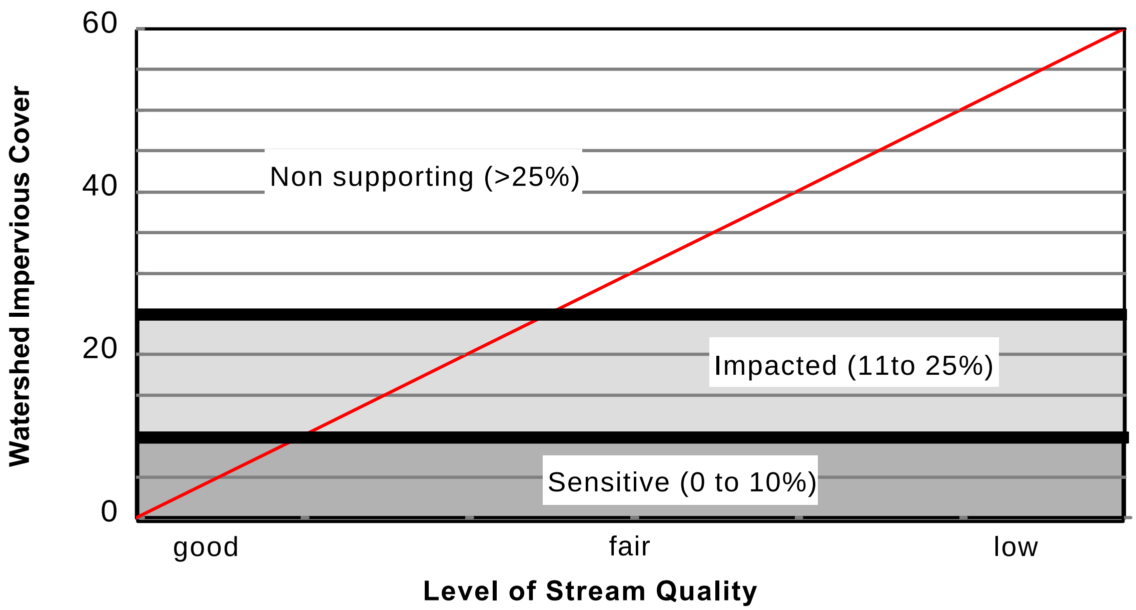
Figure 4-10. Relationship Between Urban Storm Water and Aquatic Ecosystems



Source: Adapted from Masterson and Bannerman, 1994

Schueler and Claytor (1995) also suggest a direct relationship between watershed imperviousness and stream health (Figure 4-11), and found that stream health impacts tend to begin in watersheds with only 10-20 percent imperviousness (the ten percent threshold). As shown, sensitive streams can exist relatively unaffected by urban storm water with good levels of stream quality where impervious cover is less than 10 percent although some sensitive streams have been observed to experience water quality impacts at as low as 5 percent imperviousness. Impacted streams are threatened and exhibit physical habitat changes (erosion and channel widening) and decreasing water quality where impervious cover is in the range of 10 to 25 percent. Streams in watersheds where the impervious cover exceeds 25 percent are typically degraded, have a low level of stream quality, and do not support a rich aquatic community.

Figure 4-11. Relationship Between Impervious Cover and Stream Quality



Source: Schueler and Claytor, 1995

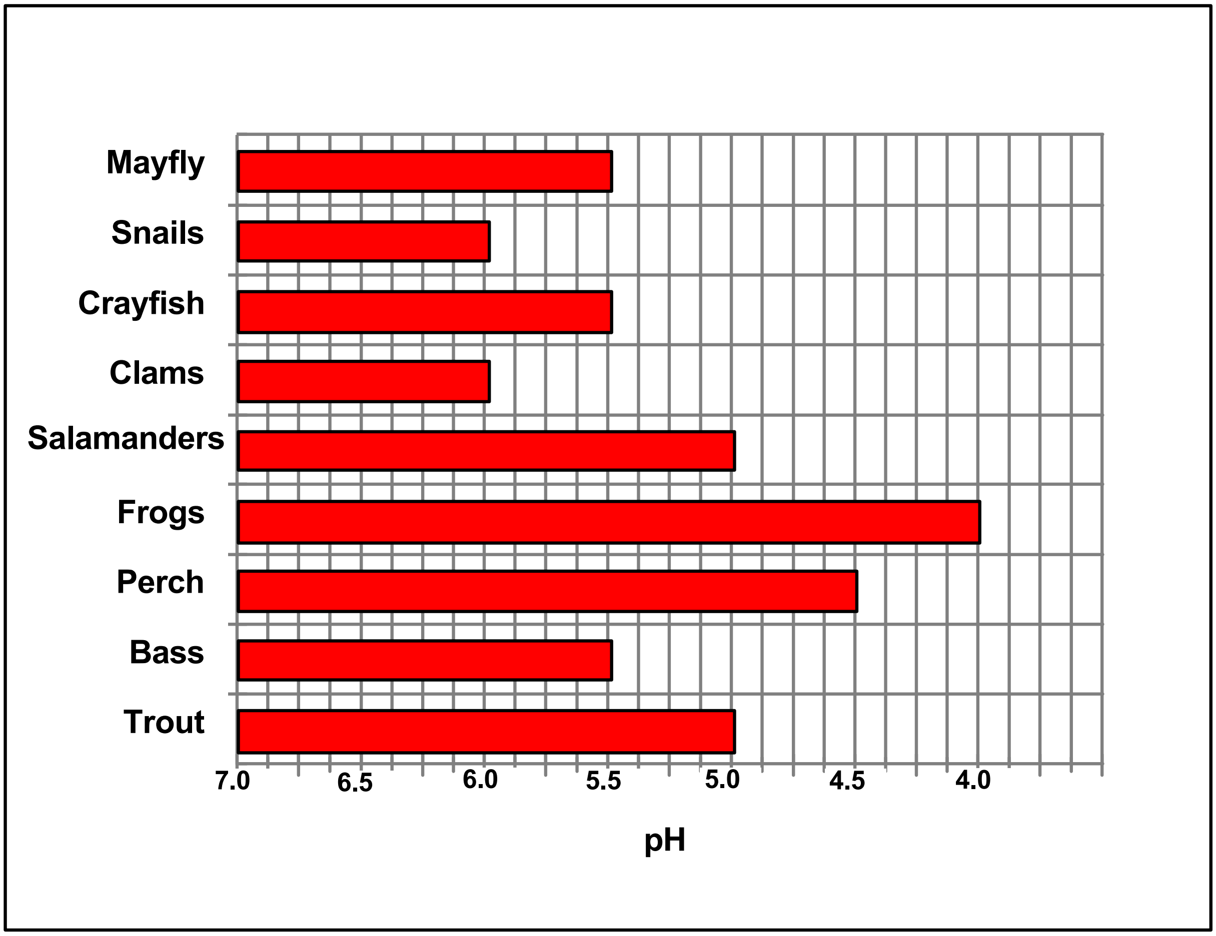
A summary of water quality impacts on habitat is presented in Table 4-14. The alteration of species distribution is the major impact, with pollutant tolerant and less sensitive species replacing native species in storm water impacted receiving waters.

Table 4-14. Water Quality Parameters Affecting Habitat

Water Quality Parameter	Habitat Effect
Bacteria	Contamination
Heavy metals	Alteration of species distribution
Toxic organics	Alteration of species distribution
Nutrients	Eutrophication, algal blooms
Sediment	Decreased spawning areas
BOD	Reduced dissolved oxygen levels
Temperature	Reduced dissolved oxygen levels
pH	Alteration of species distribution

Figure 4-12 illustrates that the pH tolerance of various forms of aquatic life varies substantially (US EPA, 1992b). The tolerance of aquatic life to changes in temperature, turbidity and toxic substances is also very important. Contaminants like heavy metals, pesticides, and hydrocarbons can alter the species distribution in receiving waters. Acute and chronic toxicity impacts may also occur. The relative toxicity of storm water samples from a variety of loading source areas is presented in Table 4-15. Some of the identified chronic toxicity effects are decreased growth and respiration rates (US EPA, 1996a). Toxic loads can reduce the hatching and survival rates of aquatic organisms, cause gross effects such as lesions or fin erosion in fish, and can eventually destroy the entire population of some sensitive species (Novotny and Olem, 1994). Hydrocarbons can be especially detrimental to benthic organisms because they can become bound to urban runoff sediments (Schueler, 1987).

Figure 4-12. Low pH Tolerance by Different Species



Source: EPA, 1992b

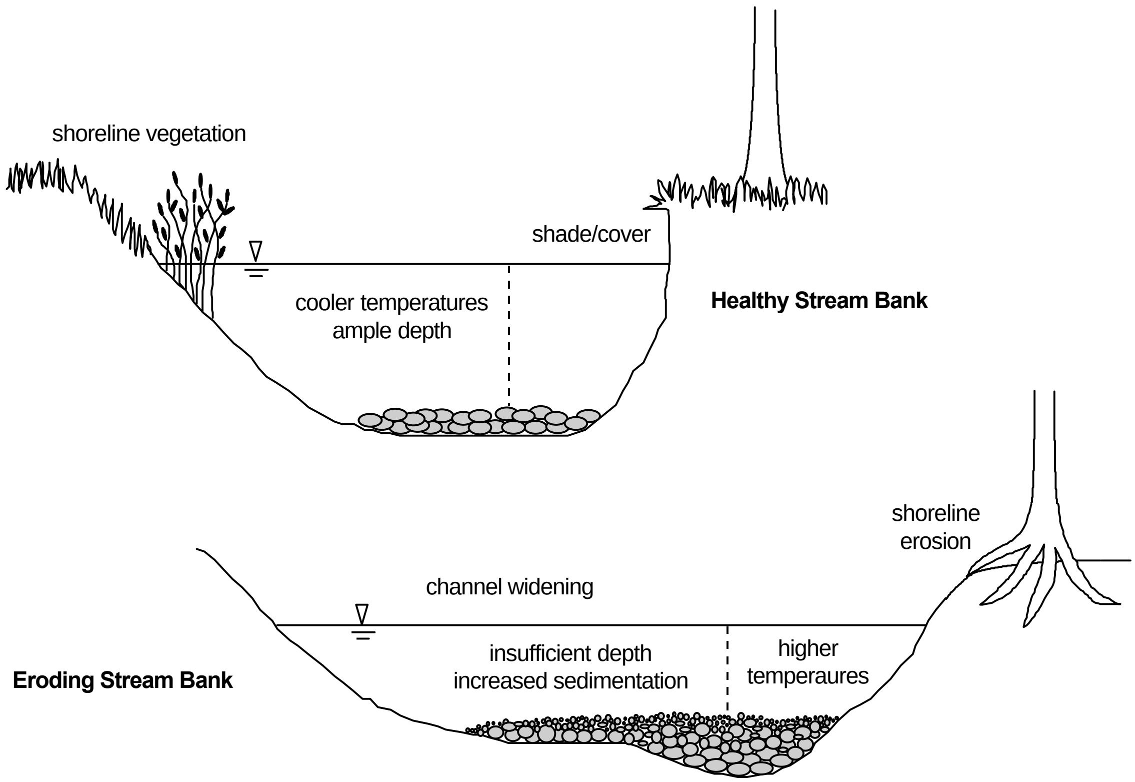
Table 4-15. Relative Toxicities of Samples Using Microtox® Measurement Method

Local Source Areas	Highly Toxic (%)	Moderately Toxic (%)	Not Toxic (%)
Roofs	8	58	33
Parking areas	19	31	50
Storage areas	25	50	25
Streets	0	67	33
Loading docks	0	67	33
Vehicle service areas	0	40	60
Landscaped areas	17	17	66
Urban creeks	0	11	89
Detention ponds	8	8	84
All source areas	9	32	59

Note: Microtox® results are primarily for comparison purposes.
Source: Pitt et al, 1995.

The physical impacts to streams due to urbanization and changes in watershed hydrology also cause many habitat changes. As illustrated in the comparison of healthy and eroding stream banks in Figure 4-13, loss of depth, sediment deposition, loss of shoreline vegetation, and higher temperatures combine to impact habitat.

Figure 4-13. Comparison of a Healthy Stream Bank and an Eroding Bank



Source: Adapted from Corish, 1995

Schueler (1987) states that sediment pollution in the form of increased suspended solids can cause the following harmful impacts to aquatic life:

- Increased turbidity
- Decreased light penetration
- Reduced prey capture for sight feeding predators
- Clogging of gills/filters of fish and aquatic invertebrates
- Reduced spawning and juvenile fish survival.

Sediment is also a carrier of metals and other pollutants, and a source of bioaccumulating pollutants for bottom feeding organisms. The rate of bioaccumulation is widely variable based upon site specific conditions including species, concentration, pH, temperature, and other factors. Barron (1995) reports that the bioaccumulation of organic contaminants results primarily from direct exposure to water and sediment rather than through the food chain.

Macroinvertebrate Impacts

The biological integrity of receiving waters impacted by urban storm water is typically reduced from more pristine, undeveloped circumstances. Impacts include a reduction in total numbers and diversity of macroinvertebrates, and the emergence of more pollutant-tolerant species. In a study in Delaware, it was found that approximately 70 percent of the macroinvertebrate community in streams in undeveloped, forested watersheds consisted of pollution sensitive mayflies, stoneflies and caddisflies, as compared with 20 percent in urbanized watersheds (Maxted and Shaver, 1997). As shown in Table 4-16, the relative abundance of pollution tolerant organisms increased with urbanization, including worms, midges and beetles.

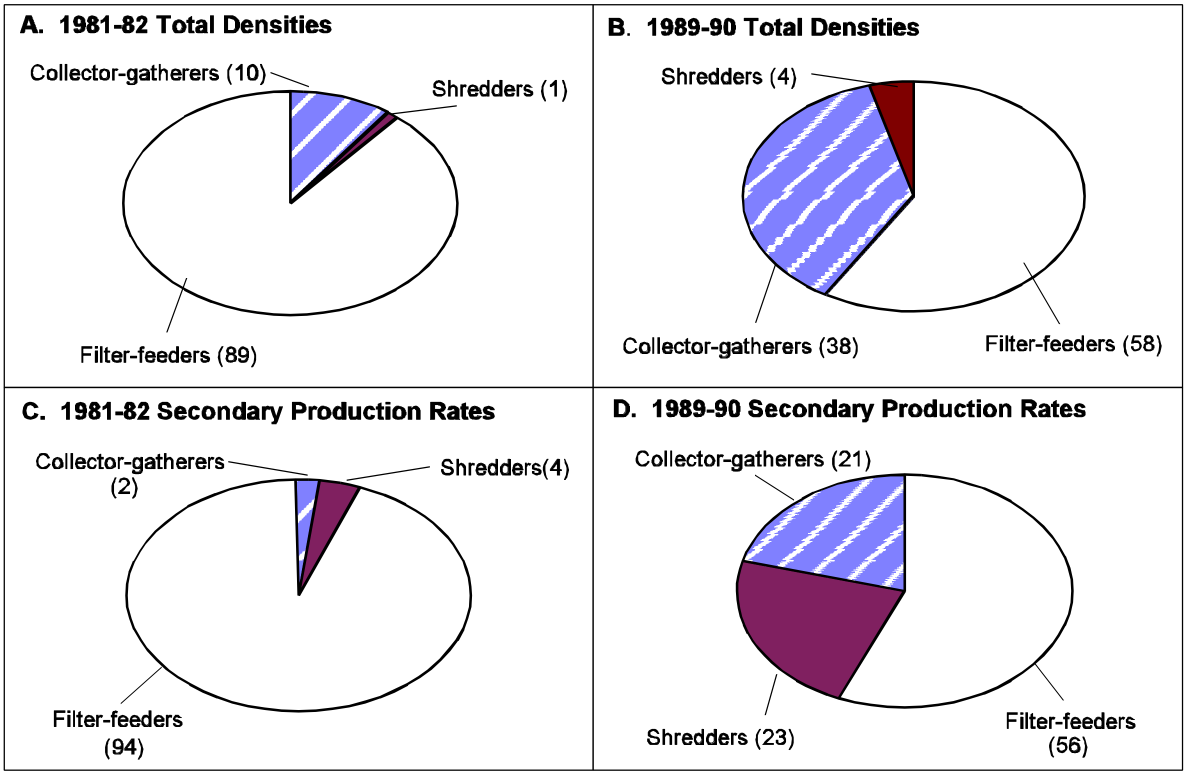
Table 4-16. Delaware Insect Population Abundance by Degree of Urbanization

Population Description				Relative Abundance by Degree of Urbanization (%)		
Class/ Order	**Genus species**	**Common Name**	**PT**	**None**	**Low**	**High**
Insecta/Trichoptera	Diplectrona modesta	caddisfly	0	14	2	1
Insecta/Ephemeroptera	Ephemerella spp.	mayfly	1	12	1	0
Insecta/Plecoptera	Allocapnia spp.	stonefly	3	10	18	3
Insecta/Ephemeroptera	Eurylophella spp.	mayfly	1	8	1	2
Insecta/Coleoptera	Anchytarsus bicolor	beetle	4	6	3	0
Insecta/Ephemeroptera	Stenonema spp.	mayfly	4	5	3	1
Insecta/Coleoptera	Optiservus spp.	beetle	4	4	2	8
Insecta/Coleoptera	Oulimnius latiusculus	beetle	2	4	3	5
Insecta/Trichoptera	Cheumatopsyche spp.	caddisfly	5	1	10	8
Insecta/Trichoptera	Hydropsyche betteni	caddisfly	6	1	4	5
Insecta/Diptera	Simulium vittatum	blackfly	7	0	8	1
Insecta/Diptera	Parametriocnemus spp.	midge	5	0	0	4
Oligochaeta	unidentified (Tubificidae)	worm	10	0	0	4

Note: rare organisms (fewer than 4 per 100 organisms) not included. Relative abundance (%) and pollution tolerance (PT) of macroinvertebrate species commonly found in Piedmont streams of Delaware for three levels of urbanization; none (0-2% impervious cover), low (6-13%), and high (15-50%); PT range from 0 (low tolerance) to 10 (high tolerance).
Source: Maxted and Shaver, 1997.

A study by Kohlepp and Hellenthal (1992) quantified the effects of sediment deposits on macroinvertebrates in Juday Creek, a tributary to the St. Joseph River in Indiana. The study included data before and after upstream channel maintenance operations introduced a large amount of sediment to the creek, similar to increased sediment yield from urban areas. A dramatic change in the species distribution of macroinvertebrates in the river was observed, and this was attributed to the changing sediment load and increased sedimentation. As shown in Figure 4-14, "the result was a shift from a community dominated by filter-feeders in both numbers and production rate in 1981-82, to a community in 1989-90 in which less desirable collector-gatherers and shredders increased in importance in terms of relative contribution to both numbers and production."

Figure 4-14. Effects of Sediment Deposits on Macroinvertebrates in Juday Creek, Indiana Proportion by Functional Feeding Group (percent)



Source: Kohlepp and Hellenthal, 1992

Fish Impacts

The health of an ecosystem is often measured by the abundance and variety of fish species present, and the presence of native species. A case study in California compared fish populations in urbanized and non-urbanized sections of Coyote Creek (Pitt, 1995). The relative abundance of different fish species in the different reaches is presented in Table 4-17. As shown, the native fish are generally replaced by introduced fish in the urbanized section.

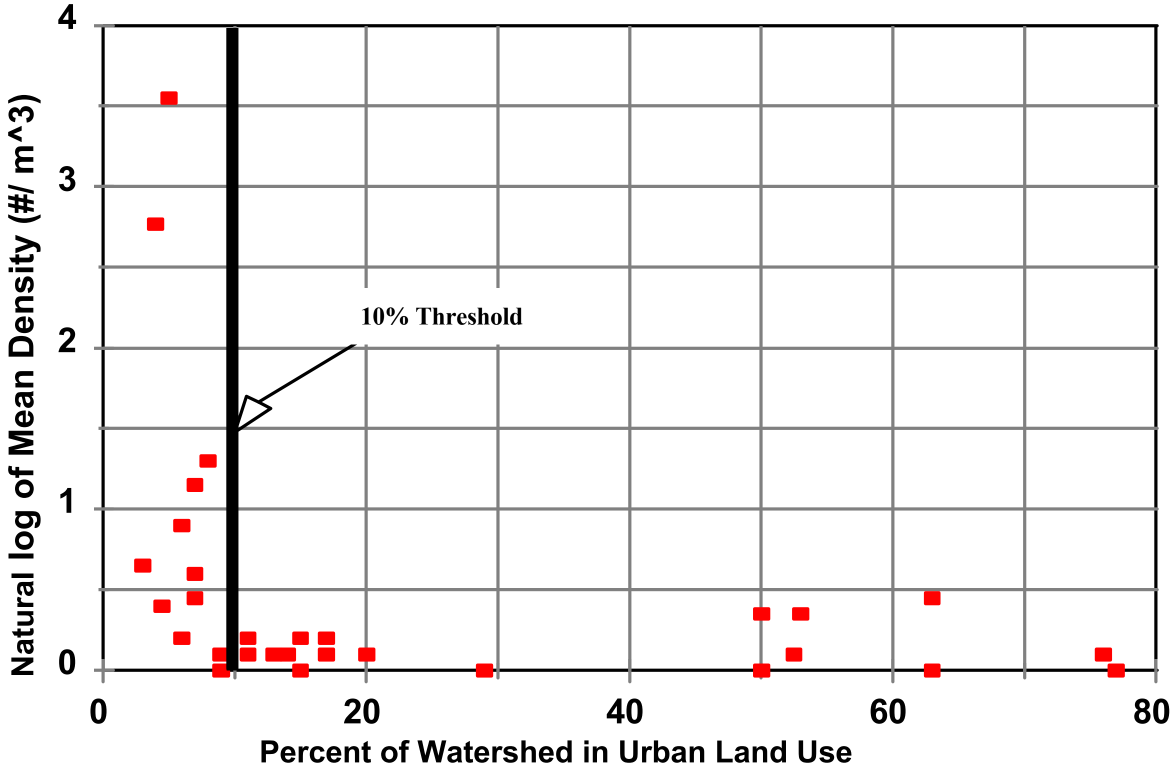
Table 4-17. Relative Abundance of Native and Introduced Fish in Urbanized and Non-Urbanized Areas in Coyote Creek, California

Species	Relative Abundance (%)	
	Non-urbanized Reach	**Urbanized Reach**
Native Fish		
Hitch	34.8	4.8
Threespine stickleback	27.3	0.8
Sacramento sucker	12.6	0.1
Introduced Fish		
Mosquitofish	5.6	66.9
Fathead Minnow	0.6	20.6
Threadfin shad	-	2.4

Source: Pitt, 1995

An illustration of the abundance of fish eggs and larvae associated with different levels of urban land use in New York is presented in Figure 4-15 (Limburg and Schmidt, 1990). This graph supports the "10 percent rule" reported by Schueler and Claytor (1995): stream impacts tend to begin in watersheds with only 10 to 20 percent imperviousness.

Figure 4-15. Average Densities of Fish Eggs and Larvae in New York



Source: Limburg and Schmidt, 1990

The change in the resident fish community due to urbanization in Tuckahoe Creek in Virginia was quantified by Weaver and Garman (1994). With urbanization increasing the percent of urban land from 7 percent to 28 percent between 1958 and 1990, a dramatic change in the fish assemblage was observed. As shown in Table 4-18, the total number of fish observed dropped sharply along with the total number of species present and the number of common species present.

Table 4-18. Effects of Urbanization on the Fish Community of Tuckahoe Creek, Virginia (Composite of 6 Sites)

Indicator	Fish Assemblage Year	
	1958	1990
% Urban (by land area)	7	28
total abundance	2,056	412
# species - total	31	23
# species - common*	21	6
% bluegill/shiner	28	67

* more than 10 individuals
Source: Weaver and Garman, 1994

4.3.3 Public Health Impacts

Public health impacts associated with urban storm water occur when humans ingest or come in contact with pathogens. While these impacts are not widely reported, they do occur, and some impacts have been documented. Examples related to swimming and contact recreation impacts and shellfish impacts are presented.

Contact Recreation Impacts

Beach closures are a common occurrence in many communities throughout the United States. Beach closures are primarily due to high levels of bacteria in water samples. The presence of medical waste and other dangerous floatable substances on beaches can also cause beach closures to occur. Storm water runoff can be responsible for both bacteria and floatables. Elevated levels of bacteria and viruses represent the most common threat to public health. Diarrhea and infection of the ear, eye, nose, or throat are possible.

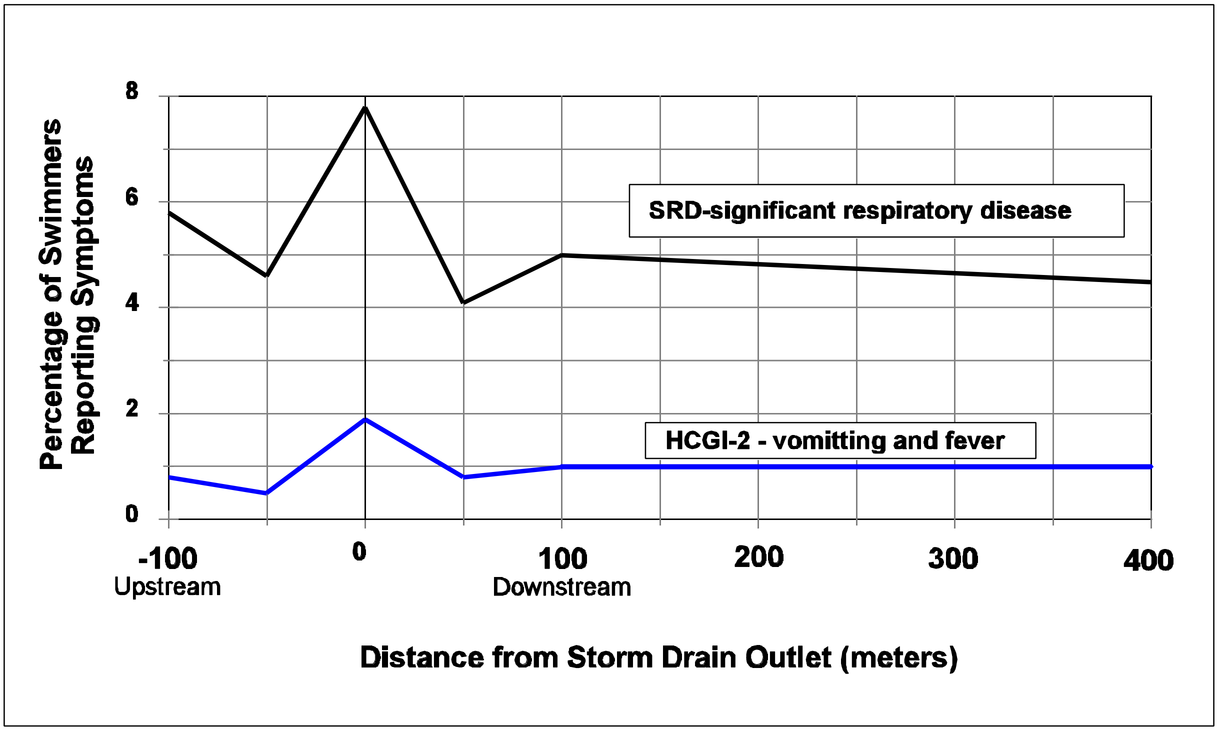
A study of epidemiological impacts associated with swimming in the vicinity of storm water outfalls in Santa Monica Bay in California was conducted in 1995 (SMBRP, 1996). The study focused on health effects, and not on possible sources of contamination to the storm drain system, such as illicit sewage connections and infiltration.[1] While the effects observed may be atypical of properly constructed and maintained storm drain outfalls, the findings indicate the potential health risks associated with pathogens. Major findings of this study are as follows:

- There is an increased risk of illness associated with swimming near flowing storm drain outlets in Santa Monica Bay.
- There is an increased risk of illness associated with swimming in areas with high densities of bacterial indicators.
- The total coliform to fecal coliform ratio was found to be one of the better indicators for predicting health risks.
- Illnesses were reported more often on days when the samples were positive for enteric viruses.
- High densities of bacterial indicators were measured on a significant number of survey days, particularly in front of drains.

People who swim in areas adjacent to flowing storm drains were found to be 50 percent more likely to get sick than people who swam in other areas. The sicknesses included fever, nausea, gastroenteritis, and flu-like symptoms such as nasal congestion, sore throat, fever, or coughing. As illustrated in Figure 4-16, swimmers who swam directly in front of storm drains were much more likely to become ill than those who swam away from the storm drains at distances of 100 to 400 meters. A comparative health outcome in terms of relative risk for swimming in front of the storm drain vs. swimming 400 meters away is presented in Table 4-19.

[1] Pilot studies conducted in the Bay prior to 1995 noted that some outfalls had regular dry weather discharges; this is a common indicator of storm drain contamination (SMBRP, 1990; SMBRP, 1992).

Figure 4-16. Health Effects Observed Relative to Distance from Santa Monica Bay Storm Drains



Source: Santa Monica Bay Restoration Project, 1996

Table 4-19. Comparative Health Outcomes for Swimming in Front of Drains in Santa Monica Bay

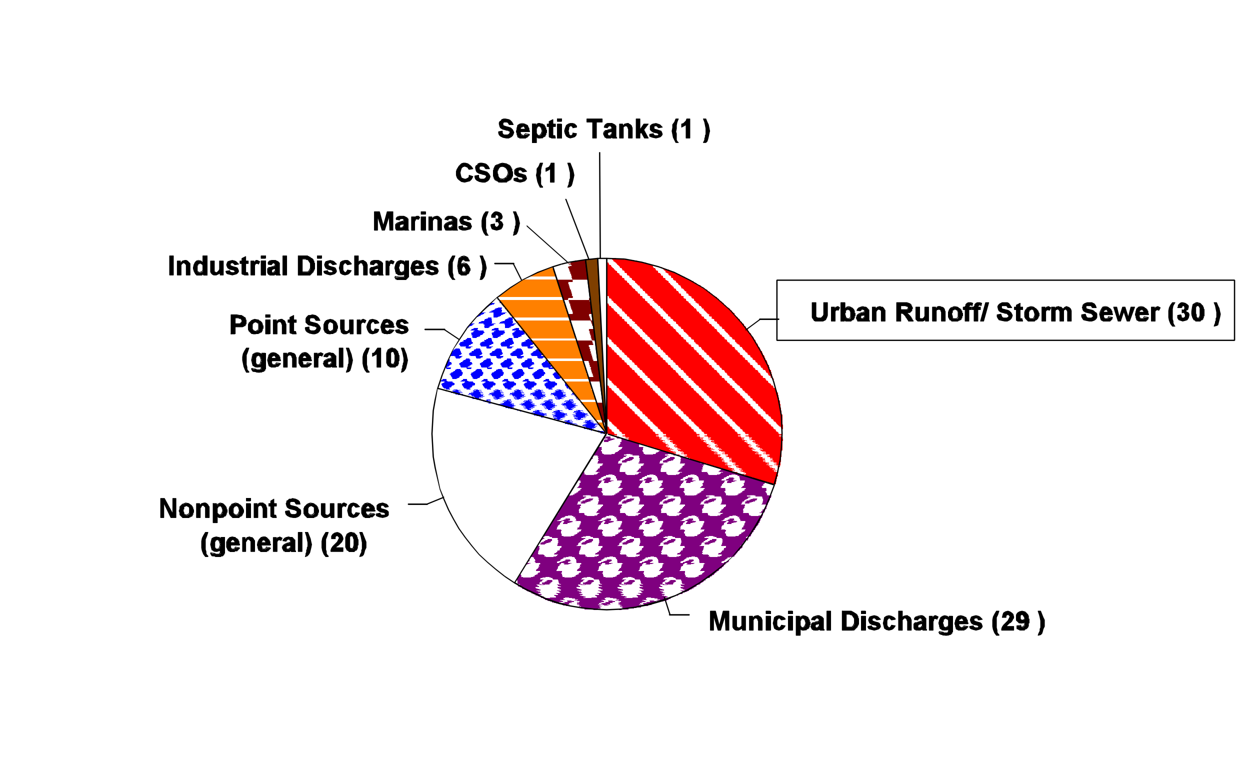
Health Outcome	Relative Risk for Swimming in Front of Drains*	Estimated No. Of Excess Cases per 10,000 Persons
Fever	57%	259
Chills	58%	138
Ear Discharge	127%	88
Vomiting	61%	115
Coughing with phlegm	59%	175
Any of the above symptoms	44%	373
HCGI-2	111%	95
SRD	66%	303
HCGI-2 or SRD	53%	314

* Compared to swimming 400 meters or more away from drains
Source: Santa Monica Bay Restoration Project, 1996

Seafood Hazard

The consumption of contaminated seafood, particularly shellfish, is a major public health problem. Shellfish are susceptible to bioaccumulating bacteria and viruses because they are filter feeders. In waters polluted by urban runoff, bacteria and viruses can be concentrated in the shellfish to much higher levels than those found in the surrounding waters. This becomes a public health concern because many potentially harmful bacteria and viruses can be ingested when people eat contaminated shellfish. As shown in Figure 4-17, the largest proportion of shellfish harvesting restrictions are caused by urban runoff (US EPA, 1995a).

Figure 4-17. Sources Associated with Shellfish Harvesting Restrictions, in Percent



Source: US EPA, 1995a

Fish can also be contaminated for a number of reasons. Recent fish sampling surveys in regions of the U.S. have shown widespread mercury contamination in streams, wetlands, reservoirs, and lakes. Based on 1997 data, 33 states have issued fish consumption advisories because of mercury contamination (US EPA, 1998a). Mercury is an urban/industrial pollutant that is released into the air and ends up in urban runoff by atmospheric deposition (Krabbenhoft and Rickert, 1995). The effects of fish contamination go beyond health issues, and hurt the recreational fishing industry as a whole.

4.3.4 Aesthetic Impacts

The aesthetic impacts associated with urban storm water are often difficult to quantify. However, aesthetic impacts are often very visible to the general public. EPA reports that "people have a strong emotional attachment to water, arising from its aesthetic qualities--tranquillity, coolness, and beauty" (US EPA, 1995c). The presence of floatables within urban waters and deposited along the banks of waterways represents a common aesthetic impact in most urban settings. Floatable wastes originate from street litter and improper solid waste disposal practices. The average total street debris loading rate in New York City was quantified at approximately 156 pounds per curb-mile per day, with a range from 3 to 2,700 pounds (HydroQual, 1995).

Aesthetic impacts from the eutrophication of urban waterways is caused in part by nutrients delivered in urban storm water. As reported by Schueler (1987), aesthetic impacts and nuisance conditions associated with eutrophication can include:

- Surface algal scum
- Water discoloration
- Strong odors
- Release of toxins.

The visual damage to urban streams from accelerated rates of storm water runoff also contribute to aesthetic impacts. These include eroded stream banks, fallen trees, and sedimentation. In summary, aesthetic impacts are often very visible in public areas where shoreline recreation occurs. Aesthetic impacts are therefore the storm water impacts most familiar to the general public.

Ottawa. ON
Paris. ON
Gatineau. QC
Montréal. QC
Québec. QC

Attachment B

Excerpt from “Evaluation of Roadside Ditches and Other Related Stormwater Management Practices”, prepared for TRCA by JFSA, April 1997

Curb & gutter with catch basins and filtration system

Curb & gutter with catch basins and exfiltration system

1.3.2 Curb & gutter with catchbasins and exfiltration system (Figure 1.5)

Examples of this alternative drainage system, which is intended for use in areas of granular soils, were recently constructed in the City of Etobicoke. From above ground, the system appears to be similar to the conventional curb and gutter with storm sewer system.

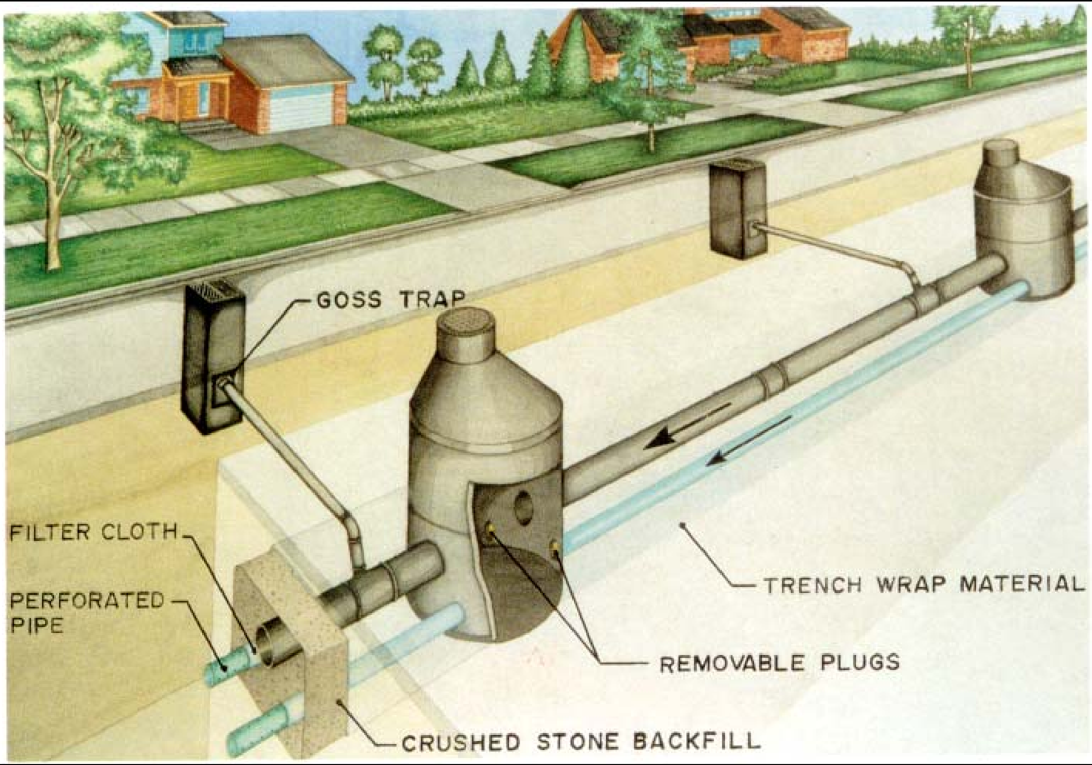


Figure 1.5:: Typical curb & gutter drainage system with catchbasins and exfiltration trenches
Source: Environmental Science & Engineering, March 1994

How the system works: Surface runoff enters the local catchbasins which are connected to a standard design storm sewer. When the water reaches the next downstream manhole the flow drops into two perforated pipes which are installed along and under the standard storm sewer. The perforated pipes are plugged at the downstream end. From the perforated pipes, the water is exfiltrated into the stone filled trench and from there seeps into the surrounding native soil. When the flow exceeds the exfiltration capacity of the perforated pipes, the water surcharges and the flow continues in the standard storm sewer located above. The process is then repeated in the next downstream pipe section.

This system can basically provide the same level of service as the conventional curb and gutter with storm sewer system but due to the nature of its innovative underground piping concept, the system can also provide significant water quality control, groundwater recharge and erosion control benefits.

1.3.3 Curb & gutter with catchbasins and filtration system (Figure 1.6)

Examples of this alternative drainage system which is suitable for use in areas where the soils are impervious or with low infiltration rates were recently constructed in the City of Etobicoke. From above ground, the system is similar to the conventional curb and gutter with storm sewer system.

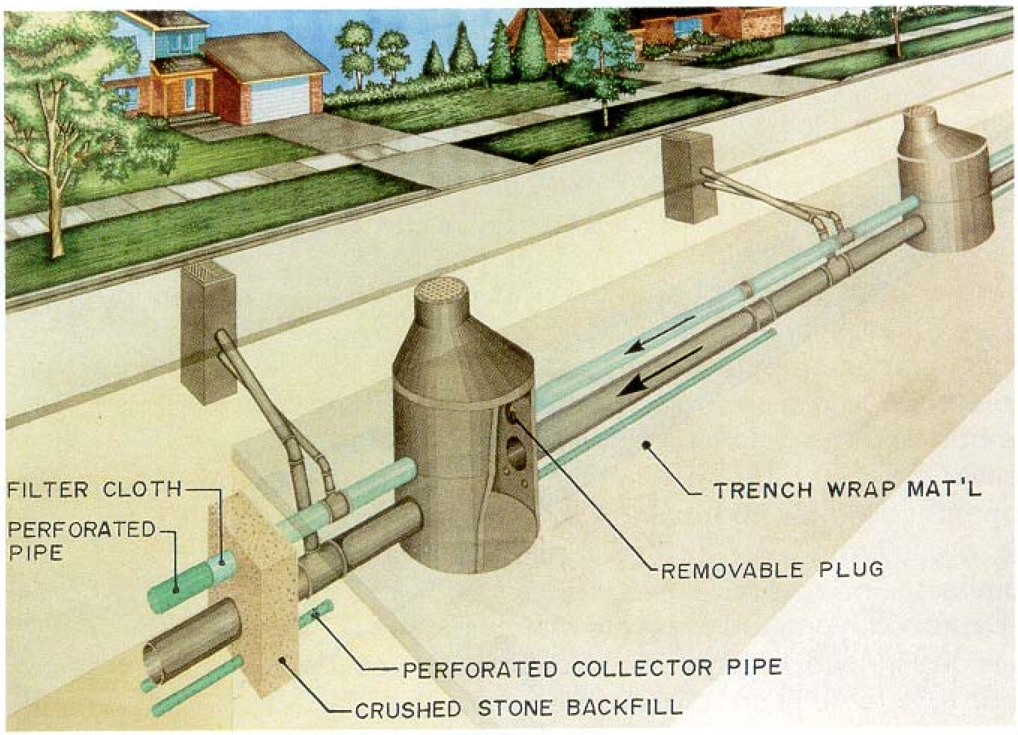


Figure 1.6: Typical curb & gutter drainage system with catchbasins and filtration trenches
Source: Environmental Science & Engineering, March 1994

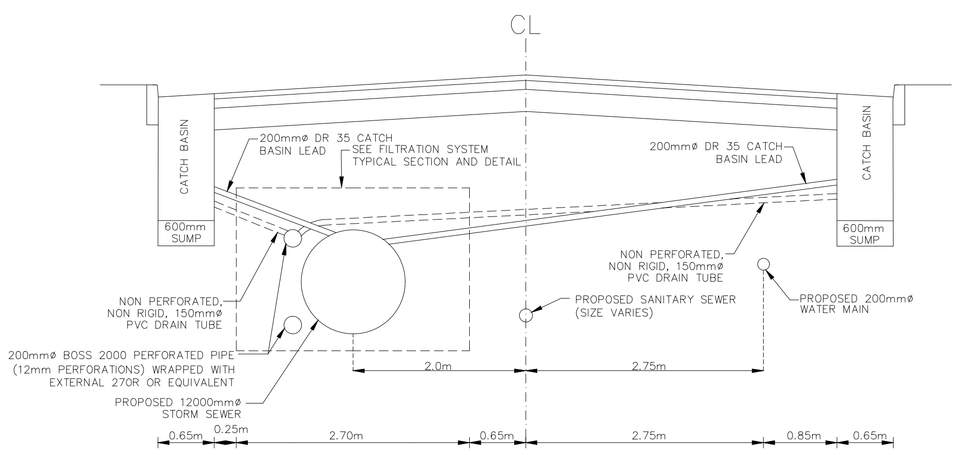
How the system works: Storm runoff is filtered through a perforated pipe into a stone filled trench and the water is collected again at the bottom of the trench by a smaller perforated foundation drain pipe which discharges back into the storm sewer system at the next downstream manhole. To accomplish this, the catchbasins have two leads arranged vertically where the lower lead is connected to the perforated pipe and the higher lead is connected to the standard storm sewer.

This system can basically provide the same level of service as the conventional curb and gutter with storm sewer system but it is expected that the filtration component of the system will provide some water quality control (eg. removal of suspended sediments) and because of its water retention characteristics, the system can also provide some erosion control benefits.

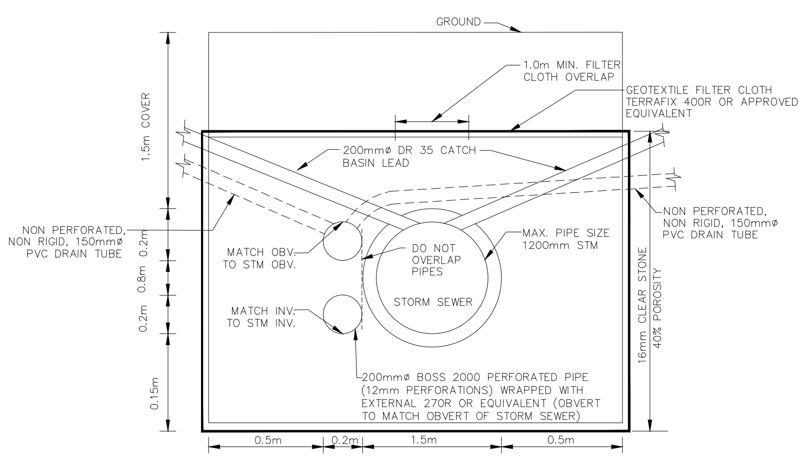
Ottawa. ON
Paris. ON
Gatineau. QC
Montréal. QC
Québec. QC

Attachment C

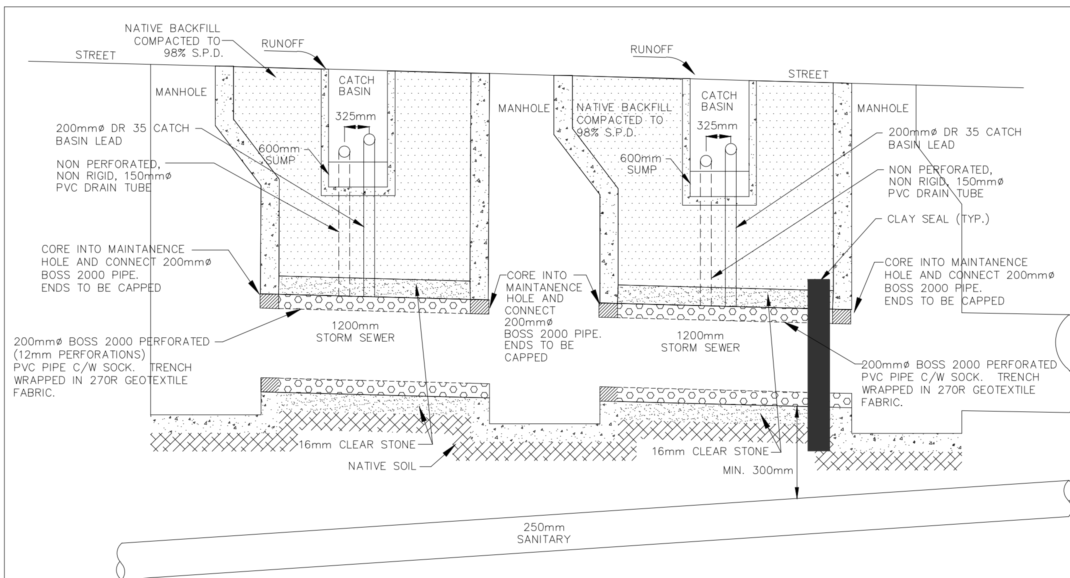
Proposed Modified Etobicoke Filtration System for the BCDC Developments



FILTRATION SYSTEM
LOCATION CROSS SECTION (TYP)
N.T.S.

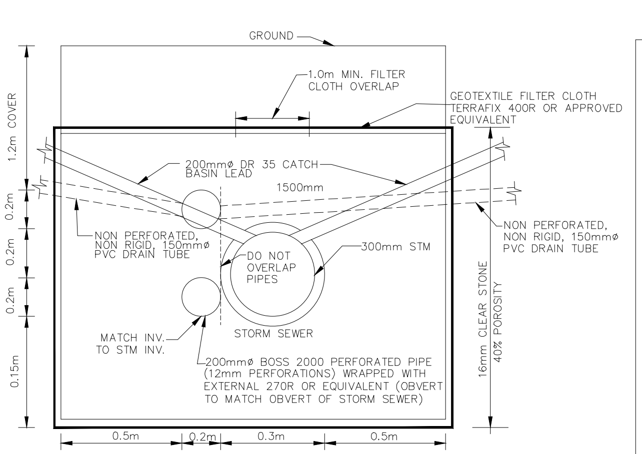


FILTRATION SYSTEM DETAIL
TYPICAL SECTION
N.T.S.



FILTRATION SYSTEM DETAIL
TYPICAL PROFILE
N.T.S.

SCENARIO 1 – DOWNSTREAM



FILTRATION SYSTEM DETAIL
TYPICAL SECTION
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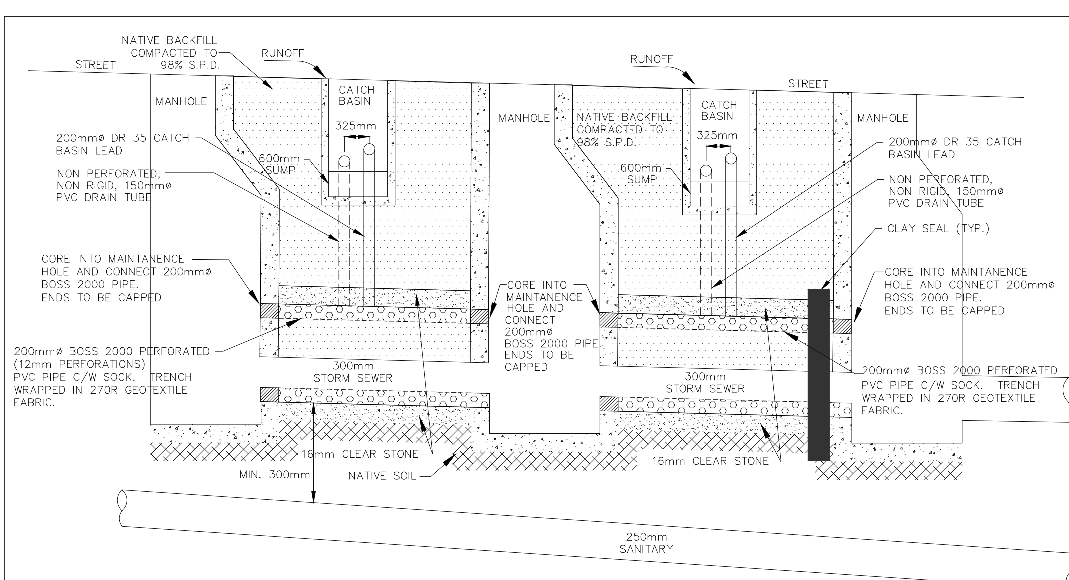

FILTRATION SYSTEM DETAIL
TYPICAL PROFILE
N.T.S.

SCENARIO 2 – UPSTREAM