Storm and Wastewater

Conveyance and End-of-Pipe Measures for Stormwater Control

This document is the thirteenth in a series of best practices that deal with buried linear infrastructure as well as end of pipe treatment and management issues. For titles of other best practices in this and other series, please refer to <*www.infraguide.ca*>.

National Guide to Sustainable Municipal Infrastructure ®

NRC · CNRC FCM Federation of Canadian Municipalities Fédération canadienne des municipalités Canada

Conveyance and End-of-Pipe Measures for Stormwater Control

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INTRODUCTION

InfraGuide® – Innovations and Best Practices

Why Canada Needs InfraGuide®

Canadian municipalities spend $12 billion to $15 billion annually on infrastructure, but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems. Municipalities[1] must provide these services to satisfy higher standards for safety, health, and environmental protection as well as population growth. The solution is to change the way we plan, design, and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the *National Guide to Sustainable Municipal Infrastructure* (InfraGuide) seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: decision making and investment planning, potable water, storm and wastewater, municipal roads and sidewalks, environmental protocols, and transit. The best practices are available online and in hard copy.

A Knowledge Network of Excellence

InfraGuide´s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. By gathering and synthesizing the best Canadian experience and knowledge, InfraGuide helps municipalities get the maximum return on every dollar they spend on infrastructure—while being mindful of the social and environmental implications of their decisions.

Volunteer technical committees and working groups—with the assistance of consultants and other stakeholders—are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner or a municipal councillor, your input is critical to the quality of our work.

Please join us.

Contact InfraGuide toll-free at **1-866-330-3350** or visit our Web site at ***<www.infraguide.ca>*** for more information. We look forward to working with you.

1 References to municipality (or municipalities) throughout this document are intended to include utility (or utilities) as well as other purveyors of services.

The InfraGuide® Best Practices Focus

Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Events such as water contamination in Walkerton and North Battleford, as well as the recent CEPA classification of ammonia, road salt and chlorinated organics as toxic substances, have raised the bar for municipalities. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

Decision Making and Investment Planning

Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.

Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

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EXECUTIVE SUMMARY

Increasing urbanization and higher public expectations for runoff control have been driving forces in the trend toward the increasing use of stormwater management principles. This document provides an overview of the rationale behind stormwater management principles and explains why implementing runoff controls is important for sustainable development. Stormwater runoff and its impact on urban and rural development, and on aquatic resources have received increased public attention. It is generally recognized that stormwater must be addressed during the planning, design, construction and operation phases of communities, in a different manner than in the past.

Historically, only the quantitative aspect has been used as a main design objective. It is now recognized that broader design criteria that include both quantity and quality parameters are needed for sustainable development. To preserve and maintain our natural resources for present and future generations, it will be necessary to plan development in ways that recognize such things as the protection of water quantity and quality, surface and groundwater linkages, and dependencies between physical and biological resources. Criteria for both quantitative and qualitative aspects are therefore discussed to provide a good overview of the different elements that should ideally be included in an integrated stormwater management plan. These criteria include the effects of increased stormwater runoff on the hydrologic cycle and the environment, impact onstream hydrology, stream morphology, stream habitat, biological community, and water quality.

The focus of this best practice is on stormwater control through conveyance and end-of-pipe measures. This involves both prevention and mitigation of stormwater runoff quantity and quality impacts through a variety of methods and mechanisms.

Stormwater best management practices need to promote the following objectives:

- Achieve healthy aquatic and related terrestrial communities.
- Reduce erosion/sedimentation impacts.
- Maintain and re-establish natural features and hydrologic processes, encourage infiltration and replenish soil moisture.
- Enhance water quality in support of specific water usage in receiving waters and minimize aesthetic nuisances.
- Protect life and property from flooding.
- Encourage multi-use facilities by providing recreational and aesthetic amenities in the urban landscape.
- Encourage reuse of stormwater by considering it as a resource and not as a nuisance.

Achieving these objectives requires educational programs and community involvement in the planning and design process.

A stormwater control program to meet these objectives may include all or some of:

- rainfall and runoff capture;
- flow attenuation;
- water quality enhancement;
- minor and major flow conveyance; and
- riparian corridor sustenance.

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 conveyance and end-of-pipe control.

Conveyance control best management practice facilities are located within the drainage system where flows are concentrated in a flow conveyance route.

To preserve and maintain our natural resources for present and future generations, it will be necessary to plan development in ways that recognize such things as the protection of water quantity and quality, surface and groundwater linkages, and dependencies between physical and biological resources.

A wide range of situations and different elements must be considered in determining the appropriate practices. These include physical suitability of the site, expected stormwater management benefits, pollutant removal benefits and environmental amenities.

End-of-pipe control facilities come at the end of the flow conveyance route.

Both types of control can provide flow attenuation, major flow conveyance, and water quality enhancement of stormwater before discharge into a receiving water body. These measures should be applied following the implementation of source and on-site controls and pollution prevention planning.

A wide range of situations and different elements must be considered in determining the appropriate practices. These include physical suitability of the site, expected stormwater management benefits, pollutant removal benefits and environmental amenities. In many instances combinations of stormwater management techniques will be required to address a range of concerns.

The effectiveness and costs for different control measures and related operation and maintenance issues are also presented, as they are essential elements in the decision-making and implementation process. In addition, design aspects and references related to cold-climate conditions are highlighted to reflect the Canadian perspective.

1. General

1.1 Introduction

Urbanization increases stormwater quantity and affects stormwater quality, producing significant hydrologic and environmental changes that can potentially result in adverse impacts on streams, other receiving waters, and their habitats. As an area develops or urban intensification takes place, undisturbed pervious surfaces become impervious with the construction of homes, buildings, roads, parking lots, and other structures. These hard surfaces increase stormwater runoff volume and flow rates, and impact the pollutant concentrations associated with runoff.

To address stormwater management objectives, stormwater runoff considerations need to be integrated fully into 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. Normally called "integrated stormwater management planning," this approach treats stormwater as a resource to be protected and includes protection of property, aquatic resources, and water quality as complementary objectives. Stormwater should be 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 that include pollution prevention, and source, on-site, conveyance, and end-of-pipe control management practices (UDFCD, 2004; Urbonas and Roesner, 1993).

1.2 Scope

This best practice is linked to the best practices for *Stormwater Management Planning* (InfraGuide, 2004) and *Source and On-Site Controls for Municipal Drainage Systems* (InfraGuide, 2003).

Conveyance control best management practice facilities are located within the drainage system where flows are concentrated in a flow conveyance route. End-of-pipe control facilities are at the end of the flow conveyance route. Both techniques can provide flow attenuation, major flow conveyance, and water quality enhancement of stormwater before discharge into a receiving water body. Both of these measures of source and on-site control measures.

The rationale to implement conveyance and end-of-pipe controls is first presented along with criteria for selecting the most appropriate measures and techniques depending on site and watershed characteristics. A description of the state-of-art methodologies for conveyance and end-of-pipe controls is then given, based on available and tested approaches. The degree of effectiveness and costs for different facilities, and related operation and maintenance issues are also presented, as they are essential in the decision-making and implementation process. Design aspects and references related to cold-climate conditions are also highlighted to reflect a northern perspective.

To address stormwater management objectives, stormwater runoff considerations need to be integrated fully into site planning and design processes.

This best practice is based on a scan carried out for the InfraGuide on conveyance and end-of-pipe measures for stormwater control. The scan included a literature search and survey of municipalities to identify state-of-art methodologies for conveyance and end-of-pipe controls. The literature search covered close to 600 documents published in Canada, the United States, Australia, Europe (mainly France, Great Britain, Germany, and Sweden) and Japan, from conference proceedings to articles, books, manuals, guidelines, and Internet sites. The scan was oriented toward finding and reviewing documents that could relate to climatic conditions similar to those observed in Canada. Therefore, existing stormwater management manuals and guidelines developed for Canadian cities or provinces and states in the United States located near the Canadian border were analyzed in greater detail. A survey questionnaire sent to over 200 municipalities from all provinces and territories included municipalities from less than 10,000 population to over 300,000 population. Responses from 126 municipalities were analyzed. The results identified the current practices and needs of the Canadian municipalities and assisted in preparing this best practice document.

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 have been listed in the references of this document. Many useful documents developed specifically for Canadian conditions by different provinces or cities are available on the Internet.

1.3 Glossary

Aesthetics (as a surface water quality parameter) — All surface waters should be free from pollutants 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.

Bankful flow — The flow which just begins to overtop the floodplain.

Buffer strips — A zone of variable width located along both sides of a natural feature (e.g., stream) 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.

Channel incision — The overall lowering of the stream bed over time.

Check dam — A small dam constructed in a ditch, gully or other small watercourse to decrease flow velocity, minimize scour, and promote sediment deposition.

Contaminant — 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.

Conveyance controls (CC) — Practices that reduce runoff 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., 2-year, 24-hour storm) that is assumed to produce runoff volume and peak flow rate of the same frequency. Other forms of rainfall input data are also used particularly in water quality simulation.

Down cutting — Deepening of the stream channel and valley.

End-of-pipe controls (EoP) — Practices that reduce runoff volumes, attenuate flow rates and treat stormwater at the outlet of drainage systems, just before it reaches the receiving streams or waters. These controls are usually implemented to manage the runoff from larger drainage areas.

Filter strip — A strip of permanent vegetation upstream of ponds, diversions, and other structures to retard the flow of runoff, causing deposition of transported material, thereby reducing loadings of sediment and other constituents.

Floodplain — The flat depositional surface adjacent to and being formed by the stream in its present hydrologic state.

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

Impervious cover — Those surfaces in the landscape that cannot infiltrate stormwater (e.g., concrete, asphalt shingles, tar and chip, etc.).

Infiltration rate — The rate at which stormwater percolates into the subsoil measured in millimetres/hour (mm/hr).

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 to address the impacts of stormwater management on community values.

Interceptor — Typically, a large sewer that intercepts lateral flows from combined or sanitary systems and conveys to a treatment facility for water quality treatment.

Loading — The quantity of a substance entering the environment.

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

Pool-riffle — Riffles and pools (calm areas) are where shallow water moves over the rocky stream bottom.

Pre-treatment — Techniques employed in stormwater best management practices to provide storage or filtering to help trap coarse materials and other pollutants before they enter the system.

Riparian — Pertaining to, or situated on, the bank of a body of water, especially of a water course such as river.

Runoff — That portion of the precipitation on a drainage area that is discharged from the area to the stream channels.

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 runoff and to manage volumes and rates of runoff, with emphasis on non-structural and semi-structural measures applied at or near the source.

Stormwater best management practices — Practices 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.

Stream corridor — The stream, its floodplain, and a transitional upland fringe.

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

Suspended solids — The amount of sediments (particulate matter) suspended in a water body.

Treatment train — An arrangement of stormwater management measures in a series to achieve the required performance.

Water Balance — The balance in a hydrologic system between precipitation or other inputs, and the outflow of water by runoff, evapotranspiration, groundwater recharge and streamflow. Also commonly referred to as water budget.

2. Rationale

2.1 Urban Stormwater

The hydrologic cycle describes the continuous circulation of water between the oceans, atmosphere, and land. Within the land phase of the hydrologic cycle, water is stored by water bodies, snowpacks, land surfaces, vegetation, and sub-surface strata. Water is transported between these storage compartments via overland runoff, stream flow, infiltration, groundwater recharge, groundwater flow, and groundwater discharge, among other processes.

Frequent small storms cumulatively produce most annual runoff and pollutant load to receiving waters. Large storms may also contribute significant pollutant loadings, but infrequently. They however represent a significant conveyance problem and are the focus of most drainage design. The impact of climatic changes and the associated changes in rainfall patterns also play a role in the changes to the hydrologic cycle.

Urbanization interferes with the natural balances of water between storage components of the hydrologic cycle. Land development affects the physical as well as the chemical and biological conditions of streams, rivers, and lakes. The addition of impervious surfaces reduces infiltration and increases the total volume of runoff. A decrease in infiltration reduces groundwater recharge, which can reduce the base flow in streams. Moreover, these changes accelerate the rate at which runoff flows, and increase the risk of surface and basement flooding and the erosive forces on stream banks and beds. This effect is further exacerbated by man-made drainage systems (Schueler, 1987).

Generally, the impacts are most severe in the downstream reaches of stormwater conveyance systems where the accumulating effect of the increased runoff due to development more frequently exceeds the conveyance system design capacity.

Urbanization affects the quantity and quality of stormwater runoff, and development increases both the concentration and types of pollutants carried by runoff. Degradation of water quality can result in a decline in plant, fish and animal diversity. It may also affect drinking water supplies and recreational uses of water, such as swimming. Figure 2–1 shows a flow chart of the sources and movement of water and potential pollutants in separate urban drainage systems.

Stormwater runoff into lakes and reservoirs can have some unique negative effects, such as siltation and nutrient enrichment, which can result in the undesirable growth of algae and aquatic plants. Lakes do not flush contaminants as quickly as streams and can act as sinks for nutrients, metals, and sediments. Stormwater can impact estuaries, especially if runoff events occur in pulses, disrupting the natural salinity of an area, providing large loads of sediment, nutrients, and oxygen-demanding materials and causing erosion problems at the discharge point.

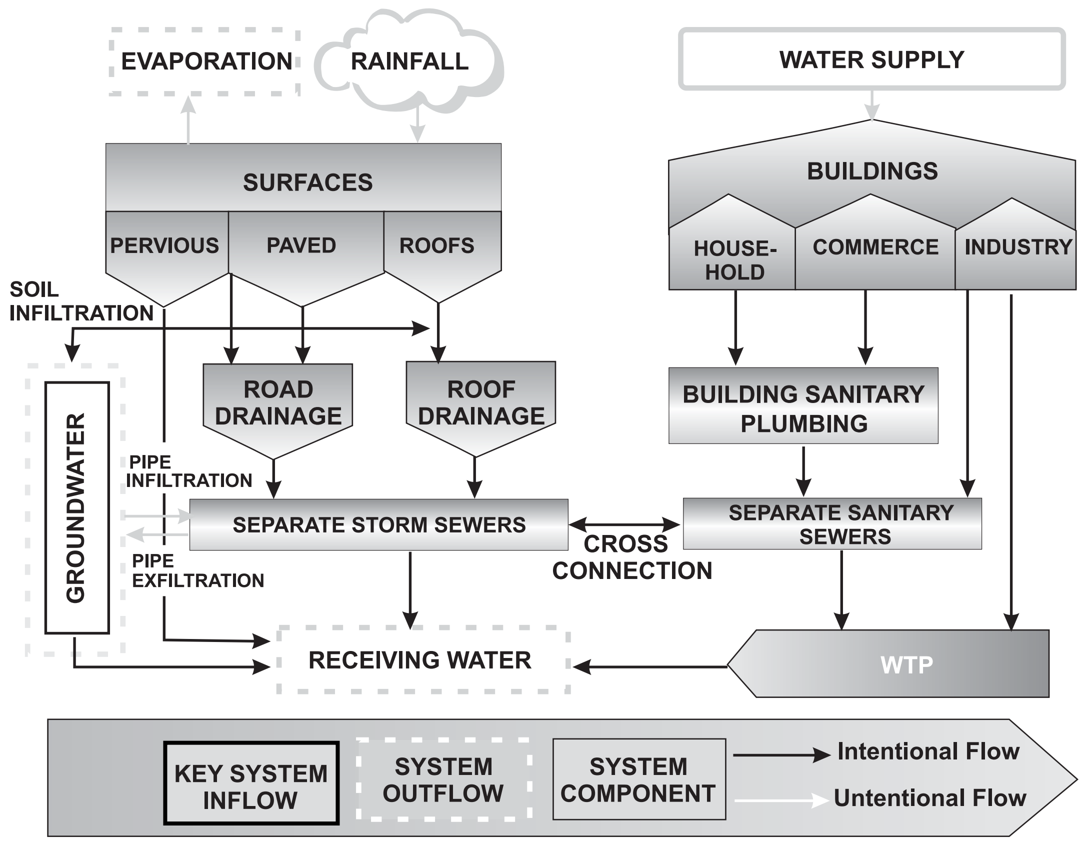
The results of increased stormwater runoff can be classified for further discussion by the impact on stream hydrology, stream morphology, stream habitat, biological community, and water quality. Further information on these impacts is included in Ontario, MOE (2003), British Columbia (2002), Maryland (2000), and New York (2001).

Stormwater runoff into lakes and reservoirs can have some unique negative effects, such as siltation and nutrient enrichment, which can result in the undesirable growth of algae and aquatic plants.

Figure 2–1
Sources and movements of water and potential pollutants in separate urban drainage systems

The changes in the rates and volumes of runoff from developed watersheds directly affect the morphology, or physical shape and character of streams and rivers.

Figure 2–1: Sources and movements of water and potential pollutants in separate urban drainage systems



Source: Butler, David and John W. Davies, 2000. Urban Drainage, (Taylor & Francis Group) E&FN SPon, London.

2.2 Impacts of Urbanization

2.2.1 Impacts on Stream Hydrology

Urbanization alters the hydrology of watersheds and streams by disrupting the hydrologic cycle. Such impacts include:

- increased flow velocities, volumes and peak flow rates;
- increased frequency of bankfull and near bankfull flows;
- increased duration and frequency of flooding and erosion;
- decreased natural depression storage and reduced potential for infiltration; and
- lower dry weather flows (base flow).

2.2.2 Impacts on Stream Morphology

The changes in the rates and volumes of runoff from developed watersheds directly affect the morphology, or physical shape and character of streams and rivers. Impacts due to urbanization include:

- stream down cutting, widening and bank erosion;
- channel incision and disconnection from the floodplain;
- loss of the riparian tree canopy;
- changes in the channel bed due to scouring and sedimentation; and
- increases in the floodplain elevation.

2.2.3 Impacts on Stream Habitat

Along with changes in stream hydrology and morphology, urbanization diminishes the habitat value of streams due to:

- degradation of habitat;
- loss of pool-riffle formation;
- loss of riparian vegetation;
- loss of substrate;
- sedimentation/fouling of the stream bed;
- reduced base flows; and
- increased stream temperature and pollution levels.

2.2.4 Impacts on Biological Community

In addition, stream corridors experience impacts on biological communities which include:

- declines in the terrestrial and bird populations, and in their abundance and biodiversity;
- succession of cold water species by warm-water species;
- reduced benthic community diversity and abundance; and
- increased representation of pollution-tolerant species.

2.2.5 Impacts on Water Quality

Polluted stormwater runoff and water quality impairment come primarily from diffuse or scattered sources—many of which are the result of human activities within a watershed. Urban drainage systems collect and convey polluted runoff to receiving waters resulting in point source pollution. The most frequently occurring pollution impacts include (Marsalek, 2003a):

- reduced dissolved oxygen levels in streams;
- increased suspended solids concentration;
- nutrient enrichment;
- microbial contamination;
- pollution by hydrocarbons, toxic materials, and road salt/deicers;
- higher water temperatures associated with runoff heating on impervious surfaces and in open surface stormwater management facilities;
- sedimentation, trash and debris; and
- reduced recreational use of near-shore waters.

2.3 Objectives and Goals of Stormwater Management

Stormwater management involves prevention and mitigation through a variety of methods and mechanisms. The primary objectives include the following:

- Achieve healthy aquatic and related terrestrial communities.
- Reduce erosion/sedimentation impacts.
- Maintain and re-establish natural hydrologic processes and encourage infiltration/replenish soil moisture.
- Protect, preserve and enhance natural features of watershed.
- Enhance water quality in receiving waters.
- Improve water quality in contact recreational waters and reduce beach closures.
- Minimize aesthetic nuisances (algae and floatables).
- Reduce basement flooding.
- Protect life and property from flooding.
- Provide recreational, educational, and aesthetic amenities in the urban landscape.
- Encourage reuse of stormwater by considering it as a resource and not as a nuisance.

Urban drainage systems collect and convey polluted runoff to receiving waters resulting in point source pollution.

3. Conveyance and End-of-Pipe Best Management Practice

3.1 General Framework

Stormwater best management practices must incorporate water quantity and quality concerns. Many common practices are limited in terms of the environmental benefits they provide. Recently, designers of stormwater management facilities recognized that stormwater quality and the impact of stormwater management facilities on the environment are important factors to consider in their selection of best management practices (Ontario, MOE, 2003; Washington, 2001; Minnesota, 2000).

Best management practices that address source controls should be a component of any stormwater management drainage plan. Source controls can have a significant effect on the total pollutant load discharged to a receiving water body. Pollution prevention planning involves public education, awareness, and participation, in addition to regulations, enforcement, and application of bylaws (TRCA and MOE, 2001; US EPA, 1999). However, source and on-site level controls alone may not reduce the total pollutant loads to acceptable levels in most development areas. Hence, it is important to consider further runoff controls and treatment using conveyance and end-of-pipe control facilities (MacViro and Gore & Storrie, 1991).

The application of best management practices to stormwater management requires consideration of a comprehensive set of evaluation criteria, which include all aspects of traditional conveyance practices and incorporate additional environmental considerations selected to preserve hydrologic conditions and water quality.

This section reviews best management practices in common use and discusses their selection and design as well as performance considerations. While the best management practices presented relate primarily to stormwater control in the final development, it is just as important that measures be taken to control stormwater during the construction phase. Sediment and erosion controls should be installed before and during construction to protect adjacent areas and natural receiving water bodies.

The practices described in this section can be applied when designing the drainage system. Although best management practices are presented as individual elements, they can be used either as stand-alone facilities or in combination when designing the overall drainage system for a particular site. Site-specific conditions, and characteristics and requirements of municipalities and regulatory agencies will govern the stormwater management solutions to be implemented.

3.2 Criteria

Design criteria for stormwater best management practices encompass the more holistic view now associated with stormwater management. This approach includes water quantity and quality, and downstream and receiving water impacts. The same criteria are also used to evaluate the effectiveness of facilities. These criteria can be classified in five categories:

- rainfall and runoff capture;
- flow attenuation;
- water quality enhancement;
- minor and major flow conveyance; and
- riparian corridor sustenance.

Pollution prevention planning involves public education, awareness, and participation, in addition to regulations, enforcement, and application of bylaws.

Controlling post-development peak flow rates through storage to values equal to or less than predevelopment conditions may be required to avoid significantly exceeding existing downstream watershed peak flow rates and velocities and more closely mimic the natural hydrologic cycle.

3.2.1 Rainfall and Runoff Capture

When impacts of urban development are significant, water balance methods can be used to determine the amount of water that should be infiltrated, evaporated or re-used to compensate for reductions caused by large impervious areas or changes to vegetation. (Graham et al., 2004 and Water Balance Model, <http://www.waterbalance.ca, 2005>).

3.2.2 Flow Attentuation

Controlling post-development peak flow rates through storage to values equal to or less than predevelopment conditions may be required to avoid significantly exceeding existing downstream watershed peak flow rates and velocities and more closely mimic the natural hydrologic cycle.

3.2.3 Water Quality Enhancement

The primary criteria used in most jurisdictions are volumetric and specify a design storm of which runoff should be captured and treated. In most cases, the selected design storm rainfall depths range from 12.5 to 25 mm, and the corresponding storage, with a drawdown time of 24 hours, would capture more than 85% of the annual runoff volume, depending on local climate (Urbonas and Roesner, 1993). This type of volumetric 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, the level of protection (for specific classes of receiving waters) and the type of best management practice considered (MOE, 2003).

3.2.4 Minor and Major Flow Conveyance

The minor system (storm sewer systems and road ditches) provides a basic level of service by conveying flows during minor storm events. The major system (streets, roads, and natural channels) conveys runoff from extreme events in excess of the minor system capacity.

3.2.5 Riparian Corridor Sustenance

This includes a healthy aquatic habitat for fish, healthy and diverse vegetation for wildlife corridor connectivity, and a visually aesthetic stream corridor that incorporates water features, vegetative cover, and buffer.

Guidelines provided by three provinces (Ontario, British Columbia, and Alberta) for planning and designing stormwater management systems are illustrated in Table 3–1, as an example.

Table 3–1
Evaluation Criteria for Stormwater Best Management Practices in Ontario, British Columbia, and Alberta

Table 3–1: Evaluation Criteria for Stormwater Best Management Practices in Ontario, British Columbia, and Alberta

Criteria Category		Ontario	British Columbia	Alberta
	Rainfall and Runoff Capture		50% of 2-year, 24 hour storm must evaporate, or be infiltrated or re-used	
	Flow Attenuation	5-year/10-year to predevelopment	50% of 2-year, 24 hour rainfall amount through to the 2-year rainfall amount and release at rates that approximate natural forested watersheds	100-year to predevelopment
	Water Quality Enhancement	Volumetric sizing of stormwater facilities to achieve basic, normal, and enhanced levels of protection corresponding to a specified level of suspended solids removal Ultimately, to achieve the provincial water quality objectives	Treat 6-month storm	85% total suspended solids removal on annual basis for particle sizes greater than 75 microns
	Minor and Major Flow Conveyance	5-year/10-year—storm sewers 100-year—major overland flow routes	5/10-year—storm sewers 100-year—major overland flow routes	5-year—storm sewers 100-year—major overland flow routes
	Riparian Corridor Sustenance	Buffers are suggested by conservation authorities based on stream conditions, etc.	Setback varies: fish bearing, permanent creeks 15 to 30+ m; non-fish bearing, permanent creeks 5 to 30 m; non-fish bearing, non-permanent creeks 5 to 15 m	Varies with each location

NOTES:

Stormwater Planning: A Guidebook for British Columbia, Province of British Columbia, May 2002.
<http://wlapwww.gov.bc.ca/epd/epdpa/mpp/stormwater/stormwater.html>

Riparian Areas Regulation, Province of British Columbia, July 2004.
<http://wlapwww.gov.bc.ca/habitat/fish_protection_act/riparian/riparian_areas.html>

3. Conveyance and End-of-Pipe Best Management Practice

3.2 Criteria

Table 3–2
Technical Objectives and Goals for Stormwater Best Management Practices

Table 3–2 identifies the different criteria that have to be assessed for each primary objective. By identifying the objective for the particular application, the design and evaluation criteria to be used during the best management practice selection process could be defined from it.

Table 3–2: Technical Objectives and Goals for Stormwater Best Management Practices

Technical Objectives		Criteria Category				
		Rainfall and Runoff Capture	**Flow Attenuation**	**Water Quality Enhancement**	**Minor and Major Flow Conveyance**	Riparian Corridor Sustenance
						
1.	Achieve healthy aquatic and related terrestrial communities	✔	✔	✔		✔
2.	Reduce erosion/ sedimentation impacts	✔	✔	✔	✔	✔
3.	Maintain and re-establish natural hydrologic processes and encourage infiltration/ replenish soil moisture	✔	✔		✔	✔
4.	Protect, preserve and enhance natural features of watershed		✔	✔		✔
5.	Enhance water quality in receiving waters			✔		
6.	Improve water quality in contact recreational waters and reduce beach closures			✔		
7.	Minimize aesthetic nuisances			✔		✔
8.	Reduce basement flooding	✔	✔		✔	
9.	Protect life and property from flooding	✔	✔		✔	
10.	Provide recreational, educational, and aesthetic amenities in the urban landscape			✔		✔
11.	Encourage reuse of stormwater	✔	✔	✔	✔	

Note: Tick marks indicate only primary criteria categories to be considered.

3.3 Description of Best Management Practices

Conveyance and end-of-pipe controls effectively reduce the impacts of urban development in a watershed. Most practices can assist in addressing quantity and quality control (ASCE/EWRI, 2001; ASCE/WEF, 1998).

Stormwater conveyance systems transport runoff from developed areas through storm sewers, roadside ditches or grassed and vegetated swales. The primary function of conveyance control facilities is to mitigate the impacts of urbanization, such as increased surface runoff, reduced soil moisture replenishment, and reduced groundwater recharge. In addition, some of these best management practices can achieve water volume reduction through infiltration. However, infiltration of poor quality stormwater can impair good groundwater. Therefore, these measures are ideally suited to the infiltration of relatively high quality stormwater, such as stormwater from rooftops or foundation drainage (CIRIA, 1996). If the quality of the stormwater is such that it may clog the system or degrade groundwater quality, pre-treatment is required (ASCE, 2000; CWP, 2000; US FHWA, 2004).

End-of-pipe control best management practices provide flow attenuation, major flow conveyance, and water quality enhancement of stormwater before discharge into a receiving water body. A number of end-of-pipe alternatives are available for application depending on the characteristics of the upstream catchment, and the regulations and requirements for water quality in the receiving waters. End-of-pipe practices that provide extended detention reduce the rate of stormwater discharge by storing the stormwater runoff temporarily and releasing it at a controlled rate. Water quality treatment is provided through enhanced settling and biological processes.

From operating and monitoring end-of-pipe best management practices, it is evident that extended detention storage provides benefits related to water quality, erosion protection, and flood prevention (TRCA and MOE, 2001; US EPA, 1993).

Tables 3–3a and 3–3b briefly describe conveyance and end-of-pipe control best management practices. Only the most common practices by municipalities across Canada have been documented in these tables (MacViro, 2002; GVSDD, 1999; Camp, 1993). Most municipalities have experience with the application and implementation of these methods. Some of the measures could be applied as conveyance control or end-of-pipe control.

The primary function of conveyance control facilities is to mitigate the impacts of urbanization, such as increased surface runoff, reduced soil moisture replenishment, and reduced groundwater recharge.

Table 3–3a
Conveyance Control Best Management Practices

Table 3–3a: Conveyance Control Best Management Practices

Stream Corridor Protection and Enhancement (mostly as a mitigation measure)	
Primary Mechanisms	Limit the supply of nutrients and sediment, stream shading, attenuate stream flow, and contribute to stream habitat diversity.
Description, Advantages, and Drawbacks	Stream corridor measures are applied within the stream riparian zone, floodplain, valley slope or crest. They include native vegetation plantings, access controls, buffer treatments, and management practices. A healthy, naturally vegetated stream corridor provides stream shading; controls the overland movement of water and associated sediments, nutrients, and contaminants; adds nutrients (leaf litter) and woody debris to the stream providing food sources and habitat; and helps stabilize stream banks. In addition, stream corridors provide wildlife habitat and, depending on the width of the corridor, offer important linkages between other natural features that promote dispersion/migration of plant and animal communities.
Channel Modification (mostly as a mitigation measure)	
Primary Mechanisms	Modify river behaviour through changes in channel and valley form.
Description, Advantages, and Drawbacks	Channel modification refers to changing channel and/or valley form by direct intervention to minimize a disturbance causing stream instability. Modifications include changing the course of a river (planform), the channel dimensions (channel and valley cross-section), or the character of the channel (roughness or thalweg). Planform modifications can create a more stable channel in cases where the channel has been straightened or in cases that involve a change in upstream inputs. Channel and valley cross-section modifications can be engineered to increase stream stability. Floodplains can be created to relieve stress on the channel during flood flows for channels that have cut into their floodplain. Channel roughness can be used to speed up or slow down flow within a channel and manage the flow characteristics.
Bank Protection (mostly as a mitigation measure)	
Primary Mechanisms	Modify river behaviour through changes in bank character.
Description, Advantages, and Drawbacks	Bank protection methods are used to slow down or arrest the movement of a stream to provide temporary or more permanent control. Materials used in bank protection works include hard measures like rock, rip-rap, gabion mats, brush, wood, and soft measures like vegetation. Bank stabilization techniques include anchored cutting systems (bioengineering), geotextile systems, and integrated systems. Anchored cutting systems use large numbers of cuttings arranged in layers or bundles that are anchored to the stream bank. Geotextiles are used to retain soils and protect from direct erosion by water. Integrated systems use numerous bank protection techniques together to achieve bank stability.
Roadside Ditches	
Primary Mechanisms	Convey and reduce peak flows; use infiltration in some cases.
Description, Advantages, and Drawbacks	Roadside ditches are channels, usually along both sides of a roadway, designed to convey runoff from impervious surfaces and adjacent slopes, and dispose of it without damage from erosion, deposition, or flooding. Roadside ditches are also designed to prevent the lengthy accumulation of standing water. In some locations ditches may have ditch blocks or check dams to slow down the water, and promote sedimentation and infiltration before discharge into the receiving water course. Ditches are primarily used to convey stormwater but, depending on soil conditions, they could also be designed to promote infiltration. For this reason, ditches are applicable in many areas that swales are not, such as where soil conditions do not promote infiltration. Another difference between roadside ditches and grassed swales is that ditches are deeper to permit the drainage of the road sub-grade.

Table 3–3a: Conveyance Control Best Management Practices (continued)

Grassed or Vegetated Swales	
Primary Mechanisms	Infiltration or filtration.
Description, Advantages, and Drawbacks	Grassed or vegetated swales are broad, shallow channels with dense vegetation covering the side slopes and bottom. Swales can be natural or man-made, and are designed to trap particulate pollutants, promote infiltration, and reduce the flow velocity of storm water runoff. Suspended solids are primarily removed by filtering through the vegetation and through settling. Dissolved constituents may also be removed through chemical or biological mechanisms mediated by the vegetation and the soil. Swales may be inadequate to drain the road sub-grade if they are too shallow, and storm sewers may still be required in some applications for road sub-grade drainage. In areas where the soils do not support good infiltration, swales may act only as filters and, hence, they do not contribute significantly to the hydrologic balance or to erosion control unless properly designed.
Pervious Pipe Systems	
Primary Mechanisms	Exfiltration or infiltration.
Description, Advantages, and Drawbacks	Pervious pipe systems are designed to exfiltrate stormwater into the surrounding soil as it is conveyed downstream, reducing runoff volumes and providing pollutant removal. However, their effectiveness depends on soil and groundwater table characteristics, the suspended solids characteristics of the stormwater, and maintenance practices. The exfiltration system is best suited in areas with pervious soils and a low water table. A variation on the system uses filtration rather than exfiltration and is applicable to areas with tighter soils. In this variation, flow from the catch basin is discharged to a length of perforated pipe within a gravel-filled trench (in which the conventional storm sewer is also bedded). The runoff filters down through the trench and is collected by a second perforated pipe at the bottom of the trench. The second pipe conveys flow to the next downstream manhole and into the conventional sewer system. If the trench volume or catch basin capacity is exceeded, a second, higher level outlet in the catch basin allows flow to be conveyed to the conventional storm sewer. Long-term clogging as a result of a lack of pre-treatment and catch basin maintenance is the major drawback.
Pervious Catch Basins	
Primary Mechanisms	Infiltration or filtration.
Description, Advantages, and Drawbacks	A pervious catch basin is a normal catch basin with a large sump, which is physically connected to exfiltration storage media. In some designs, the storage media is located directly beneath the catch basin via a series of holes in the catch basin floor. An alternate design uses the catch basin sump for pre-treatment of runoff and discharges low flows through the wall of the catch basin to the exfiltration storage media located beside the catch basin.The exfiltration of road runoff is a contentious issue due to the elevated levels of pollutants. Long-term clogging as a result of a lack of pre-treatment and catch basin maintenance is the major drawback. Frequent catch basin cleaning is required to ensure longevity. Eventually, the exfiltration storage media will become clogged and will need to be replaced.

Table 3–3a: Conveyance Control Best Management Practices (continued)

In Line/Off Line Storage	
Primary Mechanisms	Provide storage to relieve the downstream system.
Description, Advantages, and Drawbacks	In-line and off-line storage facilities are often implemented to regulate and moderate peak flows in locations where the capacity of a sewer is inadequate during high-flow events. These systems are generally installed as an alternative to upgrading an entire sewer system. Both the in-line and off-line systems incorporate a flow regulator and a large storage capacity, which makes optimal use of the downstream sewers.The in-line storage unit is typically a large-diameter pipe installed into an existing sewer system. All flow through the system enters the "superpipe" at its upstream end, and flows toward the regulator at the downstream end. Excessive flows are retained in the superpipe until the peak has passed, at which point the superpipe begins to drain the flow and the sewer system returns to normal. The off-line storage system uses a regulator to divert excessive flow out of the sewer system and into an off-line tank. The tank provides storage until the flow rates in the sewer are below the downstream capacity, at which point the stored volume is slowly released back into the sewer.
Real Time Control	
Primary Mechanisms	Better use of existing collection system facilities, to minimize flooding and maximize capture.
Description, Advantages, and Drawbacks	Real time control optimizes the use of in-system storage. Under this scenario, control structures are put in place, and flows are stored in, or diverted to, parts of the sewer system where capacity is available during a rainfall event. Two modes of control can be considered: reactive, in which the system is operated in response to its state as the storm progresses over the catchment and predictive (or anticipatory), in which the system is operated in response to the anticipated state of the system before the occurrence of a rainfall event. In addition, two types of control can be distinguished: local, which relates to a single control point, and global, which relates to the total sewer system or the integrated system. Modelling of the sewer system is required regardless of which type or mode of control is used.

Table 3–3b
End-of-Pipe Control Best Management Practices

Table 3–3b: End-of-Pipe Control Best Management Practices

Wet Ponds	
Primary Mechanisms	Storage, peak flow reduction, sedimentation and some biological uptake..
Description, Advantages, and Drawbacks	Wet ponds are the most common end-of-pipe stormwater management facility employed for new developments and large-scale redevelopments. They are less land intensive than wetland systems and are normally reliable in operation, especially during adverse conditions (e.g., winter/spring). Wet ponds can be designed to provide for water quality, erosion, and quantity control, reducing the need for multiple end-of-pipe facilities. The wet ponds can be designed with extensive landscaping and associated recreational amenities, to become the centrepiece of a development. Wet ponds are less suitable for retrofit situations and are typically unsuitable for infill situations, because of their comparatively large land area and drainage area requirements (typically > 5 ha to allow adequate turnover and sustainability). Wet ponds can have detrimental impacts on stream temperatures, and the use of wet ponds on cold-water tributaries is normally discouraged. Wet ponds also encourage mosquito breeding. They do not typically provide infiltration and so provide limited benefit from a water balance perspective. Other concerns include safety issues particularly during winter and proper operation to maximize water quality benefits
Dry Ponds	
Primary Mechanisms	Storage, peak flow reduction and sedimentation.
Description, Advantages, and Drawbacks	Dry ponds may be useful when wet ponds or wetlands are either unfeasible or undesirable. This normally occurs in retrofit situations or where temperature concerns are an overriding factor in design. As dry ponds have no permanent pool of water, they can be effectively used for erosion control and quantity control; however, the removal of stormwater contaminants in these facilities is purely a function of the drawdown time in the pond. They could be considered for multi use purposes.
Constructed Wetlands	
Primary Mechanisms	Storage, peak flow reduction, sedimentation, filtration, biological uptake and adsorption.
Description, Advantages, and Drawbacks	The constructed/artificial wetland is a preferred end-of-pipe stormwater management facility for water quality enhancement. Wetlands are normally more land intensive than wet ponds, because of their shallower depth. They are suitable for providing the storage needed for downstream erosion control purposes, but will generally be limited in their quantity control role, because of the restrictions on active storage depth. The benefits of constructed wetlands are similar to wet ponds. Hydraulic performance does not depend on soil characteristics; the permanent pool minimizes re-suspension, provides extended settling and minimizes blockage of the outlet; and the biological removal of pollutants. Constructed wetland systems suffer from the same problems as wet ponds during the cold season. They do not typically provide infiltration and so have limited benefit from a water balance perspective. Constructed wetlands can be designed with extensive landscaping and associated recreational amenities, to become the centrepiece of a development. Wetlands are generally less suitable for retrofit situations and are typically unsuitable for infill, because of their comparatively large land area and drainage area requirements to allow adequate turnover and sustainability. Constructed wetlands may encourage mosquito breeding and increase downstream water temperatures.

Table 3–3b: End-of-Pipe Control Best Management Practices (continued)

Tank/Tunnel	
Primary Mechanisms	Storage and water quality control.
Description, Advantages, and Drawbacks	Tanks/tunnels can be used as end-of-pipe controls or conveyance controls for the temporary storage of stormwater. These facilities provide storage of the flow peaks such that the interceptor is not significantly surcharged or excess flows do not result in combined sewer overflows to receiving waters. These facilities are located underground and can intercept various types of overflows. Tanks and tunnels can act as retention treatment basins by allowing the suspended solids in the stored flow contents to settle out over a period of time. When the solids have settled to the bottom of the facility, the clear water is normally disinfected and pumped to a receiving water body. The settled solids are subsequently cleaned/flushed to a sump where the contents are normally pumped into a sanitary sewer system for treatment at a treatment facility. Since they are built underground, these facilities provide minimal social/environmental impacts, except for short-term disturbances during construction.
Infiltration Basins	
Primary Mechanisms	Infiltration.
Description, Advantages, and Drawbacks	Infiltration basins are above-ground pond impoundment systems that promote recharge. Water percolating through an infiltration basin either recharges to the groundwater system or is collected by an underground perforated pipe system and discharged at a downstream outlet. The appearance of an infiltration basin is similar to that of a wet or dry pond.
Sand Filters	
Primary Mechanisms	Filtration.
Description, Advantages, and Drawbacks	Sand filters are above or below ground end-of-pipe treatment devices that promote pollutant removal from overland runoff or storm sewer systems. Sand filters can be constructed either above or below ground. They are most commonly used in a treatment train and constructed with impermeable liners to guard against native material clogging pore spaces and to prevent filtered water from entering the groundwater system. Water that infiltrates through the filter is collected by a pervious pipe system and conveyed to a downstream outlet. Some designs incorporate a layer of peat to enhance pollutant removal capabilities of the sand filter, thus making discharge to an infiltration trench a possibility.
High Rate Treatment Devices	
Primary Mechanisms	Primary treatment, high rate sedimentation.
Description, Advantages, and Drawbacks	These devices regulate both the quantity and quality of stormwater at the point of overflow. They are used to settle out solids during high flows in sewer systems. The high flow is transformed into a vortex motion as the solids and floatables settle out through the outlet pipe. When the volume of the chamber is exceeded, the flow (not solids) spills over the overflow baffle exiting the chamber to the receiving water. Recent studies examined stormwater treatment by lamellar settling with and without a polymeric flocculant addition. The studies show that the use of lamellar plates with a flocculant addition improves stormwater treatment.

Table 3–3b: End-of-Pipe Control Best Management Practices (continued)

Storage in Receiving Waters by Displacement	
Primary Mechanisms	Solids settling.
Description, Advantages, and Drawbacks	These facilities can be used to store stormwater runoff and direct the stored flows to a treatment facility or allow pollutants to settle out naturally. An example of this method is the Dunkers Flow Balancing System (DFBS). In its basic form, the system is a series of floating cells. Each cell consists of pontoons and curtains, which store the flows. As polluted stormwater enters the DFBS, lake water is displaced through an opening in the curtain. After the runoff ceases to enter the facility, a pump is activated which conveys the flows to a treatment facility or to the receiving body of water. The polluted water is gradually replaced by the lake water, and the system is ready for the next runoff event.
Screening	
Primary Mechanisms	Solids separation.
Description, Advantages, and Drawbacks	Screening devices are typically installed upstream of storage/treatment facilities or overflow structures. They are used for aesthetic reasons to remove floatable material before the water discharges to receiving waters. Some screens have fish handling devices that minimize the adverse environmental impact on aquatic life that comes in contact with the screens. Screening requires relatively high-cost maintenance and is susceptible to clogging.
Oil/Grit Separators	
Primary Mechanisms	Sedimentation, phase separation.
Description, Advantages, and Drawbacks	Oil/grit separators are a variation of traditional settling tanks. They capture sediment and trap hydrocarbons suspended in runoff from impervious surfaces as the runoff is conveyed through a storm sewer network. The oil/grit separator is a below ground structure that takes the place of a conventional manhole in a storm drain system. The separator implements the use of permanent pool storage in the removal of hydrocarbons and sediment from stormwater runoff before discharging into receiving waters or storm sewers. Oil is removed by skimming and trapping. They have a small footprint and hence are suitable for retrofit and highly urbanized areas. They must be regularly maintained otherwise resuspension of pollutants may occur.

3.4 Selection of Best Management Practices

3.4.1 Concerns

The nature of the downstream water body that will receive the stormwater discharge and the objectives identified for the application fundamentally influence the selection of best management practices. In some cases, high pollutant removal or environmental performance is needed to protect fully aquatic resources, and human health and safety within a particular watershed or receiving water. The areas of concern include the following:

- Cold- and cool-water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. The design objective for these streams is to maintain habitat quality by preventing stream warming, maintaining natural recharge, preventing bank and channel erosion, and preserving the natural riparian corridor. These objectives may be accomplished by promoting infiltration, evapotranspiration and capture and reuse of runoff, and minimizing the creation of impervious surfaces and the surface areas of permanent pools, preserving existing forested areas, bypassing existing base flow and/or spring flow, or providing shade-producing landscaping.
- Sensitive streams (Design objectives are to maintain habitat quality through similar techniques used for cold-water streams, with the exception that stream warming is not as severe a design constraint.
- Wellhead protection presents a unique management challenge. A key design constraint in protecting these areas that recharge existing public water supply wells is to prevent possible groundwater contamination by preventing infiltration of highly polluted runoff. At the same time, recharge of unpolluted stormwater may be needed to maintain the flow in streams and wells during dry weather.
- Reservoir protection of watersheds that deliver surface runoff to a public water supply reservoir is of special concern. Depending on the treatment available at the water intake, it may be necessary to achieve a greater level of pollutant removal for the pollutants of concern, such as bacterial pathogens, nutrients, sediment, or metals. One particular management concern for reservoirs is ensuring that highly polluted runoff is adequately treated so drinking water is not contaminated.
- Shellfish/beach protection requires that watersheds draining to specific shellfish harvesting areas or public swimming beaches receive a higher level of treatment to prevent closings caused by bacterial contamination from stormwater runoff. In these watersheds, best management practices are explicitly designed to maximize bacteria removal.

3.4.2 Selection Process

Completing the following questions will help in selecting a best management practice or group of practices for a site and provides information on factors to consider when deciding where to locate the facilities. Other factors such as cost effectiveness and community values should also be considered. Figure 3–1 shows a flow chart of the selection process of best management practice facilities. Design examples demonstrating the application of the selection process are provided in Appendix B.

Can the best management practice achieve the objectives and goals to be met at the site or is a combination of practices needed?

Designers can screen the best management practices list using Table 3-4 to determine if a particular practice meets the following evaluation criteria category: rainfall capture, flow attenuation, water quality enhancement, major flow conveyance, and riparian corridor sustenance. At the end of this step, the designer can determine if a single practice or a group of practices is needed to meet the objectives and goals at that particular site.

Do any physical constraints at the project site restrict or preclude the use of a particular practice?

In this step, the designer screens the best management practice list to determine if the soils, water table, drainage area, slope, headwater conditions, land use, and ownership present at a particular development site might limit the use of a practice.

Do the remaining best management practices have any important community or environmental benefits or drawbacks that might influence the selection process?

In this step, options are compared against each other with regard to operation and maintenance, riparian/aquatic habitat, community acceptance, cost, and other environmental and social factors.

Figure 3–1
Selection process for BMP facilities

Figure 3–1: Selection process for BMP facilities

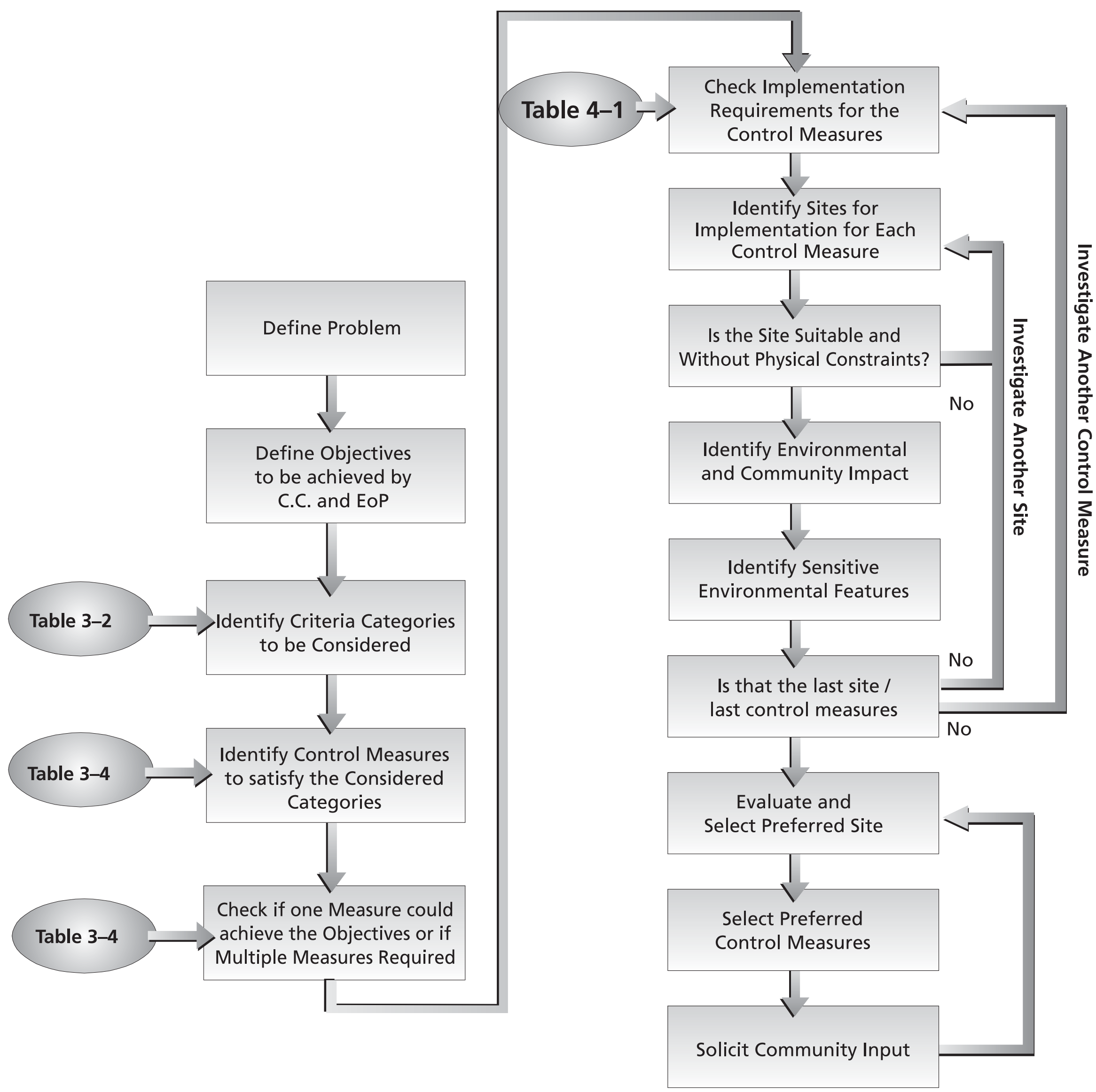


Table 3–4: Criteria for Stormwater Control Facilities by Conveyance and End-of-Pipe Best Management Practices

Technical Objectives	Criteria Category				
	Rainfall and Runoff Capture	Flow Attenuation	Water Quality Enhancement	Minor and Major Flow Conveyance	Riparian Corridor Sustenance
					
Conveyance					
Stream Corridor Protection and Enhancement			✔		✔
Channel Modification				✔	✔
Bank Protection			✔		✔
Roadside Ditches	✔	✔	✔	✔	
Grassed or Vegetated Swales	✔	✔	✔	✔	
Pervious Pipe Infiltration Systems	✔	✔	✔	✔	
Pervious Catch Basins	✔	✔	✔	✔	
In-Line Storage		✔	✔	✔	
Off-Line Storage		✔	✔	✔	
Real Time Control		✔		✔	
End-of-Pipe					
Wet Ponds		✔	✔	✔	
Dry Ponds		✔	✔	✔	
Constructed or Natural Wetlands		✔	✔	✔	
Sub-surface Detention Facilities		✔	✔	✔	
Infiltration Basins	✔	✔	✔		
Infiltration Wells	✔	✔	✔		
Sand Filters	✔	✔	✔		
High Rate Treatment Devices			✔		
Storage in Receiving Waters by Displacement			✔		
Screening Devices			✔		
Oil/Grit Separators			✔		

Note: Tick marks indicate only primary criteria categories to be considered.

4. Applications and Limitations

Tables 4–1a and 4–1b highlight the application requirements, opportunities, limitations, proven effectiveness, and cost considerations for conveyance control and end-of-pipe facilities. It is recommended that reference be made to Appendix A for additional details.

4.1 Application Requirements

It is essential to consider the application requirements for the different facilities, such as space availability, size of catchment area, hydraulic head, etc. Conveyance and end-of-pipe best management practices are different from source and on-site controls, which are mostly applied and maintained by private ownership. On the other hand, conveyance and end-of-pipe controls are basically applied, and owned, operated, and maintained by the municipality. The relative maintenance effort required for the practice in terms of frequency of inspection and maintenance needs to be considered. Community acceptance with regard to minimal nuisance problems, visual amenity, and aesthetic value is also significant (Jaska, 2000 and AEP, 1999). Public education and buy-in are generally needed and, hence, community involvement should always be encouraged.

4.2 Opportunities and Limitations

Identified opportunities are based on new developments or redevelopments, land and space requirements, and enhancement of aquatic and fisheries habitat.. Physical limitations include the presence of certain surface features, such as type of land use, type of soil, depth of bedrock, and water table, the roof-to-lot area ratio, ground topography, size of the drainage area, and condition of the existing storm sewer pipes in the area.

4.3 Proven Effectiveness

The degree of effectiveness of facilities is assessed by how well they achieve the project objectives and goals. Effectiveness is design-dependent (based on the desired level of contaminant removal, tributary area, and level of imperviousness). Generally, difficulties have usually been due to poor design (storage media, filter cloth, lack of pre-treatment), poor construction practices, poor maintenance practices, inadequate stabilization of development before construction (construction timing) or poor site physical conditions (soils, water table, bedrock depth).

Public education and buy-in are generally needed and, hence, community involvement should always be encouraged.

Table 4–1a

Application of Conveyance Control Best Management Practices

4.4 Management Practices

Table 4–1a: Application of Conveyance Control Best Management Practices

Stream Corridor Protection and Enhancement (mostly as a mitigation measure)	
Application Requirements	Implementation is easy and can be accomplished through volunteers. Primarily used in agricultural, parkland, new, or redevelopment areas. Depends on public education to be effective.
Opportunities and Limitations	Opportunities identified based on new development or redevelopment areas and physical implementation criteria.
Proven Effectiveness	Performance depends on other characteristics of the stream corridor. Its performance is difficult to measure directly.
Cost	Capital cost: low. Operation and maintenance costs: low.
Channel Modification (mostly as a mitigation measure)	
Application Requirements	Applied within the stream corridor. Requires available land, detailed modelling, and geomorphic assessment. Must assess impacts downstream and upstream.
Opportunities and Limitations	Opportunities identified based on land and space requirements, fisheries objectives, and physical implementation criteria.
Proven Effectiveness	Generally effective in restoring a self-maintaining stable channel. Failures typically occur if bankfull is set too low and frequent overtopping occurs. Modification of roughness by adding rock is a proven practice.
Cost	Capital cost: low for restoration projects and high for creation projects. Operation and maintenance costs: low.
Capital cost: low for restoration projects and high for creation projects. Operation and maintenance costs: low.	
Application Requirements	A site investigation, combined with analyses of bank failure mechanism, flow and soil conditions are required to determine which bank protection method to apply. Methods range from one or a combination of vegetation, rock, wood, brush, and fabrics. Consideration must be given to access, maintenance, urgency, and availability of materials.
Opportunities and Limitations	Opportunities identified based on land and space requirements, fisheries objectives, and physical implementation criteria.
Proven Effectiveness	Effectiveness is proven if the strength of the protection matches the forces of the attack by the stream. In many cases, bank protection methods have provided long-term protection and the stability required for ecological recovery.
Cost	Capital cost: medium. Operation and maintenance costs: low.
Roadside Ditches	
Application Requirements	Roadside ditches are most effectively applied where soils are non-erodible; ideally slopes are > 2%; and space is available for the channel cross-section.
Opportunities and Limitations	Opportunities identified based on land use, soil, ground topography, and availability of space. Also identified by the condition of the roads and existing sewer pipes in an area. More economical to be considered with the reconstruction of roads.
Proven Effectiveness	Public perceptions vary. Some urban residents view ditches as an eyesore. Other communities like the rural character of streets with ditches.
Cost	Capital cost: medium. Operation and maintenance: low.

Table 4–1a: Application of Conveyance Control Best Management Practices (continued)

Grassed or Vegetated Swales	
Application Requirements	They are primarily applicable for new or redevelopment areas with appropriate physical conditions. Infiltration or filtration requires an area with pervious soils (generally, an infiltration rate of > 15 mm/hr), bedrock and water table > 1 m below bottom of swale, and slope between 0.5% and 5% in the direction of flow.
Opportunities and Limitations	Opportunities identified are based on new development or redevelopment areas with suitable soil conditions. Opportunities are also identified by the size of the drainage area (< 15 ha) and the condition of roads and existing sewer pipes in the area. More economical to be considered with the reconstruction of roads.
Proven Effectiveness	Effective in low-grade areas, pervious soils, and for relatively short length. Most effective with a channel slope between 1% and 2%, a bottom width of min. 750 mm and grass height 75 mm. Low-gradient swales with check dams have slightly higher removal rates than high-slope swales without check dams.
Cost	Capital cost: low. Operation and maintenance costs: low.
Pervious Pipe Systems	
Application Requirements	Small drainage area (< 6 ha). Pre-treatment of road runoff may be required. Require areas with pervious soils (minimum infiltration rate of 15 mm/hr), bedrock and water table > 1 m below bottom of drainage media, slope between 0.5% and 5% (ideally 1% to 2%) in the direction of flow. Minimum setback from building foundations: 3 m down gradient (towards the building) and 30 m up gradient (away from the building). Not suitable in locations receiving large sediment loads.
Opportunities and Limitations	Opportunities identified based on the presence of certain surface features, and the condition of the roads and existing sewer pipes in an area. More economical to be considered with the reconstruction of roads.
Proven Effectiveness	Few applications in Ontario. These systems are experimental and clogging problems have been experienced.
Cost	Capital cost: high. Operation and maintenance costs: medium.
Pervious Catch Basins	
Application Requirements	Small drainage area (< 6 ha). Not suitable in locations that receive a large sediment load that could clog the pre-treatment system. Pre-treatment of road runoff may be required. New or redevelopment area with pervious soils (minimum infiltration rate of 15 mm/hr), and bedrock and water table > 1 m below bottom of drainage media.
Opportunities and Limitations	Opportunities identified based on the presence of certain surface features, and the condition of the roads and existing sewer pipes in an area, also by the project catchment area (< 15 ha). More economical to be considered with the reconstruction of roads.
Proven Effectiveness	As with pervious pipe systems, varying results have been reported. Problems would result from poor design, poor construction practices, poor site physical conditions, or inadequate stabilization of development before construction.
Cost	Capital cost: high. Operation and maintenance costs: medium.

Table 4–1a
Application of Conveyance Control Best Management Practices (continued)

Table 4–1a

Application of Conveyance Control Best Management Practices (continued)

Table 4–1a: Application of Conveyance Control Best Management Practices (continued)

In Line/Off Line Storage	
Application Requirements	Flow bypass, pumping or diversion is required during installation of in-line storage facilities, but not for off-line storage. The obvert of the storage facility remains below basement elevations while still allowing the super pipe to drain by gravity. Sufficient open space is needed near the sewer for installation of the underground off-line tank. Parks and parking lots are ideal locations. In-line/off-line storage may be designed with pumping and could be constructed using box culvert sections, tunnels and large diameter pipes.
Opportunities and Limitations	Opportunity is typically based on known hydraulic deficiencies, such as flooding. In-line storage can be applied where space exists for the large-diameter pipes. Land requirements can limit the application of off-line storage facilities, if they have to be located off the road right-of-way.
Proven Effectiveness	In Toronto, in-line storage has been used effectively in the former City of North York and off-line storage tanks have been installed in the former City of York and in Edmonton.
Cost	Capital cost: high. Operation and maintenance costs: medium.
Real Time Control	
Application Requirements	Both the potential and the limitations of real time control depend on catchment characteristics, sewer system configuration, available storage, and loading variability. Large catchments with shallow sewers, drainage networks with flat slope and available storage, and a large number of diversion points are all favourable for application of real time control. It can also be used to optimize the performance of a series of wet ponds/dry ponds discharging to a receiving watercourse or sewer system with limited capacity or augment flow elsewhere in the system to decrease surcharge.
Opportunities and Limitations	Factors that favour the use of real time control include high spatial and temporal variation in surface runoff volume and quality, low catchment slope, existing control devices in the collection system, underutilized storage during wet weather and significant pumping costs. Real time control can also be used to optimize the performance of a series of ponds with limited outfall capacity.
Proven Effectiveness	Real time control has been applied successfully to numerous urban drainage systems throughout Europe and North America.
Cost	Capital cost: medium. Operation and maintenance costs: high.

What environmental features must be avoided when locating the BMP system at a site to fully comply with local, municipal, and federal regulations?

In this step, the designer may consider whether any of the following are present at the site: waterways, stream or shoreline buffers, flood plains, conservation areas, environmentally sensitive areas, heritage sites, wetlands, and development infrastructure to avoid any adverse environmental impacts to sensitive resources.

Table 4–1b
Application of End-of-Pipe Control Best Management Practices

Table 4–1b: Application of End-of-Pipe Control Best Management Practices

Wet Ponds	
Application Requirements	Wet ponds require a minimum drainage area of 5 ha to sustain a permanent pool with an adequate turnover rate. The land required for the facility is site-specific and depends on the design (tributary area, level of water quality control, erosion and flood control, and safety concerns). Wet ponds should normally be located outside the floodplain and should not be considered on cold-water tributaries. While special cases may occur, ponds should be designed for minimum of 60% suspended solids removal.
Opportunities and Limitations	Opportunities identified based on new development or redevelopment areas. For retrofit situations, determine feasible locations based on land availability, tributary area, and outfall location. Contaminant removal and peak flow reduction should be addressed based on expected sizing and design constraints.
Proven Effectiveness	Wet ponds are the most commonly implemented end-of-pipe control with documented effectiveness in contaminant removal, and erosion and flood control. They are normally designed to remove 60% to 90% of suspended solids on an annual load basis, which normally results in the removal of 40% to 60% of phosphorus and heavy metals. Nutrient and heavy metal removals are increased by biological uptake (e.g., through the plants within the facilities), but these removals are transitory unless plant material is harvested on a regular basis.
Cost	Capital cost: medium if the cost of land is not considered. Operation and maintenance costs: medium.
Dry Ponds	
Application Requirements	Dry ponds have applications where source and conveyance controls are expected to provide contaminant removal or where stream temperature is a significant concern. The land required for the facility is site-specific and depends on the design (tributary area, level of water quality control, erosion and flood control, and safety concerns). Dry ponds should normally be located outside the floodplain.
Opportunities and Limitations	Opportunities identified based on quantity control in new development or redevelopment areas where wet facilities are not feasible or desirable. For retrofit situations, determine feasible locations based on land availability, tributary area, and outfall location.
Proven Effectiveness	Dry ponds are effective as a quantity control, but less useful as a water quality control when operated in a continuous flow-through mode. Batch operations have limited application, because of the high operational costs. For water quality applications, suspended sediment removal at the 60% annual average level may be attainable.
Cost	Capital cost: medium. Operation and maintenance costs: medium.
Constructed Wetlands	
Application Requirements	Wetlands require a minimum drainage area of 5 ha to sustain a permanent pool with an adequate turnover rate. The land required for the facility is site-specific and depends on the design (tributary area, level of water quality control, erosion and flood control, and safety concerns). Wetlands should normally be located outside the floodplain. Wetlands should not be considered on cold-water tributaries. Wetlands should be designed for minimum suspended solids removal of 60%.
Opportunities and Limitations	Opportunities identified based on new development or redevelopment areas. For retrofit situations, determine feasible locations based on land availability, tributary area, and outfall location. Contaminant removals and peak flow reduction should be addressed based on expected sizing and design constraints.
Proven Effectiveness	Wetlands are less prevalent than wet ponds, generally because of their greater land requirements. Wetlands are normally designed to remove 60% to 90% of suspended solids on an annual load basis. This typically results in the removal of between 40% and 60% of phosphorus and heavy metals, through sedimentation. Nutrient and heavy metal removals are increased by biological uptake.
Cost	Capital cost: medium. Operation and maintenance: medium.

Table 4–1b
Application of End-of-Pipe Control Best Management Practices (continued)

Table 4–1b: Application of End-of-Pipe Control Best Management Practices (continued)

Tank/Tunnel	
Application Requirements	The primary application of tanks/tunnels is in retrofit conditions where opportunities for the application of source and conveyance controls are limited due to the fully developed condition of the area. These facilities are well suited for urbanized areas, since they can be buried and will not restrict the use of parkland, beach areas, etc.
Opportunities and Limitations	Opportunities identified based on land availability, tributary area, and outfall locations.
Proven Effectiveness	Recent monitoring conducted for the Eastern Beaches tank (in Toronto) indicates the removal efficiency is 67% for total suspended solids, 43% for total phosphorus, 47% for oil and grease, and 21% to 70% for metals. Similar results can be expected for tunnels. Tunnels/tanks are effective in the control/treatment of overflows due to stormwater.
Cost	Capital cost: high. Operation and maintenance costs: medium.
Infiltration Basins	
Application Requirements	Infiltration basins are generally considered for drainage areas < 5 ha that have permeable soils. They should be used in residential areas only, and are ideal for soils with high infiltration potential and where the groundwater table is > 1 m.
Opportunities and Limitations	Opportunities identified based on land availability, tributary area, and outfall location.
Proven Effectiveness	Experienced high rate of failure, which can be attributed to poor site selection, poor design, poor construction techniques, large drainage area, and lack of maintenance.
Cost	Capital cost: low. Operation and maintenance costs: low.
Sand Filters	
Application Requirements	Sand filters can be constructed either above or below ground, and are generally only appropriate for relatively small drainage areas (< 5 ha). Very little is known of their performance and cold-climate operation and maintenance.
Opportunities and Limitations	Opportunity identified based on the presence of certain surface features, such as the type of land use, the type of soil, and ground topography.
Proven Effectiveness	Sand filters are not widely used in Canada, and should be generally applied after a detailed feasibility assessment.
Cost	Capital cost: low. Operation and maintenance costs: low.

Table 4–1b: Application of End-of-Pipe Control Best Management Practices (continued)

High Rate Treatment Devices	
Application Requirements	Pollutant removal performance of high rate treatment concentrators, at a given hydraulic loading rate, depends on the relative settleability of the flow stream being processed. Solids separation performance is much better for large heavier or gritty material than for smaller and lighter particles. The separators can be used on storm sewer systems, especially near outfalls as an end-of-pipe treatment technology. These devices provide high rate equivalent primary treatment for solids removal when properly designed. There are no moving parts to these systems and they have relatively small land requirements.
Opportunities and Limitations	Opportunity identified based on the relative settleability of the waste stream being processed. Low turbulence areas within the sewer system are the most favourable locations.
Proven Effectiveness	The effectiveness of these devices in removing fine particles with low settling velocity is questionable. This device is effective in removing scum, floating solids, and sandy particles. Lamellar plate clarification with a polymeric flocculant addition was found effective in total suspended solids removal from stormwater, at a polymer dosage of 4 mg/L.
Cost	Capital cost: medium. Operation and maintenance costs: high.
Storage in Receiving Waters by Displacement	
Application Requirements	An example of this is the Dunkers Flow Balancing System (DFBS). General application requirements include an open body of water which is sheltered, a surface area equal to about 2% to 3% of the drainage area, water depths ranging from 0 m to 10 m, and at least two sides (including shoreline) providing shelter. If the body of water is unsheltered, then the cost to construct a flow balancing system will increase considerably.
Opportunities and Limitations	Opportunity assessment would be based primarily on the application requirements.
Proven Effectiveness	Estimates of solids removal for the Scarborough, Ontario facility (1999) were in the range of 60% to 70%.
Cost	Capital cost: medium. Operation and maintenance costs: medium.
Screening	
Application Requirements	The primary application is in conjunction with treatment/storage facilities to remove the larger solids. However, screening can also be applied as a stand-alone device to remove solids before discharge to receiving waters. Stand-alone devices need to be housed in a chamber with disposal capabilities to remove the waste periodically.
Opportunities and Limitations	Opportunity identified based on land availability upstream of a storage/treatment facility or outfall structure, and impact on aquatic habitats and life.
Proven Effectiveness	Normal solids removal rate varies from 30% to 50%. However, screening devices are susceptible to clogging.
Cost	Capital cost: low. Operation and maintenance costs: high.

Table 4–1b

Application of End-of-Pipe Control Best Management Practices (continued)

Table 4–1b: Application of End-of-Pipe Control Best Management Practices (continued)

Oil/Grit Separators	
Application Requirements	Oil/grit separators are best applied in areas of high impervious cover where there is a potential for hydrocarbon spills and polluted sediment discharges. They are also used for pre-treatment of inflows to ponds/wetlands or as part of a treatment train.
Opportunities and Limitations	Opportunity identified based on land availability, tributary area, and outfall location.
Proven Effectiveness	Effective for treatment of stormwater pollution at its source or at the inlet of ponds/wetlands. Some may be effective in reducing coarse total suspended solids.
Cost	Capital cost: low. Operation and maintenance costs: medium.
High Rate Treatment Devices	
Application Requirements	Pollutant removal performance of high rate treatment concentrators, at a given hydraulic loading rate, depends on the relative settleability of the flow stream being processed. Solids separation performance is much better for large heavier or gritty material than for smaller and lighter particles. The separators can be used on storm sewer systems, especially near outfalls as an end-of-pipe treatment technology. These devices provide high rate equivalent primary treatment for solids removal when properly designed. There are no moving parts to these systems and they have relatively small land requirements.
Opportunities and Limitations	Opportunity identified based on the relative settleability of the waste stream being processed. Low turbulence areas within the sewer system are the most favourable locations.
Proven Effectiveness	The effectiveness of these devices in removing fine particles with low settling velocity is questionable. This device is effective in removing scum, floating solids, and sandy particles.Lamellar plate clarification with a polymeric flocculant addition was found effective in total suspended solids removal from stormwater, at a polymer dosage of 4 mg/L.
Cost	Capital cost: medium. Operation and maintenance costs: high.
Storage in Receiving Waters by Displacement	
Application Requirements	An example of this is the Dunkers Flow Balancing System (DFBS). General application requirements include an open body of water which is sheltered, a surface area equal to about 2% to 3% of the drainage area, water depths ranging from 0 m to 10 m, and at least two sides (including shoreline) providing shelter. If the body of water is unsheltered, then the cost to construct a flow balancing system will increase considerably.
Opportunities and Limitations	Opportunity assessment would be based primarily on the application requirements.
Proven Effectiveness	Estimates of solids removal for the Scarborough, Ontario facility (1999) were in the range of 60% to 70%.
Cost	Capital cost: medium. Operation and maintenance costs: medium.

Table 4–1b: Application of End-of-Pipe Control Best Management Practices (continued)

Screening	
Application Requirements	The primary application is in conjunction with treatment/storage facilities to remove the larger solids. However, screening can also be applied as a stand-alone device to remove solids before discharge to receiving waters. Stand-alone devices need to be housed in a chamber with disposal capabilities to remove the waste periodically.
Opportunities and Limitations	Opportunity identified based on land availability upstream of a storage/treatment facility or outfall structure, and impact on aquatic habitats and life.
Proven Effectiveness	Normal solids removal rate varies from 30% to 50%. However, screening devices are susceptible to clogging.
Cost	Capital cost: low. Operation and maintenance costs: high.
Oil/Grit Separators	
Application Requirements	Oil/grit separators are best applied in areas of high impervious cover where there is a potential for hydrocarbon spills and polluted sediment discharges. They are also used for pre-treatment of inflows to ponds/wetlands or as part of a treatment train.
Opportunities and Limitations	Opportunity identified based on land availability, tributary area, and outfall location.
Proven Effectiveness	Effective for treatment of stormwater pollution at its source or at the inlet of ponds/wetlands. Some may be effective in reducing coarse total suspended solids.
Cost	Capital cost: low. Operation and maintenance costs: medium.

4.5 Cost

Capital costs and operation and maintenance costs for stormwater best management practices are difficult to generalize as they are highly variable and depend on site-specific requirements, such as geographical location, stormwater quality criteria, design objectives, land uses and environmental considerations. Also, costs vary as a function of the local economies. The total cost of implementing a stormwater best management practice involves a number of components including the costs associated with administration, planning and design, land acquisition, site preparation and development, and operation and maintenance.

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

Operation and maintenance costs include the total labour and the expenses associated with operating, monitoring, and maintaining the best management practice at an acceptable level of performance. Appropriate operation and maintenance budgets are an essential component of all stormwater best management practices.

Where cost information is provided, references are cited. Such information should be used cautiously during the planning stage. Costs however are given, in a comparative basis as high, medium, and low. Operating costs should also include provisions for ongoing performance monitoring of the best management practice to optimize operation and maintenance requirements and determine the effectiveness of the best management practice in enhancing hydrologic and water quality conditions. Information on maintenance costs is given in Ontario, MOE, (2003), AEP (1999), Jaska (2000), and Barr Engineering (2001).

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

Table 4–2
Cold Climate Factors and Design Challenges

4.6 Cold Climate Considerations

Winter hydrologic conditions, such as ice, snow, and snowmelt warrant special considerations for best management practice selection, design, and operation and maintenance (Maksimovic, 2000).

A comprehensive review of selection and design of a best management practice in cold climates was conducted by the Center for Watershed Protection (Barr Engineering, 2001; CWP, 1997).

The cold climate factors to be considered and the associated design challenges are presented below in Table 4–2.

Table 4–2: Cold Climate Factors and Design Challenges

Cold temperature	■ Pipe freezing ■ Ice formation on the permanent pool ■ Reduced biological activity ■ Reduced oxygen levels in bottom sediments ■ Reduced settling velocities
Depth of frost line	■ Frost heaving ■ Reduced soil infiltration
Short growing season	■ Short period to establish vegetation ■ Different plant species appropriate to cold climates
Snowfall	■ High runoff volumes during snowmelt and rain-on-snow events ■ High pollutant loads during spring melt, especially chlorides ■ Impacts of road salt/deicers ■ Snow management

Other information for specific recommendations on applications in cold climates is available in the following documents for your reference: (AEP, 1999), (Jaska, 2000), (Minnesota, 2000), (New York, 2001), (Vermont, 2001), (Maksimovic, 2000) and (Marsalek et al., 2003).

5. Evaluation of Facilities

5.1 Operational Monitoring Requirements

To evaluate the effectiveness of the best management practice application, whether it is an entire program or a particular facility, normally requires operation monitoring. The type of monitoring to be considered depends on the objective of the program. The common monitoring parameters for most programs are water quantity and quality. Measurements will be required for the inflow and outflow of the system, and in some cases for the system overflow. Other monitoring parameters to be considered for particular control facilities include:

- water level, volume, and quality of water and sediment in ponds and sedimentation facilities;
- monitoring of the aquatic biota in wetlands and wet ponds; and
- monitoring of the aquatic habitat, biota, and water quality in the receiving water body.

During the planning and design stages of the best management practice, a detailed monitoring program should be established. The program will discuss monitoring objectives, parameters to be considered, location and type of equipment, frequency of measurements, and sampling (ASCE, 2000).

To evaluate the effectiveness of the best management practice, some monitoring activities may be required before implementing the practice to establish the existing conditions, which serve as the base line. Whether the practice is implemented for an existing storm drainage system to minimize problems and enhance the performance of the system, or is implemented for new development to minimize future impacts, the existing conditions could serve as a base line for evaluation purposes.

Reporting could be required by provincial or agency jurisdiction, in which case the method and frequency of monitoring the effectiveness of the implemented best management practice will need to meet the regulatory agency requirements. The municipality should consider such requirements on the planning of the monitoring program.

5.2 Research Needs

Research needs for conveyance control and end-of-pipe control for stormwater management would be basically centred on quantifying the effectiveness, limitations, and operation and maintenance requirements of some best management practice facilities (Marsalek, 2003a). Some of these facilities are relatively new, with little actual experience, while others use established technologies with widespread application, but have limited knowledge of their operation and maintenance. The following examples identify potential research needs:

- Identify sediment removal and other maintenance requirements in storage and sedimentation facilities, and correlate the results to the physical characteristics of the catchment area and the design parameters considered.
- Identify maintenance requirements for infiltration/exfiltration systems and the frequency and cost of cleaning them to maintain their efficiency during their life cycle.
- Investigate secondary environmental effects resulting from the implementation of best management practice measures (e.g., the potential impact of the rise of water temperature in surface ponds on the cold water fisheries in the receiving water).

- Identify the benefits resulting from selecting the best management practices according to the receiving water objectives and needs rather than using general regulatory criteria.
- Examine the performance of different treatment trains by which the absolute values of concentrations of the influent and effluent are considered.
- Study the impact of best management practice facilities involving open surface water on the risks to human health such as from West Nile virus or other pathogens and methods to control and minimize such risk.
- Determine the impact of road salt/deicers on best management practices.
- Determine the potential effect of climate change on drainage system design and examine the need for updating rainfall input data to account for climate change.
- Investigate adaptation of best management practices for climate change.

Appendix A:
Stormwater Best Management Practice Facilities

A.1 Conveyance Control

A.1.1 Stream Corridor Protection and Enhancement

References

- Brookes, Andrew and F.D. Shields (eds), 1996. *River Channel Restoration: Guiding Principles for Sustainable Projects*. West Sussex, England: John Wiley & Sons Ltd, 433 p.
- Rosgen, Dave, 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, Colorado.
- United States Department of Agriculture, 1998. Federal Interagency Stream Restoration Working Group; *Stream Corridor Restoration: Principles, Processes, and Practices*. United States.

Figure A–1: Vegetative plantings in the riparian corridor

A.1.2 Channel Modification

References

- Brookes, Andrew and F.D. Shields (editors), 1996. *River Channel Restoration: Guiding Principles for Sustainable Projects*. West Sussex, England: John Wiley & Sons Ltd, 433 p.
- Rosgen, Dave, 1996. *Applied River Morphology.* Wildland Hydrology, Pagosa Springs, Colorado.
- United States Department of Agriculture, 1998. Federal Interagency Stream Restoration Working Group; *Stream Corridor Restoration: Principles, Processes, and Practices*. United States.

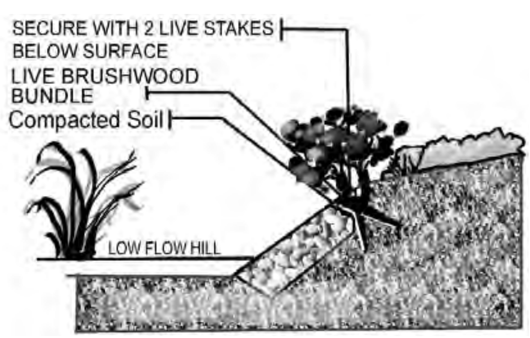
Figure A–2: Stream Meander Restoration

A.1.3 Bank Protection

References

- Brookes, Andrew and F.D. Shields (eds), 1996. *River Channel Restoration: Guiding Principles for Sustainable Projects*. West Sussex, England: John Wiley & Sons Ltd, 433 p.
- Rosgen, Dave, 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, Colorado, États-Unis.
- United States Department of Agriculture, 1998. Federal Interagency Stream Restoration Working Group; *Stream Corridor Restoration: Principles, Processes, and Practices*.

Figure A–3: Live fascine restoration



A. Stormwater Best Management Practice Facilities

A.1 Conveyance Control

Figure A–4
Armourstone protection bank

Figure A–5
Roadside ditch to replace the traditional curb and gutter system

Figure A–6
Grass swale for water conveyance and treatment

Figure A–4: Armourstone protection bank

A.1.4 Roadside Ditches

Reference

- J.F. Sabourin and Associates, 1999. *Evaluation of Roadside Ditches and Other Related Stormwater Management Practices*. The Toronto and Region Conservation Authority.
- Li, J., R. Orlando, and T. Hogenbirk, 1998. “Environmental Road and Lot Drainage Designs: Alternatives to the Curb-Gutter-Sewer System.” *Canadian Journal of Civil Engineering*. 25.

Figure A–5: Roadside ditch to replace the traditional curb and gutter system

A.1.5 Grassed Swales

References

- Li, J., R. Orlando, and T. Hogenbirk, 1998. “Environmental Road and Lot Drainage Designs: Alternatives to the Curb-Gutter-Sewer System.” *Canadian Journal of Civil Engineering*. 25.
- United States, EPA (Environmental Protection Agency), Office of Water, 1999a. “Stormwater Technology Fact Sheet: Flow Diversion.” <http://www.epa.gov/owm/mtb/fl.pdf>. Accessed November 25, 2004.
- ---, 1999b. “Stormwater Technology Fact Sheet: Vegetated Swales.” <http://www.epa.gov/owm/mtb/vegswale.pdf>. Accessed November 25, 2004.
- United States Department of Transportation, FHWA (Federal Highway Administration), 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*.
- GVRD (Greater Vancouver Regional District), 2004. Stormwater Source Controls Preliminary Design Guidelines.

Figure A–6: Grass swale for water conveyance and treatment

A.1.6 Pervious Pipe Systems

References

- Canada, Environment Canada, 1995. “Stormwater Management and Combined Sewer Overflow Control Series: Etobicoke’s Stormwater Exfiltration Project.” Great Lakes Cleanup Fund.
- Li, J., R. Orlando, and T. Hogenbirk, 1998. “Environmental Road and Lot Drainage Designs: Alternatives to the Curb-Gutter-Sewer System.” *Canadian Journal of Civil Engineering*. 25.
- GVRD (Greater Vancouver Regional District), 2004. Stormwater Source Controls Preliminary Design Guidelines.

Figure A–7: Pervious pipe exfiltration system

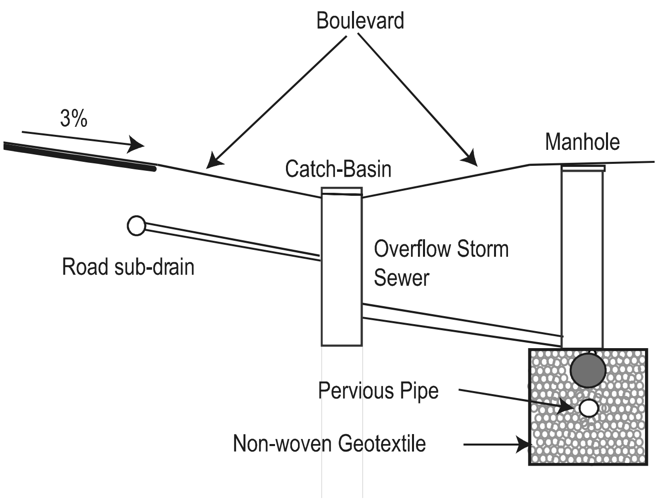


Figure A–8: Pervious catch basin

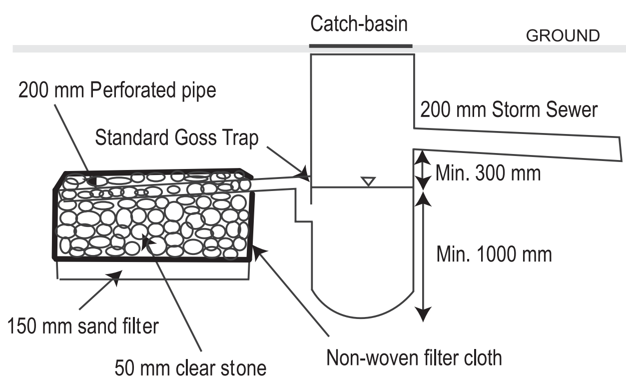
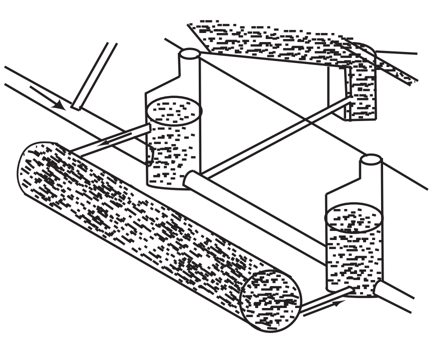


Figure A–9: In-Line/Off-Line Storage



A.1.7 Pervious Catch Basins

Reference

- United States, EPA (Environmental Protection Agency), Office of Water, 1999d. “Stormwater Technology Fact Sheet: Infiltration Trenches.” <http://www.epa.gov/owm/mtb/infltrenc.pdf>. Accessed November 26, 2004.

A.1.8 In-Line/Off-Line Storage

References

- United States, EPA (Environmental Protection Agency), 1999. “Combined Sewer Overflow Technology Fact Sheet: Retention Basins.”
- United States Department of Transportation., FHWA (Federal Highway Administration), 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*.
- WPCF (Water Pollution Control Federation), 1989. *Combined Sewer Overflow Pollution Abatement, Manual of Practice*. No. FD–17, Alexandria Virginia.

A.1.9 Real Time Control

Reference

- Schilling, W., 1996. “Potential and Limitations of Real Time Control.” Harrachov, Czech Republic: NATO Advanced Study Institute: Hydroinformatics Tools for Planning, Design, Operation and Rehabilitation of Sewer Systems.

A. Stormwater Best Management Practice Facilities

A.1 Conveyance Control

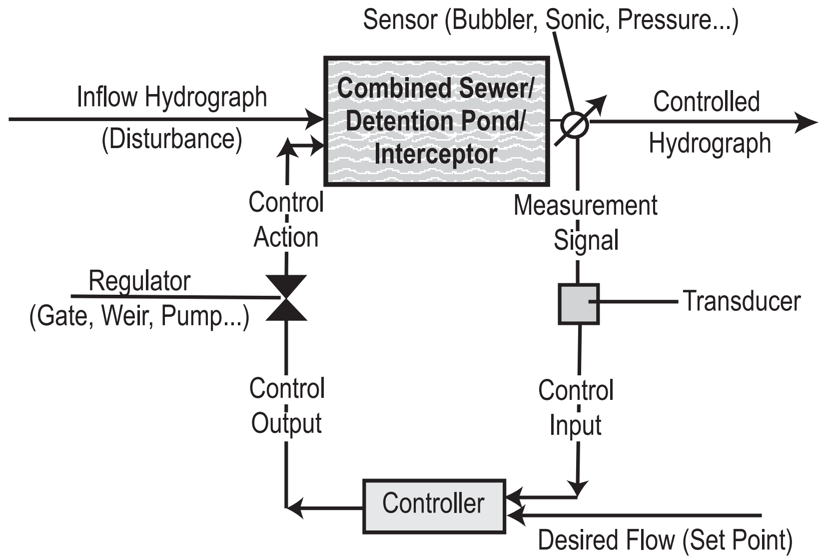
A.2 End-of-Pipe Control Best Management Practices

Figure A–10
Typical control loop in a combined sewer system

Figure A–11
Wet pond for water quality, erosion, and quantity control

Figure A–12
Dry pond for quality control

Figure A–10: Typical control loop in a combined sewer system



A.2 End-of-Pipe Control Best Management Practices

A.2.1 Wet Ponds

References

- Ontario, MOE (Ministry of the Environment), 2003. *Stormwater Management Planning and Design Manual*. March.
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Figure A–11: Wet pond for water quality, erosion, and quantity control

A.2.2 Dry Ponds

References

- Ontario, MOE (Ministry of the Environment), 2003. *Stormwater Management Planning and Design Manual*. March.
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Figure A–12: Dry pond for quality control

A.2.3 Constructed Wetlands

References

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Figure A–13: Constructed wetland

A.2.4 Tank/Tunnel

References

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Figure A–14: Tank tunnel for temporary storage of combined sewer overflow

A.2.5 Infiltration Basins

References

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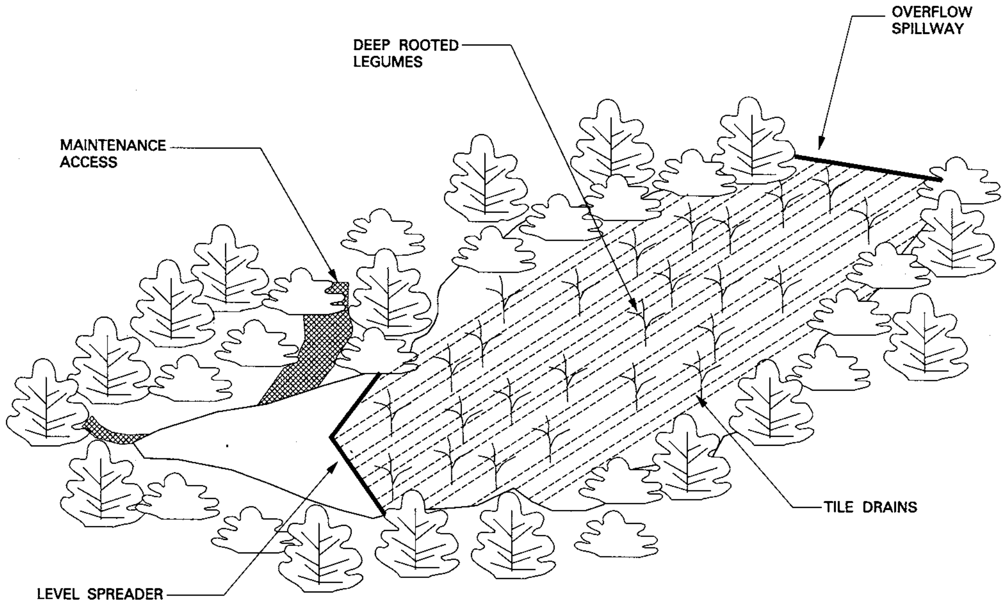
Figure A–13
Constructed wetland

Figure A–14
Tank tunnel for temporary storage of combined sewer overflow

Figure A–15: Infiltration basins



A.2.6 Filters

References

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A.2.7 High Rate Treatment Devices

References

- Averill, D., P. Chessie et al., 1996. "Pilot Testing of Physical-Chemical Treatment Options for CSO Control." WEFTEC (Water Environment Federation Technical Exhibition and Conference).
- United States Department of Transportation, FHWA (Federal Highway Administration), 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*.

Figure A–16: Schematic of a drop-in sand filter

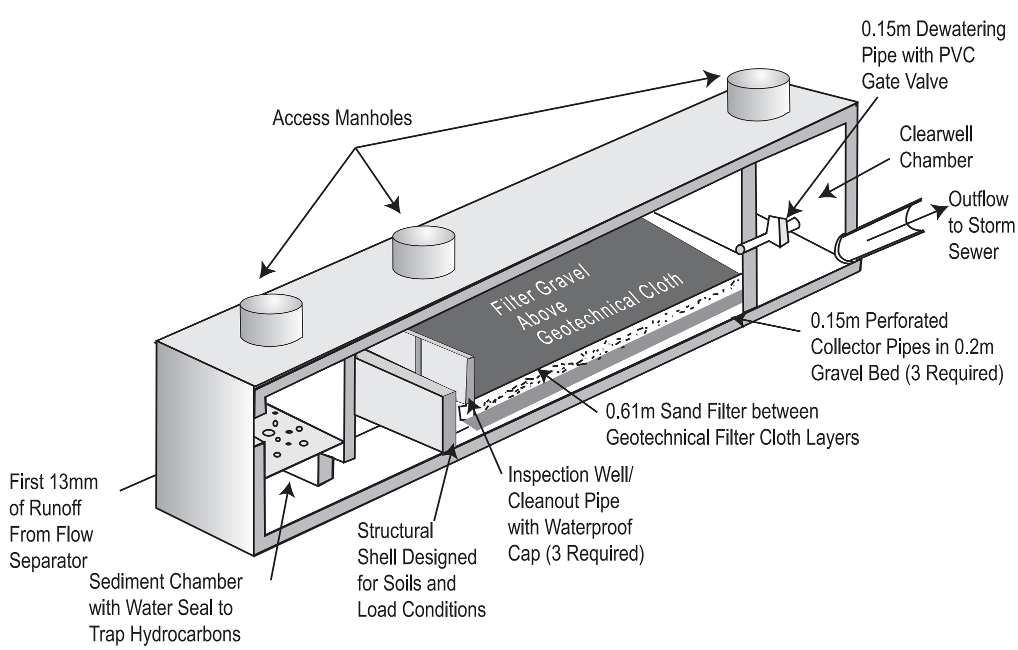
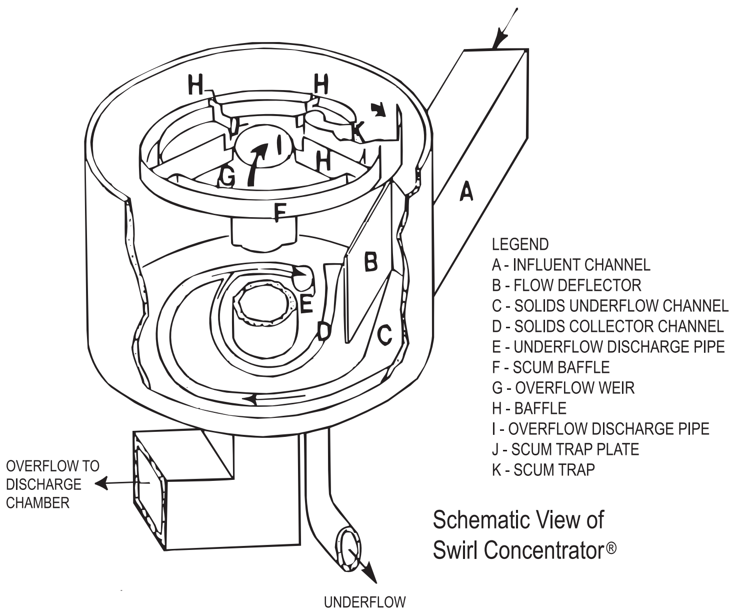


Figure A–17: Cutaway of a Swirl Concentrator®



- United States Navy, Naval Facilities Engineering Service Center, Environmental Services, nd. Web site <*http://enviro.nfesc.navy.mil*>. Accessed November 26, 2004.
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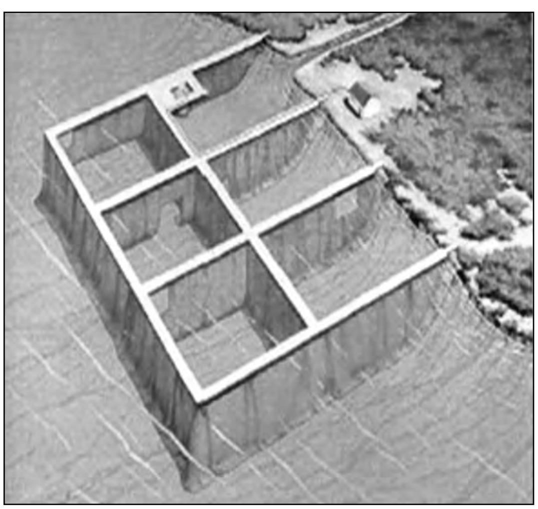
Figure A–18: Dunkers flow balancing system schematic



A.2.8 Storage in Receiving Waters by Displacement

Reference

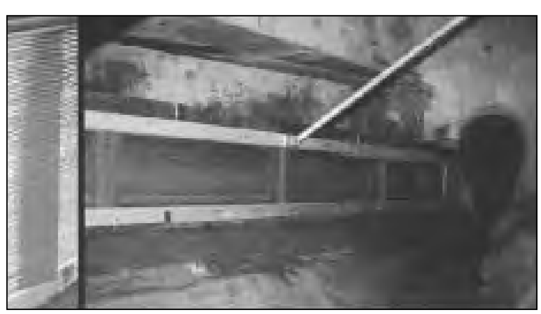
- Aquafor Beech Limited, 1994. *Environmental Study Report, Brimley Road Drainage Area – Water Quality Enhancement Strategy, Final Report*. Prepared for the City of Scarborough.

A.2.9 Screening

References

- MacViro Consultants Limited and Gore & Storrie Limited, 1991. *Sewer System Master Plan*. Prepared for City of Toronto.
- Pran, D.H. and P.L. Brunner, 1979. US Environmental Protection Agency August Publication: "Combined Sewer Overflow Treatment by Screening and Terminal Ponding." EPA–600/2–29–085, Fort Wayne, Indiana.

Figure A–19: Screening to remove floatable material from combined sewer overflow



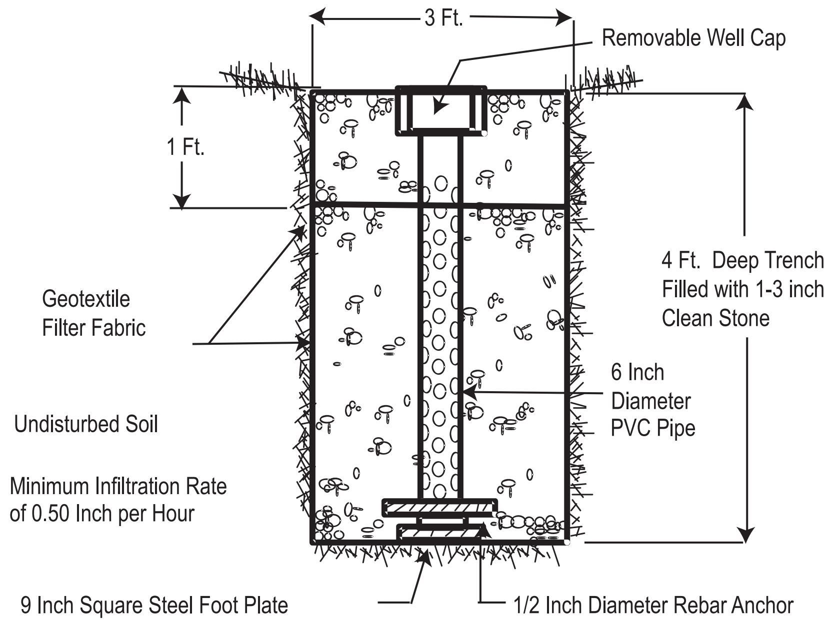
A. Stormwater Best Management Practice Facilities

A.2 End-of-Pipe Control Best Management Practices

Figure A–20
Infiltration trenches

Figure A–21
Oil/grit separator section view

Figure A–20: Infiltration trenches



A.2.10 Infiltration Trenches

References

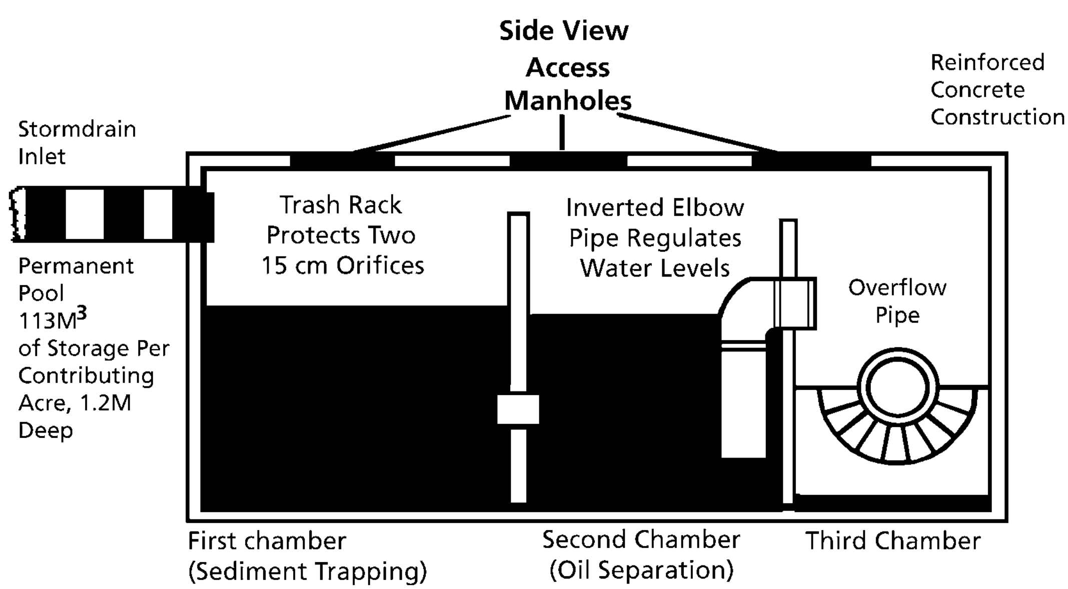
- Ontario, MOE (Ministry of the Environment), 2003. *Stormwater Management Planning and Design Manual*, March 2003.
- United States Department of Transportation, FHWA (Federal Highway Administration), 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*.

A.2.11 Oil/Grit Separators

References

- Ontario, MOE (Ministry of the Environment), 2003. *Stormwater Management Planning and Design Manual*. March 2003.
- United States US Department of Transportation, FHWA (Federal Highway Administration), 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*.

Figure A–21: Oil/grit separator section view



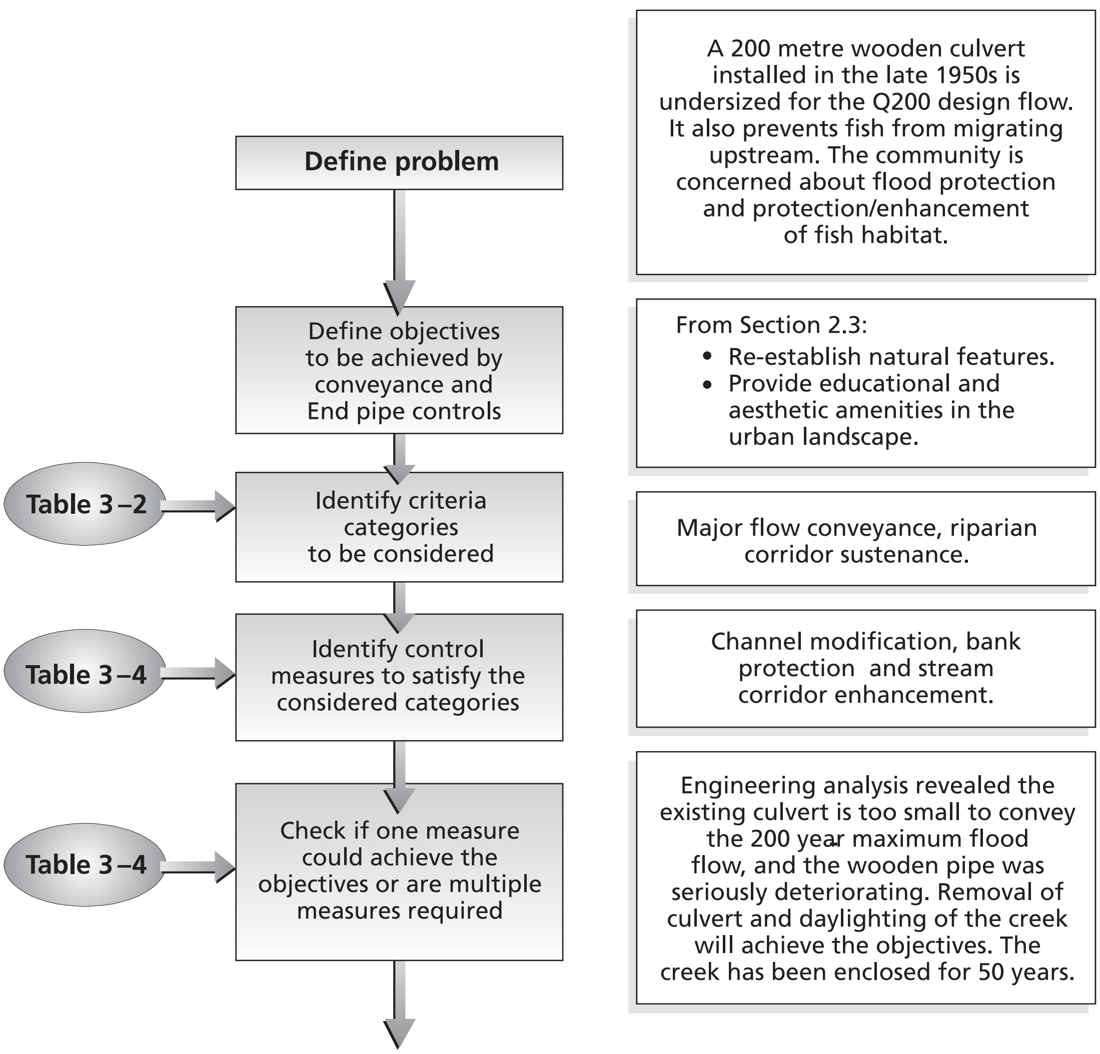
Appendix B:
Design Examples

B.1 Design Example: Daylighting Thain Creek (Culvert Replacement/Riparian Corridor Enhancement)

Figure B–1: Culvert replacement, before and after

Before

After



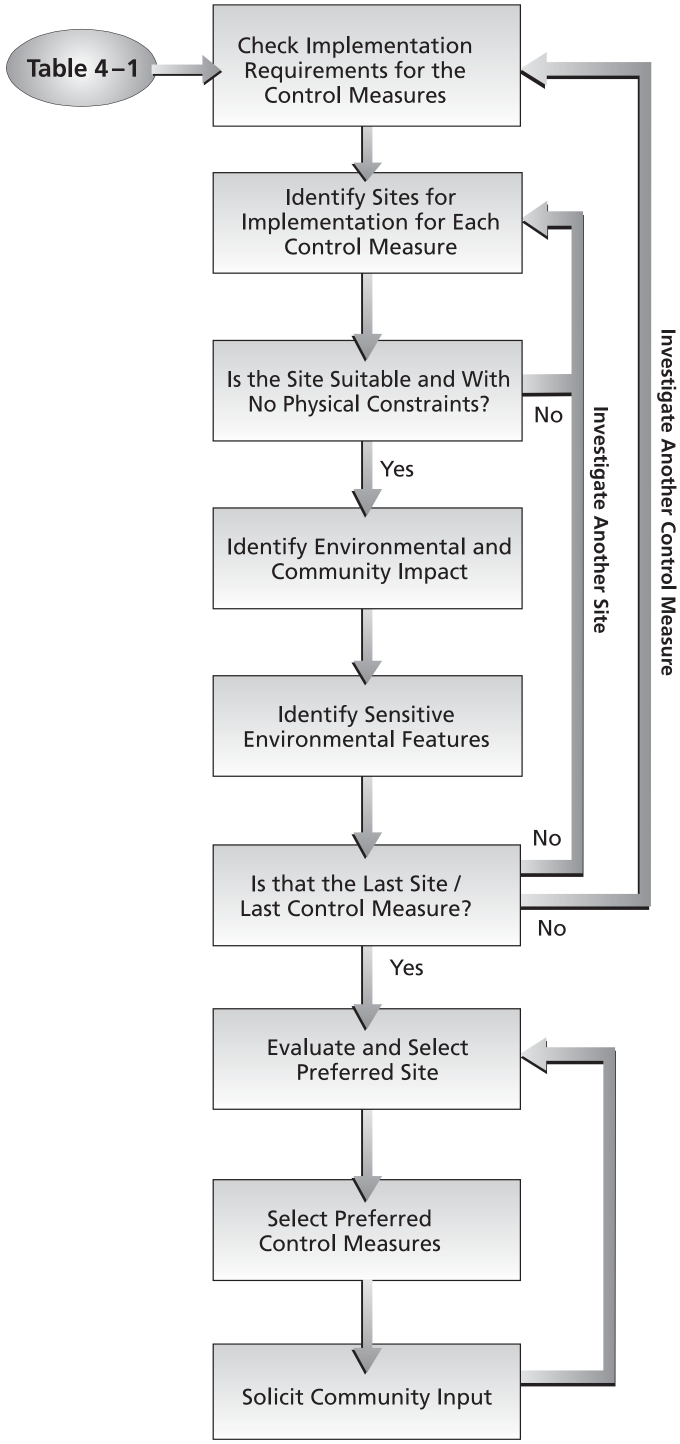
B. Design Examples

B.1 Design Example: Daylighting Thain Creek (Culvert Replacement/ Riparian Corridor Enhancement)

Figure B–1
Culvert replacement, before and after

B. Design Examples

B.1 Design Example: Daylighting Thain Creek (Culvert Replacement/ Riparian Corridor Enhancement)



Analysis determined a channel size that would provide adequate conveyance and the land required. Modelling is completed to determine water level and velocity during all flow conditions. Appropriate vegetation, rip-rap sizes, and wood debris is selected. Site investigations reviewed soil conditions and determined bank protection measures.

The channel design is determined and existing road right-of-way location is selected for the project.

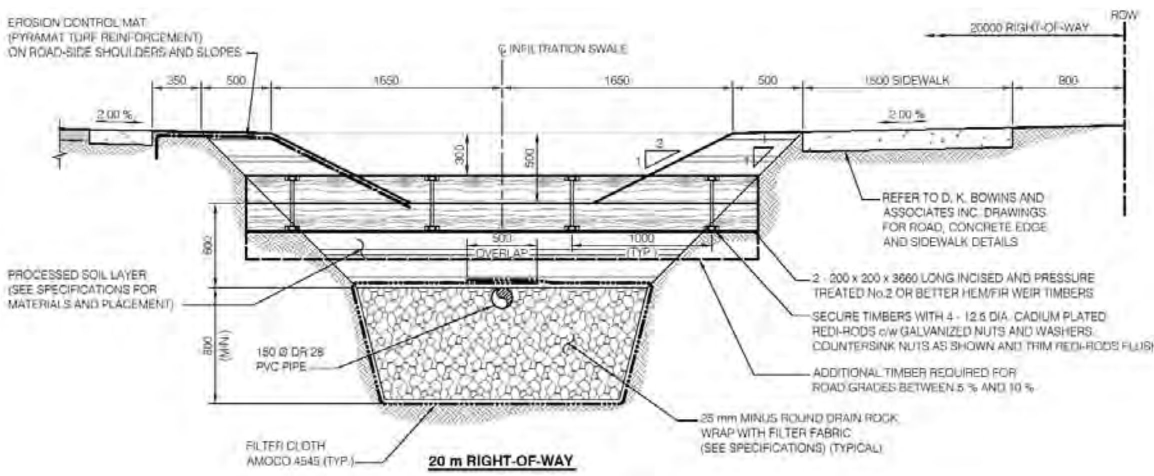
Concerns have been raised that the design comprises too much rip-rap. The design is modified to include a series of weirs and pools, and landscaping will be allow ed to naturalize, eventually providing shade for the fish, and food and shelter for birds. The rip-rap level on the banks is lowered to the Q2 level and a bio-engineered bank is constructed in its place up to the Q200 level.

The design plan is presented at a public open house that included adjacent neighbours, stewardship society, stream keepers, provincial ministry, Department of Fisheries and Oceans Canada and engineers from the municipality. The design is accepted.

The design is finalized and construction proceeds. The project was given the Award of Merit by the Consulting Engineers of British Columbia.

B.2 Design Example: Development of a 10 Ha of Land for Single Family Homes (Vegetated Swale)

Figure B–2: Example of a selected vegetated swale design



Define problem

A developer wishes to develop 10 ha of land for single family residential homes in British Columbia. The proposed development drains to a creek system with productive fish habitat. The community is concerned about the downstream impacts to fish habitat.

Define objectives to be achieved by conveyance and end-of-pipe controls

From Section 2.3:

- Achieve healthy aquatic communities.
- Maintain natural hydrologic processes.
- Maintain natural features.

Table 3 –2 → Identify criteria categories to be considered

Rainfall capture, flow attenuation, water quality enhancement, riparian corridor sustenance.

Table 3 –4 → Identify the measures to satisfy considered categories

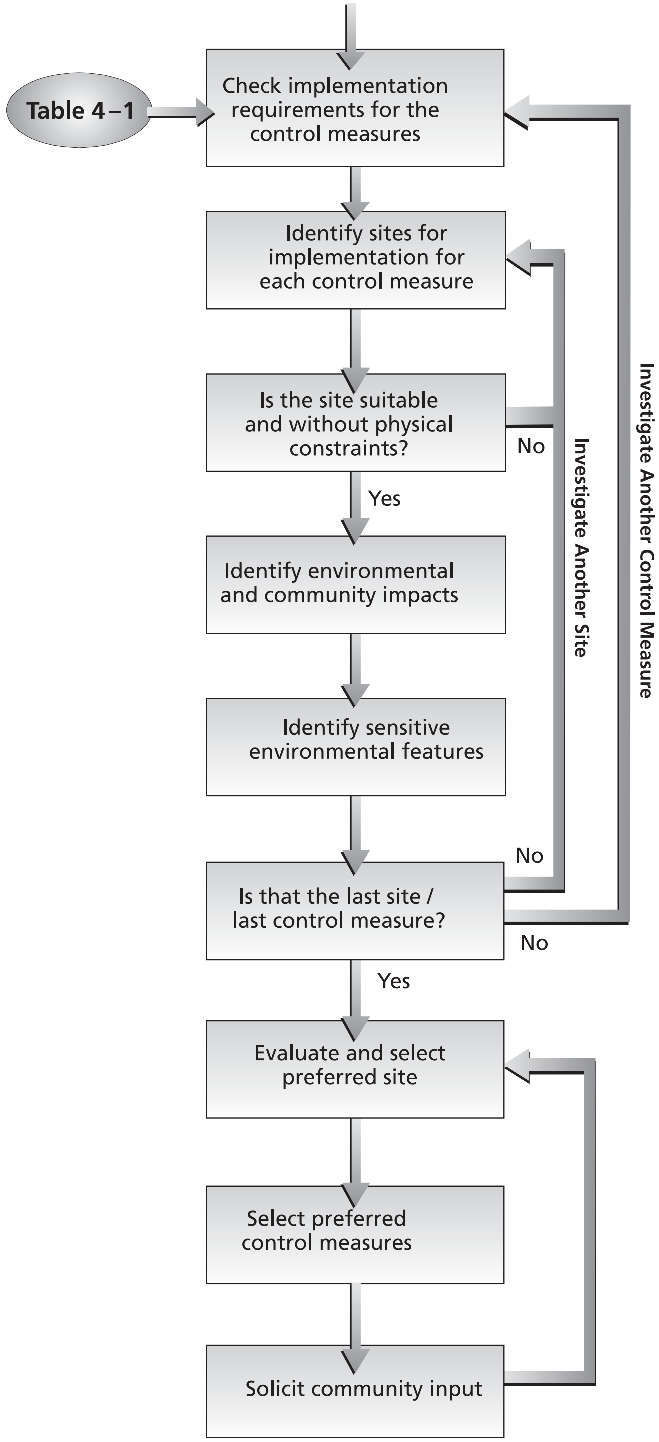
Vegetative swales along roadside, lot level controls for each home (see *Source Control Best Practices at outlet, and stream corridor Guide*), wet pond enhancement.

Table 3 –4 → Check if one measure could achieve the objectives or if multiple measures are required

Stormwater modelling indicates that to achieve the criteria for BC (see **Table 3–1**), multiple measures are required including the wet pond. However, the wet pond size can be significantly reduced due to the installation of the vegetated swales and lot level controls.

B. Design Examples

B.2 Design Example: Development of a 10 Ha of Land for Single Family Homes (Vegetated Swale)



The soils in the area have a low permeability. **Table 4–1** suggests the permeability should be >15 mm/hr. Percolation tests indicate less than 2 mm/hr. The vegetated swales and lot controls are installed with perforated pipe overflows to protect the roads from heaving. Extra soil is used, and a rock under-storage area created to hold rainwater allowing extra time for infiltration to surrounding soils.

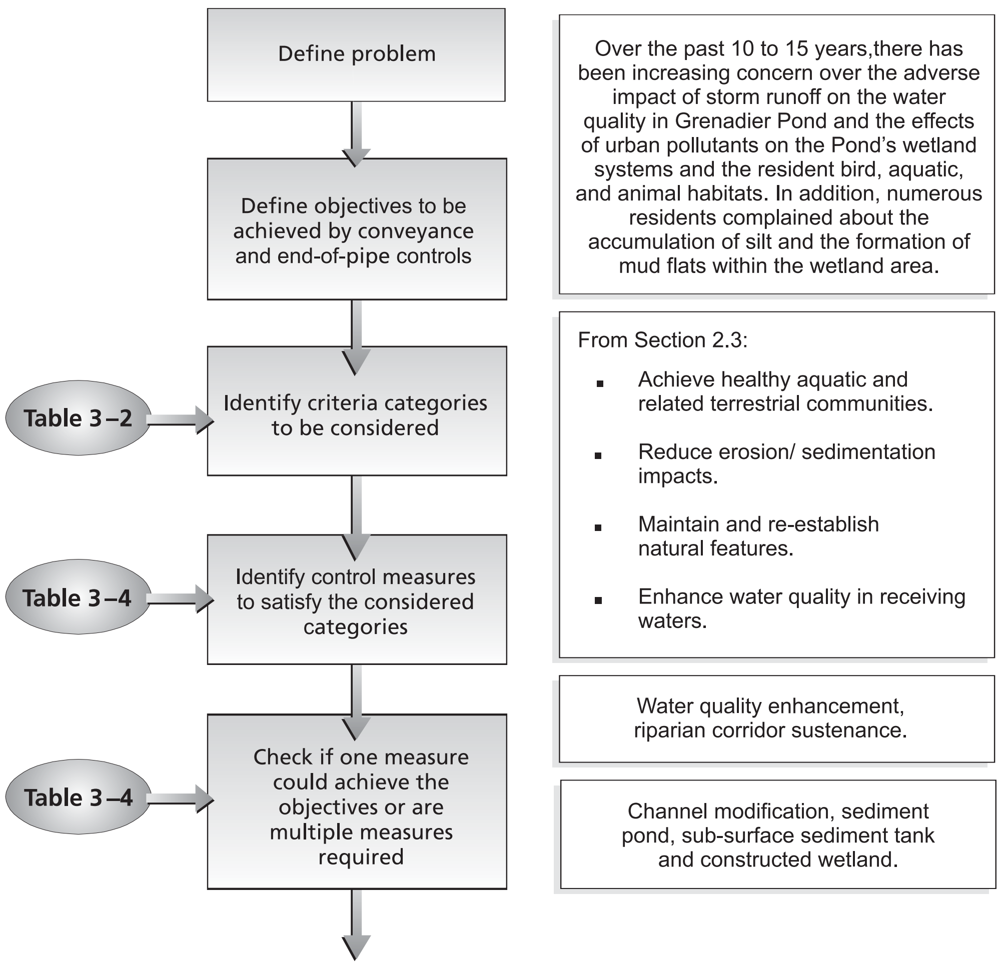
Vegetated swales are used for all roads with slopes less than 5%. Lot controls installed on all lots.

Concern has been raised that the surrounding subdivisions were constructed with traditional curb and gutter collection systems, and the proposed development may not fit in, and may look too rural. Additional vegetation is added to the swales to convert them to rain gardens.

A public open house is held to present the rain garden concept and the public loves it, but questions the maintenance requirements and who is responsible. A discussion develops, and it is resolved that the environmental benefits of the proposed plan outweigh the minor maintenance aspects, and the City is advised to expand its lawn mowing by-law to include the maintenance of rain gardens in front of homes.

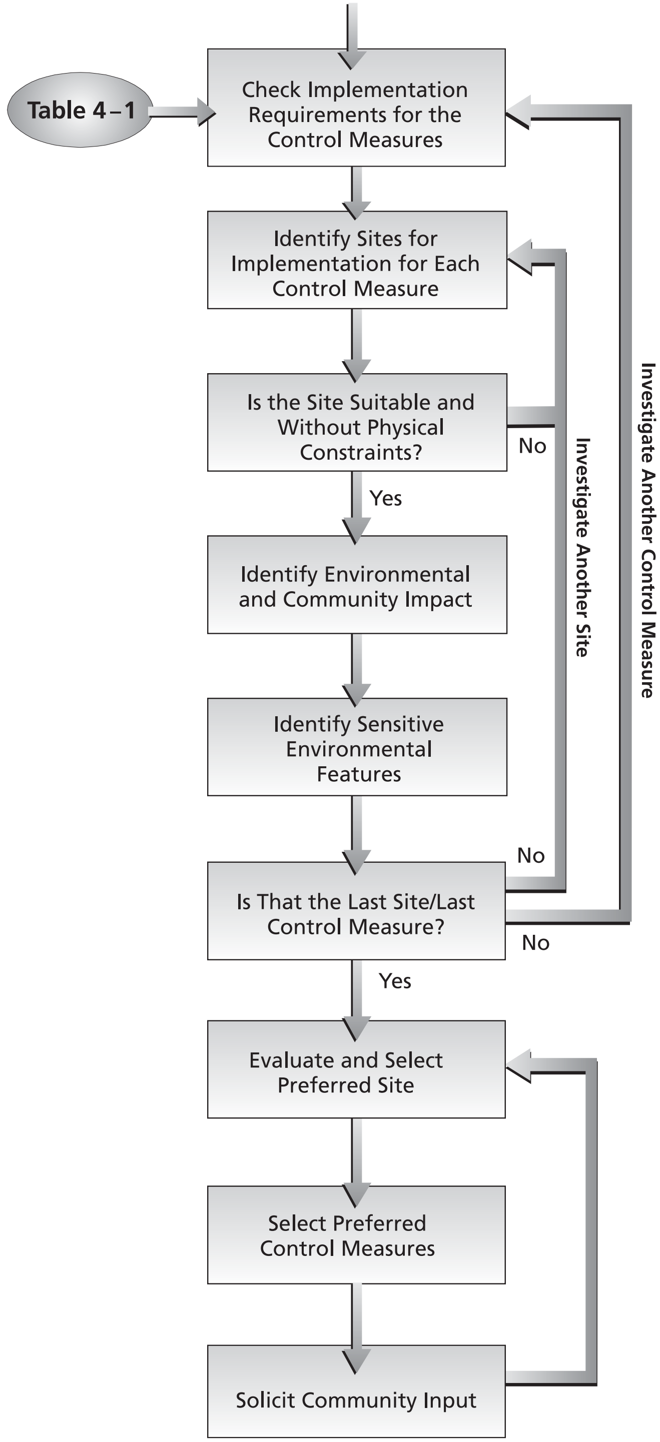
The design is finalized.

B.3 Design Example: Sedimentation Facility for Grenadier Pond



B. Design Examples

B.3 Design Example: Sedimentation Facility for Grenadier Pond



On the basis of both technical and public input, the sediment pond was identified as the preferred solution.

An existing park open space was selected as the preferred site for the new pond.

Local residents expressed concern regarding the loss of parkland and trees, and safety concerns and disruption to an existing playground.

A maximum practical pond size of 2600 m^3 (area of 0.4 hectares) was established based on site constraints, safety concerns, and discussions with local residents and approval agencies. The pond will achieve about 73% capture of the grain size particles currently discharging and creating the mud flats. The pond side slopes were planted with wetland type of vegetation to further enhance the sediment trapping capabilities of the pond and add a safety feature for the adjacent residents.

The pond has been in service for about eight years. Water quality improvements are monitored annually and sediment removal is undertaken on a three year cycle. The surrounding community is supportive of the pond and the benefits it provides to the water quality and wetland enhancements of Grenadier Pond.

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