# SOURCE AND ON-SITE CONTROLS FOR MUNICIPAL DRAINAGE SYSTEMS

## A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide
to Sustainable
Municipal
Infrastructure

Guide national pour
des infrastructures
municipales
durables

Canada

NRC · CNRC

Federation
of Canadian
Municipalities

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canadienne des
municipalités

*Source and On-Site Controls for Municipal Drainage Systems*
Issue No.: 1.0
Date: March 2003

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# FOREWORD

In spite of recent increases in public infrastructure investments, municipal infrastructure is decaying faster than it is being renewed. Factors such as low funding, population growth, tighter health and environmental requirements, poor quality control leading to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, construction and operation practices have impacted on municipal infrastructure. At the same time, an increased burden on infrastructure due to significant growth in some sectors tends to quicken the ageing process while increasing the social and monetary cost of service disruptions due to maintenance, repairs or replacement.

With the intention of facing these challenges and opportunities, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) have joined forces to deliver the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. The Guide project, funded by the Infrastructure Canada program, NRC, and through in-kind contributions from public and private municipal infrastructure stakeholders, aims to provide a decision-making and investment planning tool as well as a compendium of technical best practices. It provides a road map to the best available knowledge and solutions for addressing infrastructure issues. It is also a focal point for the Canadian network of practitioners, researchers and municipal governments focused on infrastructure operations and maintenance.

The *National Guide to Sustainable Municipal Infrastructure* offers the opportunity to consolidate the vast body of existing knowledge and shape it into best practices that can be used by decision makers and technical personnel in the public and private sectors. It provides instruments to help municipalities identify needs, evaluate solutions, and plan long-term, sustainable strategies for improved infrastructure performance at the best available cost with the least environmental impact. The five initial target areas of the Guide are: potable water systems (production and distribution), storm and wastewater systems (collection, treatment, disposal), municipal roads and sidewalks, environmental protocols and decision making and investment planning.

Part A of the *National Guide to Sustainable Municipal Infrastructure* focuses on decision-making and investment planning issues related to municipal infrastructure. Part B is a compendium of technical best practices and is qualitatively distinct from Part A. Among the most significant of its distinctions is the group of practitioners for which it is intended. Part A, or the decision making and investment planning component of the Guide, is intended to support the practices and efforts of elected officials and senior administrative and management staff in municipalities throughout Canada.

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments and suggestions from various stakeholder groups, which shaped the enclosed document. Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g. geographic location, municipality size, climatic condition).

For additional information or to provide comments and feedback, please visit the Guide at <www.infraguide.gc.ca> or contact the Guide team at infraguide@nrc.ca.

# ACKNOWLEDGEMENTS

The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure* is acknowledged and much appreciated.

This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide's Storm and Wastewater Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and by SNC-Lavalin inc., in association with Aquapraxis inc.

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This and other best practices could not have been developed without the leadership and guidance of the Project Steering Committee and the Technical Steering Committee of *the National Guide to Sustainable Municipal Infrastructure*, whose memberships are as follows:

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# EXECUTIVE SUMMARY

In the past, water management activities have often been based on singular practices that addressed individual needs and crises. In later years, there has been an evolution to multiple objective programs that manage water supply and conservation, with preservation of surface water and natural systems being a main objective. The continued growth of the population and the hydrologic impact of urbanization demand that we take a holistic approach in water resources planning and management to support our quality of life.

As stormwater run-off can cause or accentuate flooding, and is a major source of pollution to our wetlands, rivers, lakes, and estuaries, local governments must take responsibility for its appropriate control. An understanding of the origin and causes of non-point source pollution is essential to the development of comprehensive and efficient practices and measures to control the negative impacts of urban development. These measures should be integrated into multiple objective programs to ensure watershed goals are co-operatively met. Such programs will fall under provincial/regional water policies and by-laws and should be consistent with comprehensive short- and long-term objectives.

This document provides a brief overview of the rationale behind stormwater management programs and explains why implementing run-off controls is important in a sustainable development context. Using the concept of a treatment train, five different levels of control are defined: pollution prevention planning, source control, on-site control, conveyance control, and end-of-pipe control. This best practice addresses the second and third levels.

**Source controls** are measures designed to minimize the generation of, and entry of pollutants into, stormwater run-off, with emphasis on non-structural and semi-structural measures applied at or near source. **On-site (or lot-level) controls** are practices that reduce run-off volumes and/or treat stormwater before it reaches a municipal conveyance system. These controls can be either structural or non-structural in nature and applied at the individual lot level or on multiple lots that drain a small area. Typically, these techniques would be implemented on individual dwelling lots or for small commercial/industrial lots.

The negative impacts of increased stormwater runoff are classified by their effects on *water quality, stream channel morphology, localized flooding and the hydrologic cycle*. Historically, only the flooding (quantitative) aspect has been used as a main design objective but it is now recognized that criteria with a larger perspective are necessary in a sustainable development context. Criteria for each of these aspects are therefore discussed in order to provide a good overview of the different elements that should ideally be included in a stormwater control plan.

Although some of the techniques can be applied to a wide range of situations, different elements must be considered to select appropriate practices. These include the physical suitability of the site, the stormwater benefits provided, the pollutant removal benefits and the environmental amenities. A detailed description of the different practices is given, with appropriate design criteria in each case. A general approach to implement the different techniques is also provided, with a flow chart to aid in the overall stormwater analysis.

The degree of effectiveness of the different controls, and costs and operation/maintenance issues are also discussed, as they are essential elements in the decision-making process. As far as possible, design aspects and references related to cold climate conditions are highlighted to reflect a Canadian perspective.

# 1. GENERAL

## 1.1 INTRODUCTION

It is widely recognized that rapid urbanization affects water quality in receiving water bodies and run-off quantity, thereby producing significant environmental and hydrologic changes that can impact streams, receiving waters, and their habitats. As an area develops, undisturbed pervious surfaces become impervious with the construction of parking lots, buildings, homes, streets, and other structures. These impervious surfaces produce an increase in stormwater run-off, both quantitatively (discharges rates and volumes) and qualitatively (pollutants associated with run-off). These changes disrupt the natural balance of physical, chemical, and biological processes, cause pollution in natural systems, result in soil erosion that creates damage downstream and reduce the infiltration of water into the ground. In addition, the increase in run-off discharge through existing drainage systems may cause or aggravate flooding which is, arguably, the most visible (and usually the most acted upon) of the negative impacts.

To address stormwater management objectives, stormwater run-off considerations need to be integrated fully into the site planning and design processes. This involves a more comprehensive approach to site planning and a thorough understanding of the physical characteristics and resources of the site. This approach, normally called “integrated stormwater management planning”, treats stormwater as a resource to be protected and sees protection of property, protection of aquatic resources, and protection of water quality as complementary objectives. Ideally, stormwater is managed on a watershed basis, within the broad framework of land management and ecosystem planning or, at least, within a master drainage plan. This planning should be based on a hierarchy of principles which include pollution prevention, source controls, on-site (or lot-level) controls, conveyance controls, and end-of-pipe management practices.

## 1.2 SCOPE

This best practice is part of a wider project that will lead to the development of the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. It is one aspect of more than 50 that have been identified by the Guide Storm and Wastewater Technical Committee relating to linear infrastructure, wastewater treatment, customer interaction, and receiving water issues. Links with other best practices developed during the first round of the Guide are limited at this stage. These links will become more integrated as further rounds are completed.

The rationale to implement source and on-site controls is first presented, along with criteria for selecting the most appropriate measures and techniques depending on the site and watershed characteristics. A description of methodologies and technologies for source and on-site controls is then given, based on available and tested approaches. The degree of effectiveness for the different controls, and costs and operation/maintenance issues are also presented, as they are essential elements in the decision-making process. As far as possible, design aspects and references related to cold climate conditions are highlighted to reflect a Canadian perspective.

Beginning with pollution prevention, which should be the first logical step in the treatment train, this document discusses the lower levels of controls (source and on-site controls). These are typically applied to sites with a drainage area less than 5 ha and are generally more cost effective than the conveyance and end-of-pipe controls.

This best practice is not intended to be a design manual or guide for implementing a stormwater management system, with detailed technical information and design criteria. A number of such guides and manuals are already available for that purpose, and relevant information in existing documents is referenced as appropriate. Many documents developed specifically for Canadian conditions by different provinces or cities are available on the Internet, and it is easy to download and use the appropriate and up-to-date information.

## 1.3 GLOSSARY

As the terminology on stormwater source controls is not standardized and this term is used differently by various drainage professionals (Marsalek et al., 2001), it is worthwhile to define more precisely some fundamental terminology.

**Aesthetics (as a water quality parameter) —** All surface waters should be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances; produce objectionable odour, colour, taste, or turbidity; or produce undesirable or nuisance species of aquatic life.

**Biochemical oxygen demand (BOD) —** The quantity of oxygen consumed, expressed in milligrams per liter, during the biochemical oxidation of matter over a specified period at a temperature of 20° C (see also COD).

**Best Management Practices (BMP) —** See stormwater management.

**Buffer strips —** A zone of variable width located along both sides of a natural feature (e.g., stream or forested area) and designed to provide a protective area along a corridor.

**Catch basin —** A conventional structure for the capture of stormwater. It is used in streets and parking areas and typically includes an inlet, sump, and outlet. It provides minimal removal of suspended solids. In many cases, a hood is included to separate oil and grease from the stormwater.

**Check dam** — A small dam constructed in a gully or other small watercourse to decrease flow velocity (by reducing the channel gradient), minimize scour, and promote sediment deposition.

**Chemical oxygen demand (COD)** — A monitoring test that measures all the oxidizable matter found in a sample, a portion of which could deplete dissolved oxygen in receiving waters.

**Conveyance controls** — Practices that reduce run-off volumes and treat stormwater while the flow is being conveyed through the drainage system.

**Design storm** — A rainfall event of a specific size and return frequency (e.g., two-year, 24-hour storm) that is used to calculate run-off volume and peak discharge rate.

**Discharge** — Water or effluent released to a receiving water body ($m^3/s$ or L/s).

**Drainage area (watershed)** — The area contributing run-off to a single point measured in a horizontal plane, which is enclosed by a ridge line.

**End-of-pipe controls** — Practices that reduce discharge volumes and treat stormwater at the outlet of drainage systems, just before it reaches the receiving streams or waters. These controls are usually structural and implemented to manage the run-off from larger drainage areas.

**Eutrophication** — The process of over-enrichment of waters by nutrients, often typified by the presence of algal blooms.

**Event mean concentration (EMC)** — The average concentration of an urban pollutant measured during a storm run-off event. The EMC is calculated by weighing each pollutant sample in a flow of water during a storm event.

**Fecal coliform bacteria** — Minute living organisms associated with human or animal feces. These bacteria are often used as an indirect indicator of the presence of other disease-causing bacteria.

**Filter strip** — A strip of permanent vegetation above ponds, diversions, and other structures to retard the flow of run-off, causing deposition of transported material, thereby reducing sediment loading.

**First flush** — Pollutant concentrations, including suspended sediments, carried by stormwater in the beginning of a storm. These concentrations are typically higher than at the middle or end of the storm.

**Groundwater recharge** — The return of water to an underground aquifer by either natural or artificial means such as exfiltration as a BMP.

**Hydrograph** — A graph showing the variation in stage (depth) or discharge of a stream over time.

**Impervious cover (I) —** Those surfaces in the landscape that cannot infiltrate stormwater (e.g., building rooftops, pavement, sidewalks, driveways).

**Infiltration rate (*f*) —** The rate at which stormwater percolates into the subsoil measured in millimetres per hour.

**Integrated Stormwater Management Planning (ISMP) —** A planning approach to integrate watershed-based planning processes such as watershed plans, catchment plans, master drainage plans, and stormwater plans into relevant municipal planning processes such as Official Community Plans or Neighbourhood Concept Plans, Recreation and Parks Master Plans, Strategic Transportation Plans, etc., in order to address the impacts of stormwater management on relevant community values. These values may include recreation, agriculture, fisheries, greenways, heritage, archaeology, safety, transportation, economics, property values, flood protection, affordability, the environment, and related issues.

**Loading —** The quantity of a substance entering the environment (soil, water, or air).

**Non-structural BMPs —** Stormwater run-off treatment techniques which use natural measures to reduce pollution levels, do not require extensive construction efforts, and promote pollutant reduction by eliminating the pollutant source.

**One in 2 (1/2) year storm —** A flood event which occurs, on average, once every 2 years or, statistically, has a 50% percent chance of occurring in a given year.

**On-site (or lot-level) controls —** Practices that reduce run-off quantity and improve quality of stormwater before it reaches a municipal conveyance system. The controls are often structural and applied at the individual lot level or on multiple lots that drain a small area.

**Pollutant —** Any substance of such character and in such quantities that, on reaching the environment (soil, water or air), is degrading in effect, impairing the environment's usefulness or rendering it offensive.

**Porosity (*n*) —** Ratio of pore volume to total volume.

**Pretreatment —** Techniques employed in stormwater BMPs to provide storage or filtering to help trap coarse materials and other pollutants before they enter the system.

**Run-off —** That portion of the precipitation on a drainage area that is discharged from the area to the stream channels. This includes surface and groundwater run-off or seepage.

**Sediment —** Soils or other superficial materials transported or deposited by the action of wind, water, ice, or gravity as a product of erosion.

**Source controls** — Measures designed to minimize the generation and entry of pollutants into stormwater run-off and to manage volumes and rates of run-off, with emphasis on non-structural and semi-structural measures applied at or near the source.

**Stormwater best management practices (BMPs)** — Practices, techniques, and methods of managing stormwater drainage for adequate flood control and pollutant reduction by using the most cost-effective and practicable means that are economically acceptable to the community. Generally, BMPs are stormwater management methods that attempt to replicate as much of the "natural" run-off characteristics and infiltration components of the undeveloped system as possible and reduce or prevent water quality degradation. The different measures can be engineered systems (structural BMPs) that improve the quality and control the quantity of run-off (e.g., detention ponds and constructed wetlands) or pollution prevention practices designed to limit the generation of storm water run-off or reduce the amount of pollutants contained in the run-off (non-structural BMPs). Use of the term *Best Management Practices* could be confused with the more generic term *Best Practices*, but it has been kept in the present document as it is now well accepted in actual practice and relevant literature.

**Stream morphology** — The study of the structure and form of a stream or river (e.g., bank, bed, channel, depth, width, and roughness of the channel).

**Structural BMPs** — Devices constructed to provide temporary storage and treatment of stormwater run-off.

**Time of concentration** — Time required for stormwater to flow from the most remote point of a watershed to the outlet.

**Total suspended solids (TSS)** — The total amount of sediments (particulate matter) suspended in a water body.

**Treatment train** — Involves selecting a range of treatment processes arranged in an hierarchical order to ensure that the target pollutant or pollutants are removed.

**Watershed** — An area of land that contributes run-off to one specific delivery point. Large watersheds may be composed of several smaller sub-watersheds, each contributing run-off to different locations that, ultimately, combine at a common delivery point.

# 2. RATIONALE

## 2.1 GENERAL IMPACTS OF URBAN RUN-OFF

Figure 2–1 shows the general impacts of urban development on an undeveloped site. In a typical, moderately developed watershed, the net effect of urban development is a series of changes to the hydrologic conditions. These changes occur progressively with each step in the intensification of development. Hence, consideration of the impact of run-off must occur at each stage, not just when the site is initially developed. Such impacts include (Schueler, 1987):

- increased peak discharges about two to five times higher than predevelopment levels;
- an increased volume of run-off produced by each storm;
- a reduced time of concentration;
- the increased frequency and severity of flooding;
- reduced stream flows during prolonged periods of dry weather due to reduced level of infiltration in the watershed; and
- greater run-off velocity during storms.

It should be recognized that, while Figure 2–1 shows a "greenfield to developed field" scenario, many urban drainage challenges are associated with densification of and other changes to existing developments that already have had an adverse impact on the hydrology of the area. These new hydrologic conditions resulting from developments will typically produce changes in stream geometry and morphology, the primary adjustment to the increased storm flows being through channel erosion and widening. There has been a tendency to regard stormwater as a relatively minor source of pollution. However, numerous studies, such as the Nationwide Urban Runoff Program (NURP) in the United States (EPA, 1983) and others in Canada and Europe have clearly indicated that there can be significant pollution associated with stormwater run-off. In fact, the annual loading from urban run-off can be similar to that found in wastewater effluent and industrial discharges. Urban run-off is typically high in suspended solids and can contribute significant concentrations of metals, salts, nutrients, oil and grease, bacteria, and other contaminants to receiving waters. This may impact the potable water supply, aquatic habitat, recreation, agriculture, and aesthetics.

The results of increased stormwater run-off can be classified for further discussion by the impact on water quality, stream channel morphology, localized flooding, and the hydrologic cycle. The following discusses these impacts briefly; more details are provided in Appendix A.

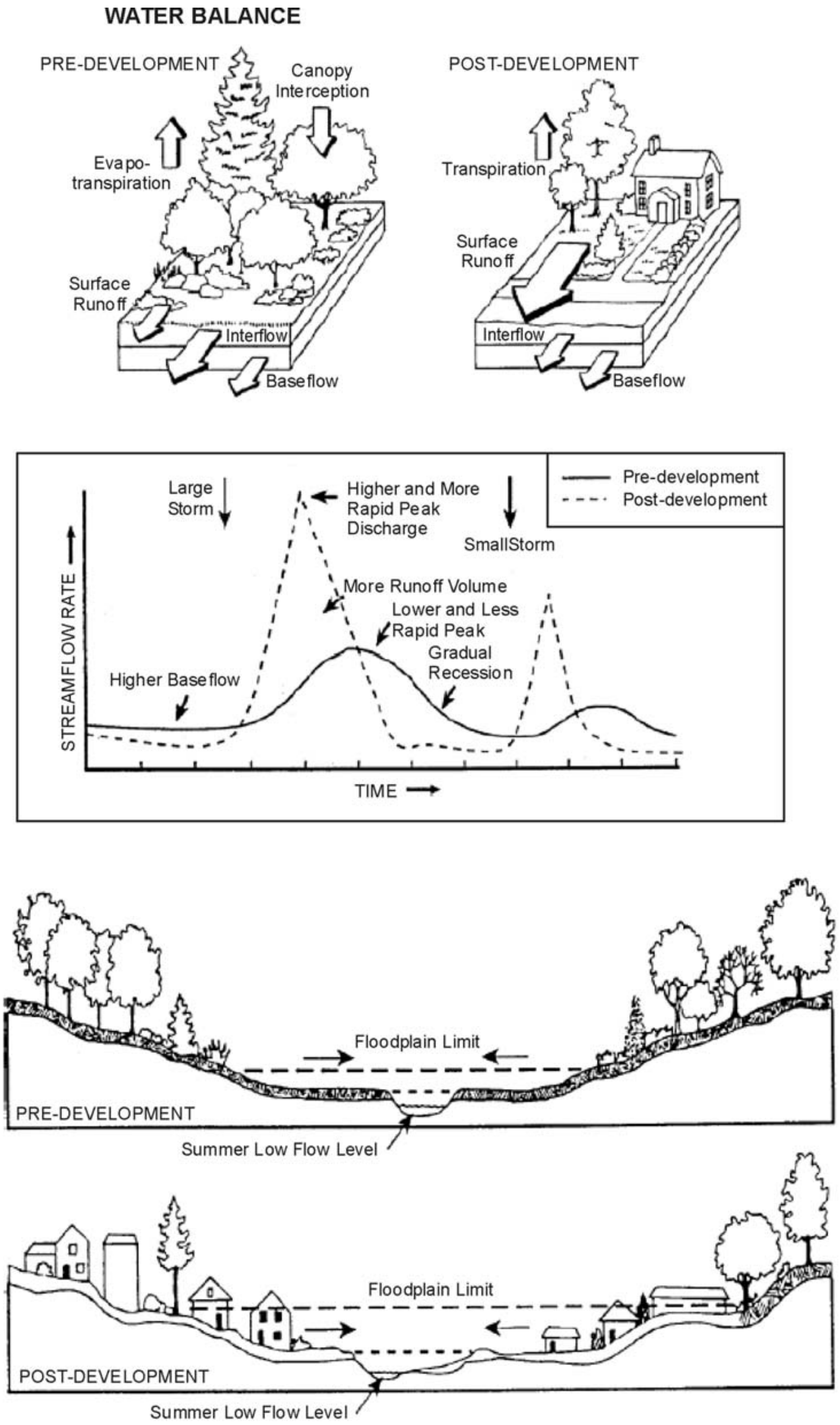


Figure 2–1: Changes in watershed hydrology as a result of urbanization (Schueler, 1987)

## 2.2 IMPACTS ON WATER QUALITY

The impact of the higher run-off rates and volumes are felt on adjacent streams and on downstream receiving waters, such as lakes, rivers, and estuaries. Pollutants associated with urban run-off that are potentially harmful to receiving waters include suspended solids, nutrients, bacteria, pathogens, metals, hydrocarbons, temperature changes, and salt from de-icing. The major sources include contaminants from residential lots and commercial areas, industrial activities, construction, streets and parking lots, lawns, and atmospheric deposition.

## 2.3 IMPACTS ON STREAM MORPHOLOGY

As a result of urban development, the “bankfull” event occurs two to seven times more frequently and the discharge associated with it can increase by up to five times. Furthermore, the total flow beyond the “critical erosive velocity” increases substantially, and the increased energy resulting from these more frequent bankfull flow events results in erosion and enlargement of the stream channel, with associated habitat degradation. The severity and extent of stream adjustment is a function of the degree of watershed imperviousness as well as the stream type. Research models suggest that a threshold for urban stream stability exists at approximately 10 percent imperviousness of a watershed. Watershed development beyond this threshold consistently results in unstable and eroding channels.

## 2.4 IMPACTS ON LOCALIZED FLOODING

Urbanization increases the frequency and severity of flooding due to increased run-off. Because of the decrease in pervious surfaces, and the related decrease in storage capacity, more frequently occurring smaller storms can create flooding problems. Generally, streamflow impact is expressed as a function of the hydrograph peak flow rate, hydrograph low flow rates, and the duration of flow. The impacts of increased peak flow rates include increased risk to life and property.

## 2.5 IMPACTS ON THE HYDROLOGIC CYCLE

Urban development can significantly alter the distribution of water in the hydrologic cycle. Groundwater recharge in stormwater management is undertaken to reduce run-off volumes, and to prevent or mitigate a reduction in dry season flows in watercourses. References for this aspect include the stormwater manual for Maryland (MDE, 2000) and an Ontario manual (MOE, 1999). The impact of reduced base flow or discharge is the loss of downstream riparian rights (i.e., the loss of domestic and agricultural water supplies), and the risk of loss to aquatic habitat and riparian vegetation.

# 3. BEST MANAGEMENT PRACTICES AND RUN-OFF CONTROLS

## 3.1 TREATMENT TRAIN AND GENERAL FRAMEWORK

BMPs vary for different sources of pollution, types of receiving waters, and the flood protection goals to be attained. A useful concept is to use a multilevel BMP approach (UDFCD, 1992), based on a treatment train concept. With this approach, run-off quality management is a set of treatment practices in series, as illustrated in Figure 3–1. Generally, the further we move the treatment away from the source of pollution, the less cost-effective the measures become. It is usually more efficient to prevent pollution with good housekeeping practices or to control pollution at or near the source than to treat stormwater run-off with end-of-pipe BMPs.

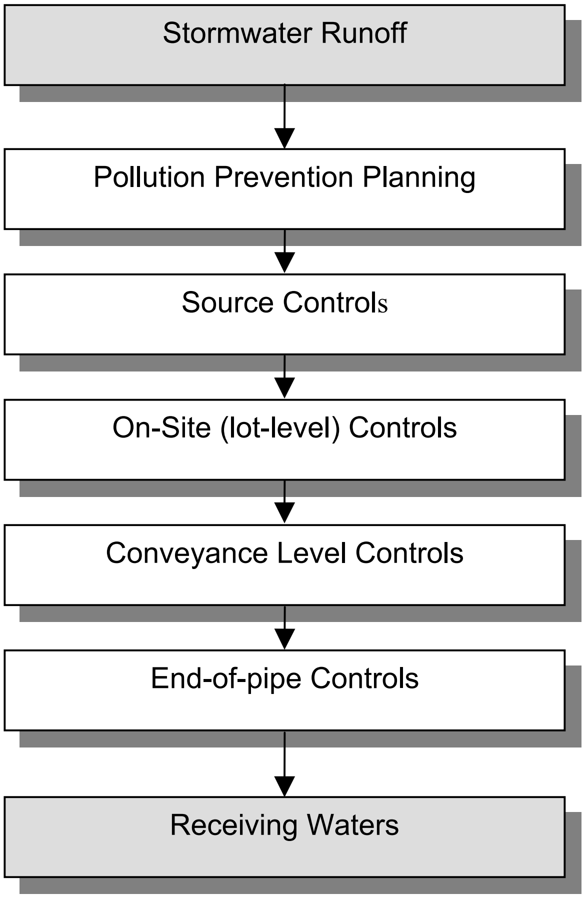


Figure 3–1: Treatment train for control of urban stormwater run-off
Source: Adapted from UDFCD (1992); Urbonas and Roesner (1993).

This document provides information for the second and third levels of control. Pollution prevention and source controls in urban areas are usually practices based on non-structural or semi-structural measures that eliminate or reduce pollutants entering the stormwater systems. This simple concept, which can be very cost-effective, requires the co-operation of the public.

## 3.2 SELECTION OF BMPS

When designing a stormwater management system for any site, the project proponent, working together with planners and design engineers, should ask the following questions:

- How can the stormwater management system be designed to meet the regulations for stormwater quantity and quality most effectively?
- What are the opportunities to meet the stormwater quality regulations, and the groundwater recharge and peak discharge standards simultaneously?
- How can the hydrologic impacts on downstream aquatic habitat be controlled and diminished?
- What are the opportunities to use comprehensive site planning to minimize the need for structural controls?
- Are there critical areas to be protected specifically on or adjacent to the project site?
- Does the project involve stormwater discharge from an area with a higher potential pollutant load?
- What are the physical site constraints?
- Is the future maintenance reasonable and acceptable for this type of BMP?
- Is the BMP option cost-effective and socially and environmentally acceptable?

Clearly, the focus of site planning and stormwater system design should be on examining the entire site to take advantage of the best available areas where run-off can be reduced, infiltrated, and treated in an integrated stormwater management system. In this context, land use and site planning should be an essential element in the overall drainage management system.

A number of competing factors need to be addressed when selecting the appropriate BMP or suite of BMPs for an area (ASCE/EWRI, 2001; ASCE/WEF, 1998; MOE, 1999; EPA, 1993, 1999). Local on-site controls should be part of a comprehensive stormwater management program. Without proper selection, design, construction, and maintenance, BMPs will not be effective in managing urban run-off. Most BMPs have applicability limitations and, therefore, cannot be applied nationwide. A few considerations to incorporate into BMP selection are:

- drained area;
- land uses;
- average rainfall frequency, duration, and intensity;
- run-off volumes and flow rates;
- soil types (e.g., clay not suitable for infiltration BMPs);
- site slopes;
- geology/topography;
- availability of land;
- future development/land use in watershed;
- proximity to environmentally significant features;
- depth to groundwater table (e.g., should be at least 1.2 m underneath the bottom of infiltration systems);
- availability of supplemental water to support vegetative BMPs;
- susceptibility to freezing;
- safety and community acceptance;
- maintenance and accessibility; and
- periodic and long-term maintenance/rehabilitation needs.

In addition to site-specific applicability requirements, factors such as BMP cost, local regulations or requirements, aesthetics, the experience of a developer or contractor with a particular design and competing receiving water considerations should be addressed. The combination of these factors make selection of appropriate BMPs a difficult and somewhat complex task, and one that should be done only by an experienced stormwater practitioner, with knowledge of local factors that affect design and performance.

The different ways of selecting BMPs proposed in the literature generally use some form of decision matrix that considers the various parameters. Elements include:

- physical suitability (e.g., the watershed area served, the soil type, the slope of the site, the depth of the water table, the proximity to foundations and wells and restricted land uses);
- stormwater benefits provided, for peak discharge control, volume control, groundwater recharge, and stream bank erosion control;
- pollutant removal benefits; and
- environmental amenities, such as low flow maintenance, stream bank erosion control, aquatic habitat creation, wildlife habitat creation, degree of thermal enhancement, landscape enhancement, recreational benefits, hazard reduction, aesthetic value, and community acceptance.

## 3.3 CRITERIA FOR BMPS

Design criteria for stormwater BMPs have evolved in the last 10 years to encompass the more holistic view that is now associated with stormwater management. These can be classified into four groups of general criteria:

- **water quality**: aquatic habitat, pollutant loading, temperature, recreation, groundwater contamination;
- **erosion potential**: land form and sensitivity to erosion;
- **water quantity**: flooding;
- **hydrologic cycle**: groundwater recharge, in-stream base flow/low flow maintenance, surface and subsurface flow paths; and
- **maintenance requirements**: these must be incorporated into the design of BMPs to ensure their long-term effectiveness.

Specific criteria are required to accommodate the entire frequency of storms anticipated over the life of the stormwater management practice. Consequently, storms range from the smallest, most frequent events (which individually produce little run-off, but occur the most frequently, and are responsible for the most groundwater recharge and impacts on water quality) up to the largest (very infrequent events that can cause catastrophic damages). Generally, the criteria for recharge storage will be the capture of about 50 percent of all run-off producing rainfall events, whereas for water quality control, the criteria should be typically between 80 and 90 percent of them. Criteria for quantity control are site-specific but are generally defined to reproduce as closely as possible the predevelopment conditions and to adapt future run-off conditions to the discharge capacities of existing drainage systems.

### 3.3.1 CRITERIA FOR WATER QUALITY CONTROL

Usually, the primary criteria used in most jurisdictions are volumetric (i.e., run-off from a specified design storm rainfall depth to be captured and treated) and, typically, the selected quantities range from 12.5 mm to 25 mm (often associated with the first flush or assumed to correspond to the capture of 80 to 90 percent of the events). The use of this type of volumetric design storm criteria remains prevalent today, although some jurisdictions have established methods for refining the size of the design event, based on area-specific conditions, such as climate or the receiving water body. Ontario has adopted an alternative approach to the volumetric sizing of stormwater facilities (MOE, 1999), with three levels of protection (basic, normal, and enhanced) corresponding to specified level of suspended solids removal.

### 3.3.2 CRITERIA FOR EROSION CONTROL

The Ontario manual (MOE Consultation Draft, 1999) provides detailed technical information on the different approaches for erosion control. The two-year storm was frequently adopted as the design event because this flow has been found to correspond to the bankfull stage (the top-of-bank of the “active” channel before the flow spills out onto the flood plain). It is also the flow that performs the most work, in terms of sediment moved and the shaping of the active channel. The manual provides practical guidance which has been effective in specific circumstances. However, users must exercise judgement and flexibility to adapt the guidance provided as stormwater management solutions should be developed on a site-specific basis. The boundary material and other geomorphologic parameters must also be considered and stricter criteria might be necessary.

### 3.3.3 CRITERIA FOR QUANTITY CONTROL

Good design of urban drainage systems must minimize the risk to life and property damage. Generally, accepted criteria state that maximum peak flow rates must not exceed predevelopment values for the two-year through 100-year return periods. The post-development run-off peak may even be less than predevelopment levels for the implementation of water quality measures, measures to reduce stream bank erosion, and methods to increase base flow or enable future development. Return period (two years through 100 years) peak flow rates must be determined on a site-specific basis.

Controlling post-development peak flow rates through storage to values less than predevelopment conditions (over-control) may be required to maintain existing downstream watershed peak flow rates. It should be pointed out that, in some cases, downstream rates can increase, even though site run-off is controlled to predevelopment levels. The timing of detained run-off peaks from specific points of a watershed (through on-site controls) may result in the coincidence of peaks and need to be verified**.** Providing site storage in the lower or mid portions of a basin will probably increase downstream peak flow rates as attenuated run-off will peak near the same time as upstream run-off. Controlling run-off in the upper portions may reduce downstream peak flow rates as the peaking times are significantly different. The potential impacts of site-attenuated run-off on downstream watershed peaks should be calculated on a site-specific basis.

### 3.3.4 CRITERIA FOR PRESERVATION OF HYDROLOGIC CYCLE

When the impacts of urban development are significant, water balance methods can be used to determine the amount of water that should be infiltrated to compensate for reductions caused by large paved areas or changes to vegetation. References that can be used to develop appropriate criteria are the Maryland and Ontario manuals (MDE, 2000; MOE, 1999) and the BC Provincial Guidebook Columbia (Stormwater Planning: A Guidebook for British Columbia, 2002).

### 3.3.5 MAINTENANCE REQUIREMENTS

Maintenance activities must be supported in the design of BMPs. BMPs that control sediment require proper access to support periodic sediment removal. BMPs that utilize vegetation should have a biomass management plan in place. BMPs that are operated and maintained by the public must be supported by public information programs.

## 3.4 DESCRIPTION OF BMPS

### 3.4.1 SOURCE CONTROL

Source control as a component of pollution prevention planning and hydrologic impact prevention is the most cost-effective way to reduce the impacts of urban run-off. Most practices can assist in addressing the four criteria, quantity, quality, stream erosion, and hydrologic cycle, but they are more often associated with quality and quantity control. They are usually of a non-structural nature and include the following general practices (ASCE/WEF, 1998; Camp, 1993; GVSDD, 1999; Marsalek et al., 2001; TRCA and MOE, 2001; Urbonas and Roesner, 1993).

**Public Education, Awareness and Participation**

This is essentially an institutional practice intended to change the way the public manages many constituents that could have an impact on pollution. An effective program can be developed through the steps listed below.

- Define and analyze the problem (the sources of pollution, what causes them).

- Identify stakeholders (commercial business, industry, landholders and residents, school/youth groups, and municipal staff).

- Know the target group. Establish a complete profile, develop the best methods of communication.
- Set objectives: informative messages, emotional messages, responsibility messages, empowering messages, action messages (clear, simple language, technically sound statements, break the concept up into simple statements).
- Design the methods by selecting techniques suitable for the group targeted.
- Form action plans and timelines. Identify costs, funding sources and trim the project to fit the resources.
- Monitor and evaluate. Collect information and records to see how effective this is, recognizing that there may be a lag in public response.

### Land-Use Planning and Management of Developing Areas

These practices are most effective when they are applied during the site-planning phase of a new development or retrofit of existing areas. They can have a significant impact on quantity control as well as quality control. By-laws are typically required to implement and enforce land-use plans, including those relating to stormwater run-off quality. One basic parameter to minimize is the extent of the directly connected impervious areas (DCIAs). The Web site of the Center for Watershed Protection <www.cwp.org> provides detailed technical information on how to develop and implement by-laws.

A relatively recent concept is the low-impact development (LID), which is a site-design strategy to maintain or replicate the predevelopment hydrologic regime by creating a functionally equivalent hydrologic landscape. LID principles are based on controlling stormwater at the source by the use of micro-scale controls that are distributed throughout the site. This is unlike conventional approaches that typically convey and manage run-off in large facilities located at the base of drainage areas. Several recent reports in the United States document this approach (Prince George’s, 1999a,b) as well as recent Canadian Guides (MOE, 1994, 1999). Appropriate and careful site planning and design can be used to provide effective run-off control at a relatively low cost, but future maintenance costs also have to be considered.

### Integrated Stormwater Management Planning (ISMP)

Integration of stormwater management with land use planning is practised in a number of municipalities. An emerging practice in British Columbia is integrating watershed based planning processes such as watershed plans, catchment plans, master drainage plans, and stormwater plans. Integration into relevant municipal planning processes addresses the impacts of stormwater management on relevant community values. These values may be recreation, agriculture, fisheries, greenways, heritage, archaeology, safety, transportation, economics, property values, flood protection, affordability, the environment, and related issues (GVRD Integrated Stormwater Management Planning, Terms of Reference template, Working Draft Report, 2002). This approach treats stormwater as a resource that is to be protected and views the other values as complementary objectives.

**Modified Use, Releases, and Disposal of Chemicals Entering Stormwater**
These measures employ planning, and environmental and building by-laws and regulations to reduce releases of harmful chemicals into stormwater. This can generally be achieved by modifying some activities, the use of certain products, and their handling and disposal practices. Road salts, pesticides and household hazardous waste are examples of chemicals that can be controlled and managed through regulations and programs (Horner et al., 1994; Maksimovic, 2000; Marsalek et al., 2001, TRCA and MOE, 2001).

**Development and Enforcement of Sewer By-laws**
The types of activities addressed here include illegal dumping control, removal of contaminated sediment from sewers, prevention, detection, and removal of illicit connections and control of leaking sanitary sewers.

**Housekeeping Practices**
Toxicants entering stormwater can be reduced by good housekeeping practices employed by the general public, municipal employees, businesses, and others. These measures focus on introducing and following good procedures for storage, handling, and transporting materials, which could end up in stormwater. Successful implementation requires education and training (ASCE/WEF, 1998; Marsalek et al., 2001; NVPDC, 1996; EPA, 1999; WDE, 2001).

**Control of Construction Activities**
Many municipalities, provinces, and states have produced separate documents to describe specific planning and management activities to reduce the impact of construction on stormwater quality. These techniques usually have many similarities with other structural techniques, except they are essentially temporary. The steps included in such controls include erosion control, sediment collection, site water control, equipment storage and maintenance, materials storage, and litter control.

**Maintenance Activities**
Street cleaning, maintenance of parks, appropriate domestic waste collection, catch basin cleaning, and general road, storm channel, and creek maintenance are typically included in this type of source controls.

### 3.4.2 ON-SITE CONTROLS

On-site controls are practices that reduce run-off volumes and improve stormwater quality before it reaches a conveyance system. These controls are applied at the individual lot level or on multiple lots that drain a small area.

When determining the suitability of on-site controls, the site constraints should be carefully considered. These include:

- controlled lot grading;
- surface ponding, rooftop storage;
- adsorptive landscaping and rain gardens:
- green roofs;
- on-lot infiltration systems;
- sump pumping of foundation/weeping tile drains;
- downspout disconnection;
- superpipe storage;
- grassed swales;
- buffer and filter strips;
- oil/grit separators; and
- permeable pavements (surfaces).

The measures can be divided in two general categories. The first category is for measures to reduce water quantity concerns or infrastructure costs. Surface ponding (on parking lot, rooftop, or backyard) and superpipe storage belong to this category, and they are essentially measures designed to reduce peak flow rates. The other category of techniques controls the peak rates, but they also improve water quality and can contribute to both erosion protection and flood control through a reduction in the surface run-off volume. Examples are vegetative techniques, such as buffer/filter strips and oil/grit separators, which are most often used as special BMPs and as pretreatment measures in series with some other practices.

### Reduced Lot Grading

This measure implies reducing the usual two percent minimum slope for the lot grade. It is recommended that to ensure proper foundation drainage, grading within two to four metres of a building should still be maintained at two percent or higher. (Local municipal standards should be reviewed to ensure compliance). Outside this envelope, the grading can be flattened to 0.5 percent to promote greater depression storage and natural infiltration. The type of soil and long-term behaviour as far as compaction is concerned also need special consideration as the overall grades may be substantially reduced over time through compaction.

Reduced lot grading can be implemented for soil types with a minimum infiltration rate of 15 mm/hr or greater (MOE, 1999). This generally implies soils coarser than loam; clay soils are usually not suitable.

**Surface Ponding on Parking Lots**
Generally, parking lot storage is economical with slightly increased costs for construction and is applicable to commercial and industrial lots. Parking lot storage has been widely applied for infill development scenarios to mitigate the need for downstream storm sewer size increases. Although it is often difficult to reduce downstream post-development peak flow rates for new sites using only parking lot storage (the water depths and volumes being too important), the available volume can be used efficiently with other techniques to reduce post-development run-off.

Storage is created when run-off rates are greater than the capacity of the inlet control device (ICD). ICDs can be placed in maintenance manholes or in catch basins, and premanufactured ICDs can take the form of an orifice plate or plug over the outlet pipe to a catch basin or maintenance hole. The ICDs can be installed at each catch basin (which will enable the individual control of storage cells on the parking lot surface) or at the property boundary (in which case the water levels will probably be the same at each storage cell). Installing the ICD at the property boundary, in a municipality-owned manhole, will ensure that the ICD will not be removed or altered. Vortex-type ICDs are preferable when the control discharge is less than about 14 L/s (less prone to clogging).

The ponding areas should be as far away as possible from buildings and the slopes could be at a minimum of 0.5 percent (MOE, 1999) (although a one percent slope is recommended). Generally, ponding depths are limited to 300 mm for durations that are deemed acceptable (normally a few hours even for extreme events). The acceptable limiting discharge will vary with each region and site, as prescribed ideally by a master stormwater management plan. As an example for the Montréal area, a limiting discharge of 40 L/s/ha to 50 L/s/ha for a sub-basin of 0.4 ha to 0.7 ha (100% impervious) with slopes of 1% has been shown to provide acceptable water depths and flooding duration for most cases (Rivard and Dupuis, 1999). For a large parking lot, this implies that the total area should be sub-divided in smaller units (cells) with individual areas (each draining to a unique low point) less than 0.7 ha to meet the criteria. This also illustrates the fact that if the predevelopment discharge to be attained is, for example, 10 L/s/ha or lower, other means of ponding besides storage on the parking lot surface will have to be provided. Usually, the lower the limiting discharge, the smaller the ponding cells on the surface should be; obviously, underground storage can also be provided at higher costs.

### Surface Ponding on the Rooftop

Generally, rooftop storage is applicable to large flat commercial and industrial rooftops as residential roofs are usually peaked with few opportunities for storage. Calculations must be made to determine the number, the location, and the discharge rate for each hopper. Discharge rates for premanufactured rooftop drainage hoppers are specified by the manufacturer. Typically, discharge values for each hopper can range from 1 L/s to 15 L/s (MOE, 1999). Storage is user-determined for dead level or slightly sloped roofs. Large commercial roofs can store 50 mm to 80 mm of run-off (as a reference, the 100-year, 24-hour rainfall amount for southern Ontario is approximately 100 mm). Detention times are usually between 12 and 24 hours. Structural/mechanical engineers should supervise the detailed design of rooftop storage to ensure loading rates are not exceeded, taking, as appropriate, wet snow and other critical loads, into consideration**.** A maximum depth of 10 mm should be allowed before water can flow through the roof hoppers. Roof supports must be adequate to support the weight of the ponded water.

### On-Lot Infiltration Systems

These types of systems are used for stormwater detention from relatively small drainage areas, mainly single family dwellings. They provide some reduction in overland flows and enhancement of water quality. On-lot infiltration systems may be simply designed pits with a filter liner and rock drain material or more complex systems with catch basin sumps and inspection wells. Examples of on-lot infiltration systems are given in Figure 3–2; infiltration trenches are illustrated in Figure 3–3. Detailed information on design guidance is provided in various references (ASCE/WEF, 1998; CWP, 1997; CIRIA, 1996; Jaska, 2000; MDE, 2000; MOE, 1999). General design considerations for on-lot infiltration systems are as follows.

- There should be a significant distance from the bottom of the pit to the high groundwater table. This may vary from ≥0.8 m. to ≥1.2 m, depending on local conditions and constraints. Local authorities should be consulted or test holes should be drilled to ensure proper distances are provided.

- The distance between the bottom of the pit and bedrock should be ≥1.2 m.

- The trench should be located at least 4 m away from the foundation of the nearest building.

- The trench should comprise clean (properly washed) 50 mm diameter stone and be lined with suitable geotextile.

- The total void volume of the trench should be based on the storage required for the appropriate design storm, based on the effective porosity of the trench media (usually assumed to be 35 to 40 percent). The required infiltration surface area (bottom surface area) to drain the system within 48 hours is calculated from the 24-hour sustained percolation rate.

- The trench should be located close to the ground surface, but factors such as the depth of trench storage, frost heave potential, and surrounding soil stratification should be considered.

- A filter should be incorporated into the soakaway pit design or the sump to limit solids and debris entering the system. An overflow pipe should be included where possible.

- On-lot infiltration systems should generally not be constructed on fill material, under parking lots, or under multi-use areas.

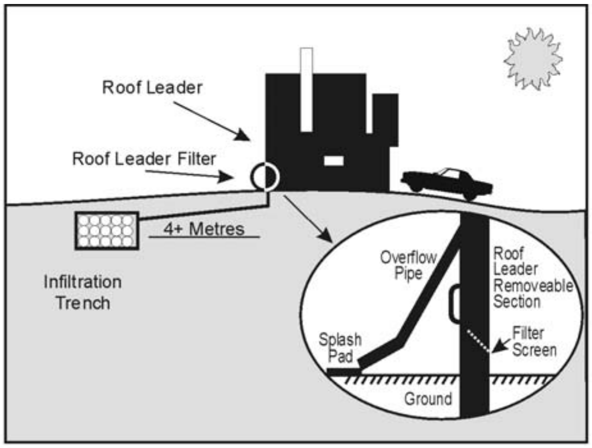
- For infiltration systems draining parking lots, one or two pretreatment devices in series should be used before the infiltration system to extend its useful life without clogging.

Generally, it is important to assess local soil conditions and percolation rates before using infiltration systems on a large scale. Infiltration systems offer the possibility to reduce run-off volumes and peak flows, reduce pollutant loads and allow, in some cases, the use of smaller storm sewer systems. Their disadvantages are related to long-term maintenance and potential clogging, and the fact they can have negative impacts on groundwater.

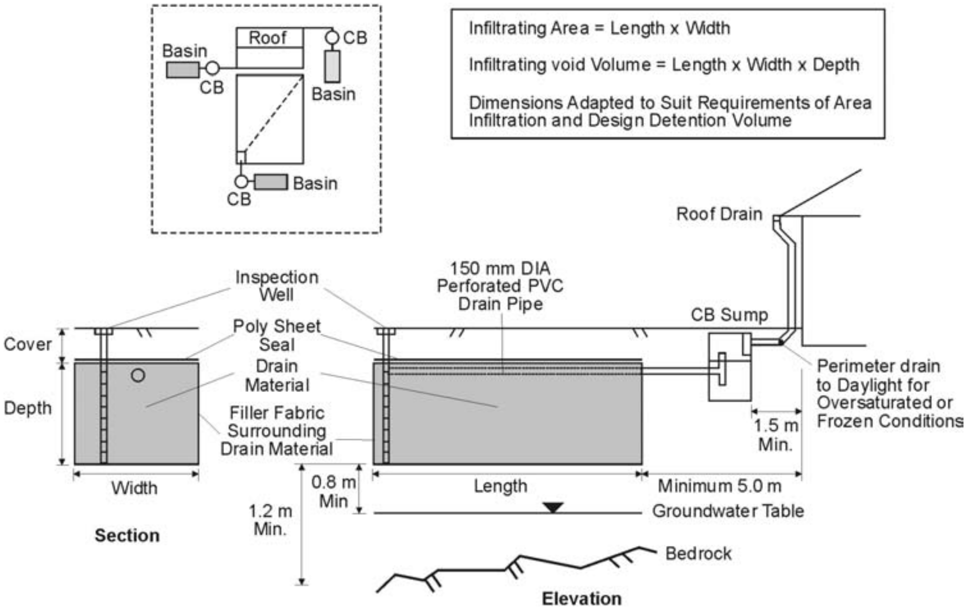
**Sump Pumping of Foundation/Weeping Tile Drains**

Although current development standards allow foundation drains to be connected to the storm sewer, an alternative can be to allow sump pumps to discharge foundation drainage to either the surface or soakaway pits. Either option is preferable to the connection of foundation drains to the storm or sanitary sewer. The municipality should be contacted before recommending this type of control, as some municipalities do not permit it. In some municipalities, a “third pipe” or foundation drain collector system (with a gravity connection) is used in very flat areas where potential basement flooding is a concern.

The discharge point should be at least 2 m from the foundation, and there should be sufficient grading away from the foundation wall when the sump pump is discharging to the surface of the ground. This conveys the drainage away from the building. The outlet for sump pumps that discharge to the ground surface should be at least 0.5 m above the ground to prevent blockage from ice and snow during the winter.

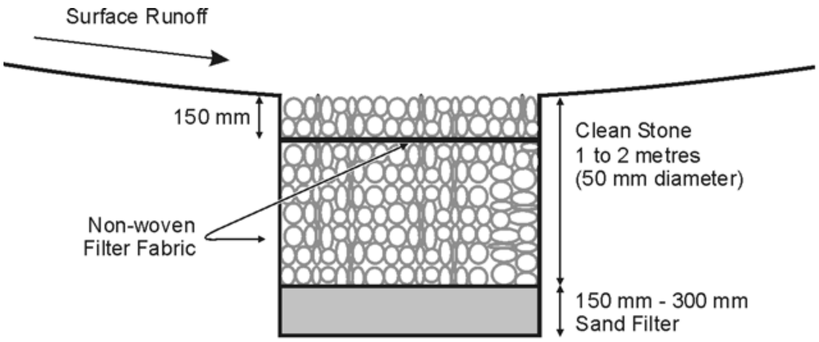


(a) Source: MOE (1999)

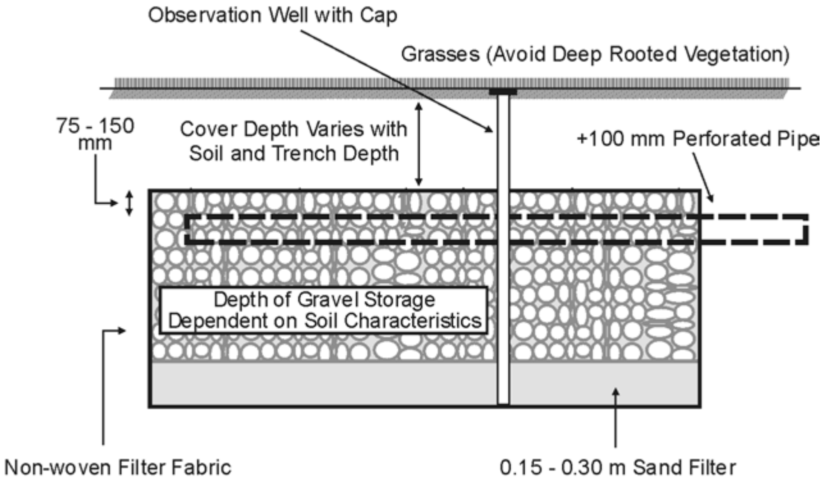


(b) Source: Jaska (2000)

Figure 3–2: Examples of on-lot infiltration systems



(a) Source: MOE (1999)



(b) Source: Jaska (2000)

Figure 3–3: Examples of infiltration trenches

**Superpipe Storage**

Superpipes can be used to reduce peak flow rates by providing sub-surface storage. Premanufactured pipe is typically used for the installation. The outflow rates must be controlled to ensure run-off is detained in the superpipe. This technique is usually more costly than surface storage and is typically used for areas with limited space. A volume of crushed stone surrounding a perforated pipe can also be used to provide the needed volume. General design recommendations include the following.

- Outlets must be sized to control specified outflow rates not exceeding allowable limits. The length and diameter of the superpipe will be a function of the storage required.

- A minimum slope of 0.5 percent is recommended to facilitate drainage of the pipe. However, slopes should be kept to a minimum; steep slopes will reduce the amount of storage within the pipe.

- Access points are required for cleaning purposes.

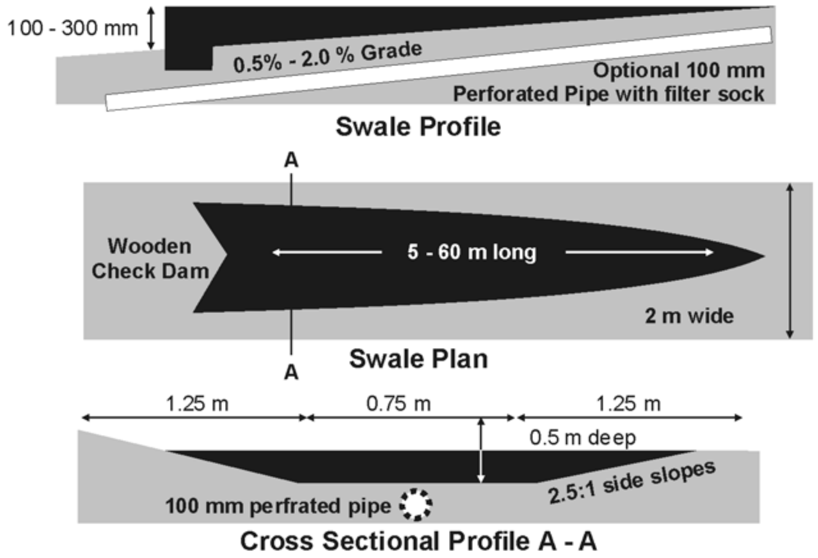
- Emergency overflow routes should be included in the design.

Surface overflow paths (emergency escape routes) should be included in case the outlet gets plugged.

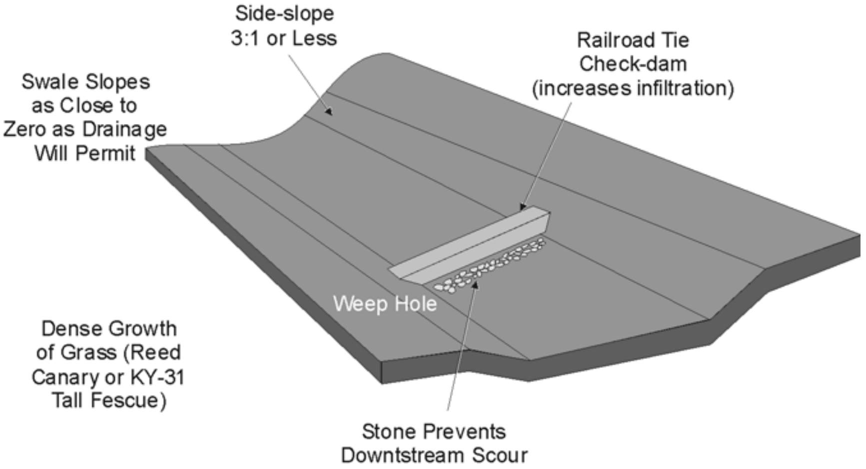
**Grassed Swales**

Historically, grassed swales were constructed for stormwater conveyance. However, stormwater objectives have changed and now grassed swales are being used to store, infiltrate, and convey road and on-lot stormwater run-off. The grass or emergent vegetation in the swale reduces flow velocities, prevents erosion, and filters stormwater pollutants. If designed properly, grass swales are effective BMPs for water quantity and quality at the on-site level. Water quality enhancement will depend on the contact area between the water and the swale and the longitudinal slope. Deep narrow channels are less effective for pollutant removal than shallow wide swales. Safety issues regarding conveyance depths and velocities must be considered. Figure 3–4 illustrates grassed-swale systems. Deeper swales, with more storage capacity, can also be used around a parking lot to provide additional storage.

Deep narrow swales are less effective for pollutant removal than shallow wide swales. Given typical urban swale dimensions (0.75 m bottom width, 2.5:1 side slopes, and a 0.5 m depth), this generally limits the contributing drainage area to less than 2 ha (to maintain a flow of less than 0.15 $m^3/s$ and a velocity that is lower than 0.5 m/s). Grassed swales are most effective for stormwater treatment when a minimum channel slope is maintained (e.g., less than one percent), and a wide bottom width (more than 0.75 m) is provided. Grassed swales with a slope up to four percent can be used for water quality control purposes, but effectiveness diminishes sharply as velocities increase. Grass should be allowed to grow higher than 75 mm to enhance the filtration of suspended solids. Additional design guidance is provided in other references (ASCE/EWRI, 2001; GVSDD, 1999a; Jaska, 2000; Schueler, 1987; Young et al., 1996).



(a) Source: MOE (1999)



(b) Source: Scheuler (2000)

Figure 3–4: Examples of grassed swale systems

### 3.4.3 PRETREATMENT AND SPECIAL PURPOSE BMPS

Many stormwater practices benefit from pretreatment, typically for on-site controls in the form of biofiltration in swales and vegetative filter strips located upstream of filtration or infiltration facilities. Such pretreatment can also be provided by oil/grit separators, which trap sediment and free oil. These separators are particularly well suited for use with subsurface measures without pretreatment chambers incorporated into the design.

The benefits of pretreatment include extending the operational life of stormwater management facilities adversely affected by sediment, increasing the maintenance intervals for ponds, and improving the visual appeal of ponds and wetlands by preventing oil sheens and large sediment deposits by the inlet. Oil/grit separators are also important at commercial, industrial, and transportation sites where spills may be a problem. Since most spills are small and are not weather dependent, separators effectively control potentially serious problems. Pre-treatment practices that are most often in series with other BMPs include filter strips, buffer strips, and oil/grit separators. Porous pavement is also discussed as a special purpose BMP.

**Filter Strips**

These engineered conveyance systems are designed to remove pollutants from overland run-off. Generally, filter strips treat small drainage areas (<2 ha). A typical filter strip consists of a level spreader (to ensure uniform overland flow) and vegetation. The vegetation filters out the pollutants and promotes infiltration of the stormwater.

There are generally two types of filter strips: grass and forested. Further research is required to compare the efficiency of these two types of filter strips for water quality enhancement. Filter strips are best used beside buffer strips, watercourses, or drainage swales since sheet flow from the filter strip is difficult to convey in a traditional conveyance system, such as pipes or swales. Filter strips may also be used along overland escape routes and in parks and other landscaped areas. Filter strips serve as pretreatment systems to other BMPs. Figure 3–5 illustrates the parameters associated with filter strips. Guidance is provided in other documents (ASCE/EWRI, 2001; ASCE/WEF, 1998; MOE, 1999; Schueler, 1987).

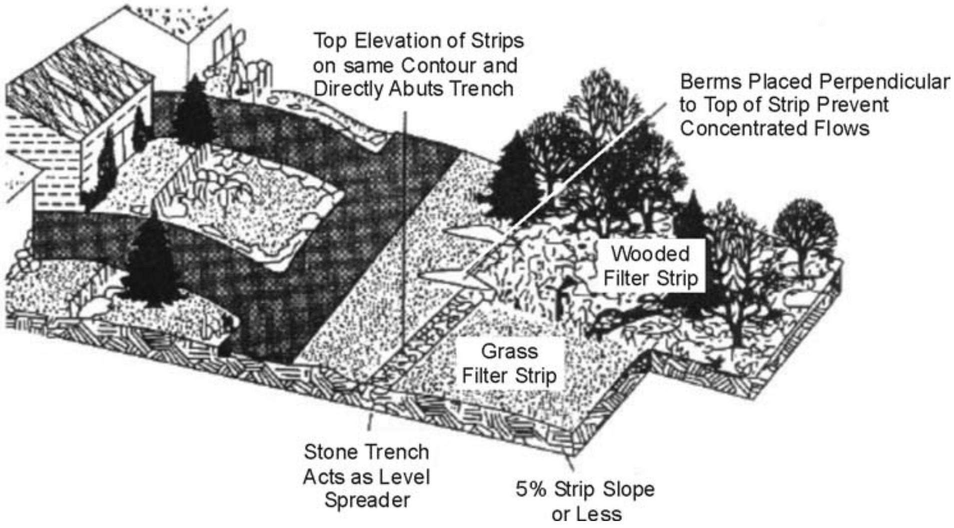


Figure 3–5: Grassed and wooded filter strips
Source: Schueler (1987).

**Buffer Strips**

Buffer strips are natural areas between development and receiving waters. They are intended to protect the stream and valley corridor system, and to preserve vegetated riparian areas within the valley system to minimize the impact of development on the stream itself (i.e., filter pollutants, provide shade, and bank stability, etc.). Although buffer strips may only provide limited benefits in terms of stormwater management, they are an integral part of the overall environmental management. The protection of stream and valley corridors provides significant benefits to wildlife, aquatic and terrestrial habitats, and linkages between natural areas.

**Oil/grit Separators**

Oil/grit separators are a variation of the traditional settling tank designed to capture sediments and trap hydrocarbons (oils) in stormwater run-off. An oil/grit separator is an underground retention structure that takes the place of a conventional manhole in the storm sewer system. There are essentially two design types of oil/grit separators available: three-chamber and bypass. Three-chamber separators operate most effectively when constructed off-line; only low flows should be directed to the separator. An example is provided in Figure 3–6. Bypass separators should be installed on-line. An example is provided in Figure 3–7.

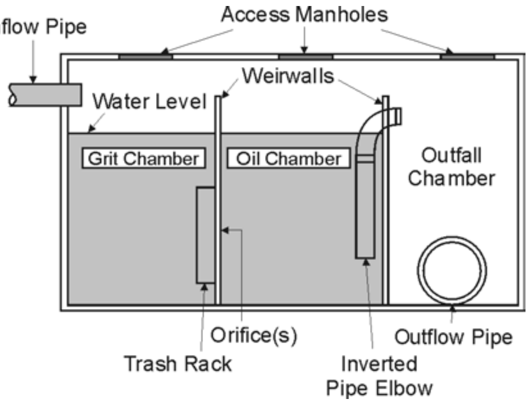


Figure 3–6: Three-chamber oil/grit separator
Source: Jaska (2000).

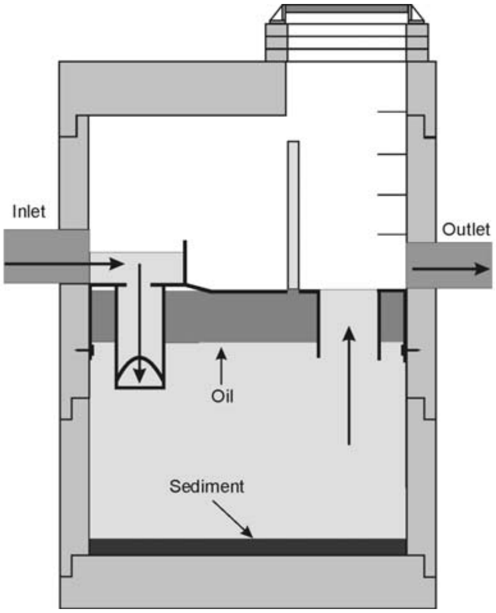


Figure 3–7 : By-pass oil/grit separator
Source: Stromceptor Canada Inc.

### Porous (or Permeable) Pavement

With this alternative to conventional pavement, run-off is diverted through a porous pavement layer into an underground storage layer. The stored run-off gradually infiltrates into the native soil. There are various types of permeable pavement systems such as porous asphalt, pervious concrete and solid pavers laid with gaps. Porous pavements can provide both water quantity and quality control. They are, however, not used in Canada on a large scale and more studies are needed to confirm their long-term effectiveness and sustainability as applied to cold-climate regions. Pavements using interlocked stone or concrete pavers set with a sand base can provide an alternative porous surface to allow rainwater infiltration. These systems are usually suitable for parking lots or low traffic areas.

# 4. APPLICATION

## 4.1 GENERAL PROCESS FOR IMPLEMENTATION

Stormwater management provides an integrated approach to water management (water quality, flooding, erosion, recharge), recognizing that stormwater management solutions must be economically efficient to construct and maintain. In most subdivison-size applications, end-of-pipe measures can be selected to address water quality, and erosion and quantity control. Many designers tend to select a multi-purpose, end-of-pipe solution and assume they are done. This usually results in a stormwater management plan which does not meet all objectives or which does so inefficiently.

It should be clearly recognized that end-of-pipe BMPs rarely address recharge objectives. Further, neglect of source and on-site controls results in greater volumes of direct run-off which increases the cost of storm infrastructure and causes oversizing of erosion control and, to a lesser extent, quantity control storage. The treatment train approach (using lot-level, conveyance, and end-of-pipe controls, in series) has been assumed by many to be a means of providing more cost-efficient quantity control and better water quality control. While this is a benefit, the main reason for the treatment train is that stormwater objectives involving recharge, base flow, temperature, and erosion control cannot be effectively dealt with by end-of-pipe controls alone. They can, however, be more cost-effectively addressed by source or on-site controls.

Figure 4–1 provides a general flow chart to aid in the overall stormwater analysis. It formalizes many aspects discussed in this document, giving an overview of the different elements to be considered at the municipal level. For sparsely developed areas (less than 10 percent), it is sometimes not necessary to have a comprehensive master plan if no obvious problems are apparent. If the municipality is developing more intensively, criteria should be in place for the different classes of potential problems (quantity, quality, stream morphology, and hydrologic cycle), and a treatment train for each aspect should be defined and implemented as necessary.

Many lot-level techniques and other source controls will be implemented on lands held in private ownership. This is a significant challenge in designing and implementing a stormwater management strategy. Consequently, maintenance and the long-term effectiveness of the system are contingent on the actions of the landowner. As a result, the long-term performance of a system of combined lot-level initiatives is difficult to quantify, particularly when time is considered. Over time, if maintenance levels are inadequate, the long-term performance of the system could be compromised. Landowner education is the single most important element in selection, application and ongoing effectiveness of voluntary site level best management practices. The successful application of lot-level landscape solutions also requires the commitment of the municipality and creative partnerships with the developer, municipality, and landowner to realize consistent benefits over the long term.

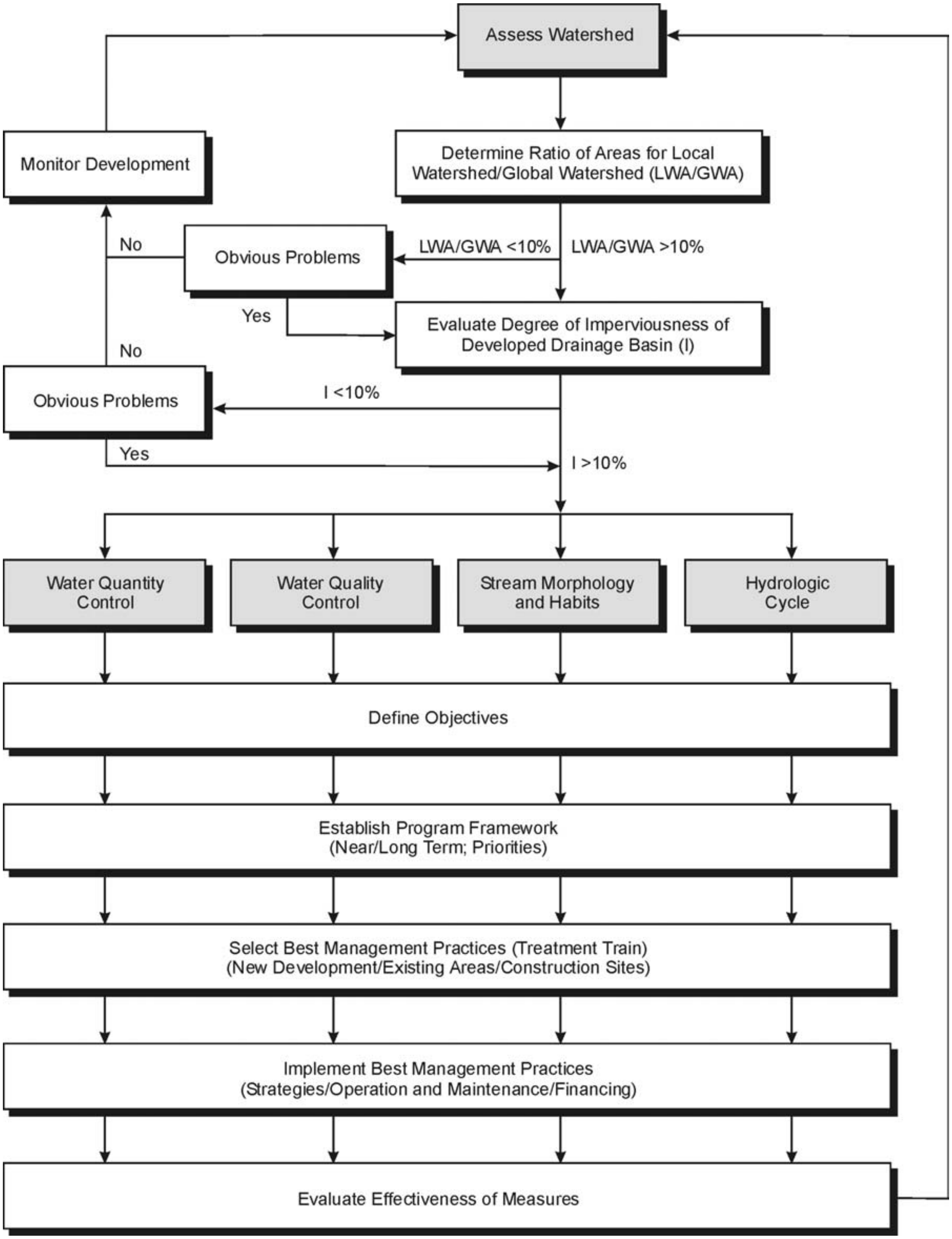


Figure 4–1: General flow chart to develop a stormwater management plan

## 4.2 EFFECTIVENESS OF SOURCE AND ON-SITE CONTROLS

BMP performance can vary considerably based on differences in the design criteria and performance standards the BMP must meet. The U.S. EPA Web site <http://www.epa.gov/npdes/menuofbmps/menu.htm> contains relevant information. In Canada, the effectiveness of different BMPs, specifically source and on-site controls, is being assessed (GVSDD, 1999a; MOE, 1999). Comparing pollutant removal efficiency for similar BMP types with very different performance goals may result in widely disparate efficiency estimations. Despite these shortcomings, some general ranges of expected BMP efficiency have been compiled from the literature (CWP's National Pollutant Removal Performance Database (Brown and Schueler, 1997a), GVRD's *Interim Report on Effectiveness of Stormwater Source Control,* 2002, the ASCE National Storm Water BMP Database at http://www.bmpdatabase.org/, the Ontario Manual (MOE, 1999), the *Stormwater Pollution Prevention Handbook* produced in Ontario (TRCA and MOE, 2001)). Readers are encouraged to consult the referenced information resources for more detailed BMP performance data than is presented in this document.

Table 4–1 presents a summary of expected effectiveness and associated considerations regarding source controls. Generally, the effectiveness of pollution prevention measures and source control is more diffuse and difficult to establish clearly (EPA, 1999). Table 4–2 provides the same type of information for on-site controls. Other references provide additional data (AEP, 1999; ASCE/EWRI, 2001; ASCE/WEF, 1998; Jaska, 2000; MDE, 2000; MOE, 1999; Schueler, 1987).

The effectiveness of BMPs at controlling stormwater flows depends on:

- reductions in the peak flow rate across the BMP;
- total storage volume provided in the BMP;
- infiltrative capacity of the BMP;
- retention time in the BMP;
- relationship of post-development hydrologic conditions to predevelopment hydrology; and
- retention volume necessary for receiving stream channel protection.

Table 4–1: Expected Effectiveness and Relevant Considerations for Source Control

| Type of Source Control | Effectiveness and Institutional Considerations |
|---|---|
| Public education program | Difficult to assess overall effectiveness, but should be a part of any source control program, to promote a clear identification and understanding of the problems and the solutions. Costs estimates are given in GVSDD (1999a). |
| Land-use planning | By-laws are required to implement and enforce land-use plans. Site plans for projects must be reviewed for compliance. Additional staff may be required. Interdepartmental and decision-making co-operation is crucial. Restrictions on certain land uses required to mitigate stormwater pollution may not be politically feasible. |
| Sewer use by-laws | Should be an essential element of any stormwater management plan and address the many elements that could have a negative impact on receiving waters (e.g., illegal dumping control, removing contaminated sediments from sewers, preventing illicit connections). |
| Housekeeping practices | Besides sewer use by-laws, a program is necessary to promote efficient and safe housekeeping practices for storage, use, clean-up and disposal of potentially harmful materials, such as fertilizers, pesticides, cleaning solutions, paint products, and automobile products. For the public, the housekeeping practices are usually addressed through education. |
| Control for construction sites | As many studies have shown, this can be a very important (and uncontrolled) element increasing run-off-induced pollution in streams. A specific guide for this aspect, describing the recommended techniques to control erosion and pollution during construction activities, should be developed and implemented. |
| Street cleaning | Any street-cleaning program for water quality improvement requires significant capital and an operations and management budget; there is a definite cost-benefit relationship between increased sweeping/frequency and pollutant removal. Oil and grease, and fine sediment cannot be taken care of by sweepers (metals are associated with fine sediment). To reduce pollutant loadings significantly, street sweeping must be carried out frequently (daily), which is usually not economically feasible. Based on studies done by the Ontario Ministry of Environment and Energy (MOEE), street sweeping programs undertaken once or twice per month remove less than five percent of pollutant loadings. However, one advantage of street sweeping is the control of street coarse solids (with their associated pollutants) and enhancing the aesthetics of stormwater discharges. See EPA (1999) for more information on effectiveness. |
| Catch basin cleaning | Catch basins, with and without sumps, can collect debris and sediment. The regular cleaning of accumulated sediments in catch basins can reduce the amount of pollutants discharged to receiving waters. |

Table 4–2: Expected Effectiveness and Relevant Considerations for On-Site Control

| On-Site Control | Relevant Aspects for Implementation |
|---|---|
| Controlled lot grading | There is little experience with a reduced lot grading as standard practice at a subdivision scale. The largest impact this practice will have is on the homeowner's use of his or her land. The ponding water on lots may take 24 to 48 hours to drain, which may restrict the active use of the land. This impact will be the greatest during the spring, with negligible impacts during the summer. |
| Ponding (parking, roof, or backyard) | Lot storage is highly effective in reducing downstream peak flow rates; the volume of storm run-off to the sewer system is not reduced as discharge occurs over a much longer duration. Normal parking lot maintenance procedures are suitable for parking lot storage areas. |
| Infiltration systems | On-site infiltration systems offer the possibility to reduce run-off volumes and to control quality. The potential for clogging (maintenance problems) for residential lots is reduced compared to larger end-of-pipe infiltration systems since the systems only accept roof drainage (roof drainage contains less suspended solid than road run-off). The impact of such systems on pollutants loading of the groundwater (where there is a well water supply) and on the groundwater table should be considered. |
| Sump pump for foundation drains | Although preferable, foundation drainage by sump pumps is not always feasible. In areas where the seasonally high water table is within 1 m of the building foundation drains, sump pumps should not be used. This requirement is imposed to prevent excessive sump pump operation in areas with high water tables and to prevent a looped system whereby the sump pump discharges maintain the foundation drainage. In these areas, a separate (third) pipe should convey foundation drainage to the receiving water. |
| Superpipe storage | Superpipes are very effective in reducing site peak flow rates. Special design and maintenance considerations are required for cleaning. |
| Grassed swales | Grassed swales are most effective for stormwater treatment (suspended solids) when a minimum channel slope is maintained (e.g., <1%) and a wide bottom width (>0.75 m) is provided. Effectiveness diminishes as velocities increase. Length should be at least 75 m and small check dams can help to increase detention times. |
| Buffer/filter strips | They are best implemented as one of a series of techniques in a treatment train, as pretreatment to other techniques. |
| Oil/grit separator | In recent years, there have been many refinements of existing designs introduced for oil/grit separators, and new designs have come to market. The designer is encouraged to review relevant monitoring studies for further guidance. It continues to be recommended that oil/grit separators may be used for spill control or, in the case of stormwater quality control, oil/grit separators may be implemented as part of a multi-component approach or as a stand-alone facility if data supports it. |

## 4.3 COLD CLIMATE CHALLENGES

One important aspect to consider for Canadian cities is how winter conditions affect BMP selection, design, and operation/maintenance. An extensive review of BMP selection and design in cold climates was performed by the Center for Watershed Protection (CWP, 1997). In this review, major considerations for cold-climate snowmelt and stormwater management were identified. The additional challenges that make some traditional BMP designs less effective or unusable warrant further consideration and are presented in Table 4–3.

Table 4–3: Cold Climate Challenges for Stormwater BMPs

| Climate Condition | Design Challenge |
|---|---|
| Cold temperature | • Pipe freezing<br>• Permanent pool ice-covered<br>• Reduced biological activity<br>• Reduced oxygen levels during ice cover<br>• Reduced settling velocities |
| Deep frost line | • Frost heaving<br>• Reduced soil infiltration<br>• Pipe freezing |
| Short growing season | • Short period to establish vegetation<br>• Different plant species appropriate to cold climates |
| Snowfall | • High run-off volumes during snowmelt and rain-on-snow events<br>• High pollutant loads during spring melt<br>• Impacts of road salt/de-icers<br>• Snow management may affect BMP storage |

Many of the recommendations made in the CWP document address depth of cover and backfilling practices, which are standard in Canada. The recommendations regarding storage volume increases and designs to limit problems due to freezing also warrant consideration. Other relevant references for specific recommendations on BMP applications in cold climates are included in the bibliography (AEP, 1999; CWP, 1997; GVSDD, 1999a; Barr Engineering, 2001; Jaska, 2000; Maksimovic, 2000; MPCA, 2000: NYDEC, 2001; VNR, 2001).

## 4.4 COSTS AND OPERATION

Capital costs and operating costs of stormwater BMPs are difficult to estimate from reported construction and maintenance activities in other locations. Most BMPs have site-specific requirements that are a function of the stormwater quality, local conditions, and design objectives, as well as environmental considerations, land uses, and public preferences. Also, costs vary from one location to another as a function of the local economies. Capital and operating costs of any particular BMP will have a great deal of variability. And, especially for on-site controls, the long-term maintenance responsibility can be a problem, because many of these practices are implemented on private property.

The total cost of implementing a stormwater BMP involves a number of components including the costs associated with administration, planning and design, land acquisition, site preparation, site development, and operation and maintenance.

**Capital costs** are the total costs, including labour and materials associated with the actual on-site construction, of the BMP facility.

**Engineering costs** include labour and expenses, and all the costs associated with planning and final design of the BMP. Engineering costs for BMPs may be greater than the traditional allotment of 10 percent of the total capital cost.

**Operation and maintenance costs** include the total labour and the expenses associated with operating and maintaining the BMP at an acceptable level of performance. Appropriate operation and maintenance budgets are an essential component of all stormwater BMPs. The unit costs of operation and maintenance are difficult to determine, based on the experience of other municipalities. As with capital costs, operation and maintenance costs can vary considerably from municipality to municipality and from site to site, because of differences in drainage basin characteristics of run-off and sediment load, meteorological differences, labour, and equipment costs, disposal costs, and design/performance objectives for the facility.

**Contingency costs** are associated with unforeseen construction elements required over the construction period. Contingency costs for BMPs are expected to be more than the traditionally allowed 15 percent of the total capital cost.

Canadian references for cost estimates of source and on-site controls include the Ontario manuals (MOE, 1994, 1999), the Ontario *Stormwater Pollution Prevention Handbook* (TRCA and MOE, 2001), GVSDD (1999a), AEP (1999), and Jaska (2000). Other relevant U.S. references are given in the Bibliography (ASCE/EWRI, 2001; ASCE/WEF, 1998; Schueler, 1987; EPA, 1999; Young et al., 1996; GVRD, 2002). Table 4–4 summarizes some of these costs for on-site structural measures. Note that this information should be used for planning purposes only as site-specific costing should be determined in all cases.

As with most construction activities, economies of scale must be considered in using unit costs to arrive at preliminary cost estimates. Aesthetic and safety considerations can also add to the basic cost of construction. Phasing in construction activities can be an important factor in the overall cost.

Table 4–4: Costs Information for On-Site Control (for planning purposes)

| On-Site Control | Cost Information |
|---|---|
| Ponding (parking, roof, or backyard) | Different types of flow control devices exist to restrict the flow in catch basins. Typically, the prices could vary from \$200 to \$600 for an inlet control device (depending on the restricting flow and the number of devices), which would be added to the cost of each catch basin. |
| Infiltration systems | The cost of a crushed stone basin can be \$28/$m^3$ and \$20,000/ha for infiltration trenches. |
| Downspout disconnection/sump pump for foundation drains | For existing areas, downspout disconnections can have an average cost of \$200 (TRCA and MOE, 2001). Costs for sump pump installation in a new house vary from \$300 to \$1,500; the cost can be significantly higher for a retrofit. |
| Superpipe storage | Costs depend on the storage provided. |
| Grassed swales | Costs may vary from \$20 to \$75/m, depending on local conditions, swale dimensions, and the amount of internal storage provided. |
| Buffer/filter strips | Costs are usually relatively low. |
| Oil/grit separator | Costs depend on the type of device used and the volume to be treated. Data from manufacturers should be investigated, but typical costs for an oil/grit separator for a parking lot would be between \$15,000 and \$40,000. |

An annual budget of 3 to 5 percent of the total construction costs should be allowed for operation and maintenance of most BMPs. Infiltration trenches are the exception, with a recommended allowance of 5 to 10 percent of construction costs for surface facilities and 10 to 15 percent for underground facilities. Operating costs should also include provisions for ongoing performance monitoring of the BMP to optimize operation and maintenance requirements and determine the effectiveness of the BMP in enhancing hydrologic and water quality conditions. Information on maintenance costs is given in AEP (1999) and in other references already given in this section.

# APPENDIX A: BACKGROUND INFORMATION FOR WATER QUALITY

There has been a tendency to regard stormwater as a relatively minor source of pollution. However, numerous studies like the Nationwide Urban Runoff Program (NURP) (1983) in the United States, and others in Canada and Europe, have clearly indicated there can be significant pollution in stormwater run-off. In fact, the annual loading from urban run-off can be similar to that found in wastewater effluent and industrial discharges. This can affect the potable water supply, aquatic habitat, recreation, agriculture, and aesthetics.

Adverse impacts on receiving waters associated with stormwater discharges can be significant. These include:

- short-term changes in water quality during and after storm events, including temporary increases in the concentration of one or more pollutants, toxins, or bacteria levels;
- long-term water quality impacts caused by the cumulative effects associated with repeated stormwater discharges from a number of sources; and
- physical impacts due to erosion, scour, and deposition associated with the increased frequency and volume of run-off that alters aquatic habitat.

The net effect of urbanization is to increase pollutant loading over predevelopment levels. The impact of the higher export is felt on adjacent streams and on downstream receiving waters, such as lakes, rivers, and estuaries. Pollutants associated with urban run-off potentially harmful to receiving waters include:

- nutrients (nitrogen/phosphorus);
- suspended solids;
- temperature;
- pathogens (bacteria/viruses);
- metals;
- hydrocarbons;
- organics; and
- salt (sodium, chloride)

These pollutants degrade water quality in receiving waters near urban areas, often impair use and exceed criteria in water quality standards. In urban streams, higher concentrations can cause water quality problems, such as turbidity, nutrient enrichment, bacterial contamination, organic matter loads, toxic compounds, temperature increases, and increased instances of trash or debris. The quantity of these pollutants per unit area delivered to receiving waters tends to increase with the degree of development in urban areas. Figure A–1 shows the effects of pollutants on water resources; in terms of relative importance, nutrients and solids account generally for a larger part of the total quantity of pollutants.

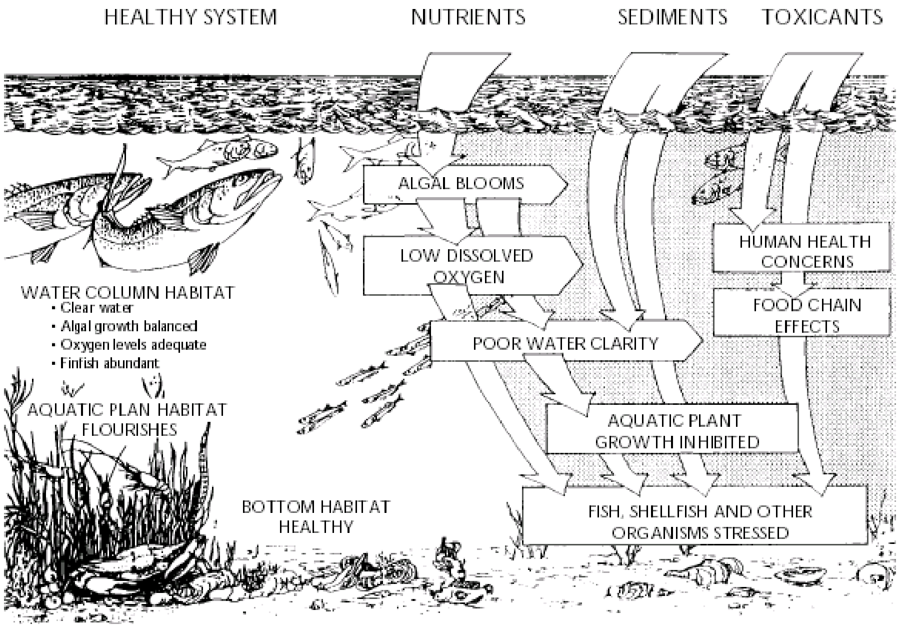


Figure A–1. General effects of non-point source pollutants on water resources

The pollutants found in urban storm water run-off originate from a variety of sources including contaminants from residential and commercial areas, industrial activities, construction, streets and parking lots, and atmospheric deposition. Contaminants commonly found in stormwater run-off, their likely sources, and the related impacts are summarized in Table A–1. These impacts are significant, and water quality control should be integrated in any stormwater management plan developed in a sustainable development framework.

The most comprehensive study of urban run-off was NURP, conducted by the EPA (1983) between 1978 and 1983. NURP examined the characteristics of urban run-off, the similarities or differences between urban land uses, the extent to which urban run-off is a significant contributor to water quality problems nationwide, and the performance characteristics and effectiveness of management practices to control pollution loads from urban run-off. Sampling was conducted for 28 NURP projects, which included 81 specific sites and more than 2300 separate storm events. Median event, mean concentrations (EMCs) for the 10 general NURP pollutants for various urban land use categories are presented in Table A–2.

The NURP results indicated a significant difference in pollutant concentrations in run-off from different urban land use categories. There is a significant difference, however, in pollutant concentrations in run-off from urban sources compared to non-urban areas. Some studies compared the water quality in urban run-off with domestic wastewater and found that, for some parameters, the concentrations in urban run-off compare to that found in untreated domestic wastewater. When untreated urban run-off is discharged directly to receiving streams, the concentration of pollutants can be much higher than for treated domestic wastewater.

Table A–3 gives the results from Canadian studies and provides concentrations for chemical constituents in stormwater. One parameter that can be important for water quality control with Canadian conditions is chloride, which is associated with snowmelt. The snow pack can also store hydrocarbons, oil and grease, chlorides, sediment, and nutrients. The pollutant load during snowmelt can be significant, and the chemical traits of snowmelt change over the course of the melt event. Oberts (Maksimovic, 2000) studied this phenomenon, and described four types of snowmelt run-off (Table A–4). Oberts and others have reported that 90 percent of the hydrocarbon load from snowmelt occurs during the last 10 percent of the event. From a practical standpoint, the high hydrocarbon loads experienced toward the end of the season suggest that stormwater management practices should be designed to capture as much of the snowmelt event as possible.

Recent research suggests a direct relationship between watershed imperviousness and stream health: stream health impacts tend to begin in watersheds with only 10 to 20 percent imperviousness (the 10 percent threshold). Sensitive streams can exist relatively unaffected by urban stormwater with good levels of stream quality where impervious cover is less than 10 percent, although some sensitive streams experience water quality impacts at as low as five percent imperviousness. Affected 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.

### Public Health Impacts

Public health impacts associated with urban stormwater occur when humans ingest or come in contact with pathogens. While these impacts are not widely reported, they do occur, and some have been documented.

Beach closures are a common occurrence in many communities and 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

Table A–1: Summary of Main Stormwater Pollutants, Sources, Effects, and Related Impacts

| **Stormwater Pollutant** | **Sources** | **Effects** | **Related Impacts** |
|---|---|---|---|
| Nutrients (nitrogen/phosphorus) | Urban landscape run-off (fertilizers, detergents, plant debris, sediment, dust, gasoline, tires), agricultural run-off (fertilizers, animal waste), failing septic systems. | Phosphorus is the primary nutrient of concern in most freshwater systems.<br>Nitrogen is the primary concern in most saltwater systems, but can be a concern in streams as well. | Algal growth; reduced clarity; lower dissolved oxygen; release of other pollutants. Nutrients can limit recreational values (swimming, boating, fishing, and other uses), reduce animal habitats and contaminate water supplies. |
| Suspended solids | Construction sites, other disturbed and non-vegetated lands, eroding banks, road sanding, urban run-off. | Increased turbidity and deposition of sediment. | Increased turbidity; reduced clarity; lower dissolved oxygen; deposition of sediments; smothered aquatic habitat. |
| Pathogens (bacteria/viruses) | Animal waste, urban run-off, failing septic systems. | Presence of bacteria and viral strains, including fecal streptococcus and fecal coliform in high numbers. Bacteria levels are usually higher in summer when warm temperatures are beneficial to reproduction. | Human health risks via drinking water supplies; contaminated shellfish-growing areas and swimming beaches. |
| Metals (lead, copper, cadmium, zinc, mercury, chromium, aluminium, and others) | Industrial processes, normal wear of automobile brake lines and tires, automobile emissions, automobile fluid leaks, metal roofs. | Increased toxicity of run-off and accumulation (biomagnification) in the food chain. | Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain. |
| Hydrocarbons (oil and grease, Polycyclic Aromatic Hydrocarbons (PAHs) | Industrial processes, automobile wear, automobile emissions, automobile fluid leaks, waste oil. | Degraded appearance of water surfaces; limiting water and air interactions (lower dissolved oxygen). Hydrocarbons have a strong affinity for sediment. | Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain. |
| Organics (pesticides, polychlorinated biphenyl/PCBs, synthetic chemicals) | Pesticides (herbicides, insecticides, fungicides, etc.); industrial processes. | Increased toxicity to sensitive animal species and fishery resources and accumulation (biomagnification) in the food chain. | Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain. |
| Salt (sodium, chlorides) | Salting of roads and uncovered salt storage. | Toxicity to organisms, reduction of fishery resources and increased levels of sodium and chloride in surface and ground waters. Could stress plant species' respiration processes through their effect on soil structure and can cause the loss of other compounds necessary for plant viability, and lead to plant mortality or reduced growth or diversity by root and leaf damage. | Toxicity of water column and sediment. Salt can cause the loss of sensitive animal species, plant species, and fishery resources and contaminate surface and ground waters. |

closures to occur. Stormwater run-off 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. Fish can also be contaminated for a number of reasons, and this contamination goes beyond health issues, having the potential to hurt the recreational fishing industry as a whole.

### Aesthetic Impacts

The aesthetic impacts associated with urban stormwater are often difficult to quantify. However, they are often very visible to the public. The presence of floatables within urban waters and deposited along the banks of waterways represents a common aesthetic impact in most urban settings, particularly in public areas where shoreline recreation occurs. Floatable wastes originate from street litter and improper solid waste disposal practices. Aesthetic impacts from the eutrophication of urban waterways is caused, in part, by nutrients delivered in urban stormwater. The visual damage to urban streams from accelerated rates of stormwater run-off also contribute to aesthetic impacts. These include algae blooms, eroded stream banks, fallen trees, and sedimentation.

Table A–2. 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 |

Source: NURP (EPA, 1983).

Table A–3: Storm Outfall for Wet Weather (City of Edmonton, mixed land use)

| **Constituent** | **30th Ave Storm** | | **Groat Rd Storm** | | **Quesnell Storm** | | **Total Storm** | |
|---|---|---|---|---|---|---|---|---|
| | **Spring** | **Summer** | **Spring** | **Summer** | **Spring** | **Summer** | **Spring** | **Summer** |
| BOD (mg/L) | 20 | 13 | 28 | 19 | 20 | 16 | 22 | 16 |
| COD (mg/L) | 102 | - | 145 | - | 124 | - | 130 | - |
| TSS (mg/L) | 155 | 104 | 290 | 227 | 162 | 189 | 180 | 164 |
| $NH_3$-N (mg/L) | 1.14 | 0.48 | 1.6 | 0.67 | 0.99 | 0.34 | 1.26 | 0.5 |
| TKN (mg/L) | 4.0 | 2.3 | 5.2 | 0.9 | 3.9 | 2.4 | 4.4 | 2.7 |
| Total N (mg/L) | 5.9 | 4.2 | 6.2 | 4.2 | 4.7 | 3.3 | 5.6 | 3.9 |
| Total P (mg/L) | 0.88 | 0.42 | 1.08 | 0.69 | 0.85 | 0.55 | 0.95 | 0.60 |
| Total Dissolved P (mg/L) | 0.54 | - | 0.40 | - | 0.48 | - | 0.50 | - |
| Chloride (mg/L) | 168 | 26 | 157 | 40 | 117 | 26 | 153 | 30 |
| FC (X $10^3$ cfu/100mL) | 26 | 40 | 58 | 91 | 16 | 33 | 28 | 49 |
| *Giardia lamblia* (#/100L) | 2,640 | 6,970 | 19,180 | 33,590 | 2,170 | 8,360 | 4,030 | 12,510 |
| *Cryptosporidium* (#/100L) | 1,840 | 1,480 | 2,780 | 2,670 | 1,720 | 2,050 | 1,990 | 2,010 |

Notes: Source: City of Edmonton

1. Spring – samples collected from storm outfalls during snowmelt conditions (January-April).
2. Summer – samples collected from storm outfalls during rainfall events (May - December).
3. For *Crytosporidium* and *Giardia lamblia*, data are for 1998 to 2002.
4. Values presented are median values except for FC, *Cryptosporidium* and *Giardia lambllia* (geoman).

Table A–4: Run-Off and Pollutant Characteristics of Snowmelt Stages

| **Snowmelt Stage** | **Duration/Frequency** | **Run-off Volume** | **Pollutant Characteristics** |
|---|---|---|---|
| Pavement melt | Short but many times in winter | Low | Acidic, high concentrations of soluble pollutants, chloride, nitrate, lead. Total load is minimal. |
| Roadside melt | Moderate | Moderate | Moderate concentrations of both soluble and particulate pollutants. |
| Pervious area melt | Gradual, often at end of season | High | Dilute concentrations of soluble pollutants, moderate-to-high concentrations of particulate pollutants, depending on flow. |
| Rain-on-snow melt | Short | Extreme | High concentrations of particulate pollutants, moderate-to-high concentrations of soluble pollutants. High total load. |

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