Roads and Sidewalks

Road Drainage, Design Alternatives and Maintenance

This document is the seventh in a series of best practices for the design, maintenance and management of municipal roads and sidewalks. 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   Federation of Canadian Municipalities   Canadä

Road Drainage, Design Alternatives and Maintenance

Issue No. 1.0

Publication Date: November 2003

INTRODUCTION

InfraGuide – Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 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 responding both to higher standards of 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: Innovations and Best Practices (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: 1) municipal roads and sidewalks 2) potable water 3) storm and wastewater 4) decision making and investment planning 5) environmental protocols and 6) transit. The best practices are available on-line and in hard copy.

A Knowledge Network of Excellence

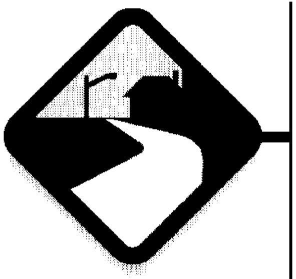
InfraGuide´s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. 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.

The InfraGuide Best Practices Focus



Municipal Roads and Sidewalks

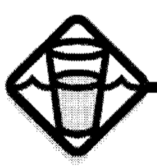
Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Just as $1 of timely rehabilitation will save $5 of reconstruction, $1 of timely prevention will delay $5 of rehabilitation. Municipal roads and sidewalks best practices address 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. The best practices set out will ensure for instance that the right treatment is selected for the right road at the right time and will provide guidance in implementing individual treatments successfully, e.g. crack-sealing, rut mitigation. 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.

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.

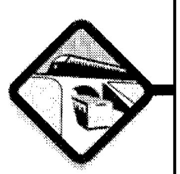
Environmental Protocols

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.



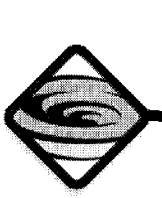
Potable Water

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.



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. 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.

TABLE OF CONTENTS

TABLES

FIGURES

ACKNOWLEDGEMENTS

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

This best practice was developed by stakeholders from Canadian municipalities and road specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide's Roads and Sidewalks Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and by Totten Sims Hubicki Associates (TSH).

Mike Sheflin, P.Eng., Chair
Former CAO Regional Municipality
of Ottawa-Carleton, Ontario

Brian Anderson
Ontario Good Roads Association,
Chatham, Ontario

Vince Aurilio, P.Eng.
Ontario Hot Mix Producers Association,
Mississauga, Ontario

Don Brynildsen, P.Eng.
City of Vancouver, British Colombia

Al Cepas, P.Eng.
City of Edmonton, Alberta

Brian E. Crist, P.Eng.
City of Whitehorse, Yukon

Michel Dion, P.Eng., M.Sc.
Axor Experts-Conseils, Montréal, Quebec

Cluny Matchim, C.E.T.
Town of Gander, Newfoundland and Labrador

Abe Mouaket, P.Eng.
IM Associates, Toronto, Ontario

Tim J. Smith, P.Eng., M.Sc.Eng.
Cement Association of Canada,
Ottawa, Ontario

Sylvain Boudreau, P.Eng., M.Eng.
Technical Advisor, NRC

In addition, the Roads and Sidewalks Technical Committee would like to thank the following individuals for their participation in working groups and peer review:

Al Cepas, P.Eng
City of Edmonton, Alberta

Michel Dion, P.Eng., M.Sc.
Axor Experts-Conseils, Montréal, Quebec

Tim Haynes, E.A.IV.
City of Regina, Saskatchewan

Bob Lorimer, P. Eng.
Lorimer and Associates, Yukon

Cluny Matchim, C.E.T.
Town of Gander, Newfoundland and Labrador

Susan Siopis, P. Eng
The Regional Municipality of Durham, Ontario

Acknowledgements

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

Project Steering Committee:

Mike Badham, Chair
City Councillor, Regina, Saskatchewan

Stuart Briese
Portage la Prairie, Manitoba

Bill Crowther
City of Toronto, Ontario

Jim D'Orazio
Greater Toronto Sewer and Watermain Contractors Association, Ontario

Derm Flynn
Mayor, Appleton, Newfoundland and Labrador

David General
Cambridge Bay, Nunavut

Ralph Haas
University of Waterloo, Ontario

Barb Harris
Whitehorse, Yukon

Robert Hilton
Office of Infrastructure,
Ottawa, Ontario

Joan Lougheed
City Councillor, Burlington, Ontario
Stakeholder Liaison Representative

Saeed Mirza
McGill University, Montréal, Quebec

René Morency
Régie des installations olympiques
Montréal, Quebec

Lee Nauss
City Councillor, Lunenburg, Nova Scotia

Ric Robertshaw
Region of Halton, Ontario

Dave Rudberg
City of Vancouver, British Columbia

Van Simonson
City of Saskatoon, Saskatchewan

Basile Stewart
Mayor, Summerside, Prince Edward Island

Serge Thériault
Department of Environment
and Local Government,
Fredericton, New Brunswick

Alec Waters
Alberta Transportation,
Edmonton, Alberta

Wally Wells
Dillon Consulting Ltd., Toronto, Ontario

Technical Steering Committee:

Don Brynildsen
City of Vancouver, British Columbia

Al Cepas
City of Edmonton, Alberta

Andrew Cowan
City of Winnipeg, Manitoba

Tim Dennis
City of Toronto, Ontario

Kulvinder Dhillon
Province of Nova Scotia,
Halifax, Nova Scotia

Wayne Green
City of Toronto, Ontario

John Hodgson
City of Edmonton, Alberta

Bob Lorimer
Lorimer & Associates,
Whitehorse, Yukon

Betty Matthews-Malone
Haldimand County, Ontario

Umendra Mital
City of Surrey, British Columbia

Anne-Marie Parent
City Councillor, City of Montréal, Quebec

Piero Salvo
WSA Trenchless Consultants Inc.,
Ottawa, Ontario

Mike Sheflin
Former CAO, Regional Municipality
of Ottawa-Carleton, Ontario

Konrad Siu
City of Edmonton, Alberta

Carl Yates
Halifax Regional Water Commission,
Nova Scotia

EXECUTIVE SUMMARY

This best practice describes the main features of road drainage, selection of design alternatives, and maintenance of road drainage systems. The intent is to assist municipalities in managing all components of road drainage, in terms of planning, design, construction, asset management, maintenance, and rehabilitation, while considering local economic, environmental, and social factors.

This best practice addresses the considerations taken into account when developing a road drainage system for both rural and urban road systems, using a number of planning, design, and implementation steps. The best practices in the engineering design functions for roads and road drainage will draw upon three fundamental and essential resources including:

- sound engineering knowledge and skills;
- appropriate technical reference manuals or guidelines; and
- supporting analytical and evaluation tools.

Proper road drainage design can result in significant cost savings in terms of maintenance and rehabilitation. Road design methods that are less expensive to implement typically tend to be of lower quality and lack durability, therefore requiring more frequent replacement or rehabilitation. Spending less capital dollars will then lead to spending more money in maintenance than would spending more capital dollars on a higher quality, more durable road design. To provide for an approach with the highest value, the development of a road drainage design must be completed under a life-cycle costing approach; where the costs of the design, construction, operation of the road, maintenance, rehabilitation and reconstruction of the road are considered, and a balanced solution chosen.

The best practices presented in this document address the six steps required in the planning, design, and implementation of road design alternatives. The steps include planning, design, construction, operation and maintenance, quality control, monitoring and assessment, and rehabilitation. A number of key issues/items need to be considered while proceeding through the steps:

- the overall drainage plan (i.e., the need for major/minor systems, the need for storm water management);
- the selection of drainage criteria;
- the need for a closed drainage system;
- the need for an open drainage system;
- road surface drainage/right-of-way drainage; and
- structural design of the roadway.

The best practices presented in this guide provide typical and/or generic values for each key issue listed above, which may be used to design roadways with effective road drainage.

Road drainage is a subset of a larger set of systems designed to manage storm water and is a mandatory component of the design and operation of every road. Proper design and maintenance is critical to the basic safe functioning of the road and for reducing adverse impacts on the natural and social environment adjacent to, upstream, or downstream from the road. As such, the best practices presented in this guide are limited in terms of:

- geology/topography;
- urban/rural setting;
- water quantity/water quality;
- road classification;
- municipality size;
- climate/seasonal variations;
- regulatory authorities/planning authorities;
- engineering capabilities;
- asset management; and
- operations and maintenance.

Please refer to Section 4 to review the limitation of the best practices presented in this guide.

1. General

1.1 Introduction

This document outlines the best practices for road drainage, selection of design alternatives, and maintenance of road systems. Proper road drainage design can result in significant cost savings in terms of maintenance and rehabilitation. This best practice document is part of the *National Guide to Sustainable Municipal Infrastructure* (InfraGuide). InfraGuide assists municipalities in managing all components of municipal infrastructure projects, including planning, design, construction, asset management, maintenance, and rehabilitation, while considering local economic, environmental, and social factors.

This best practice guide is based on a review of relevant existing literature, as well as a detailed survey of 11 municipalities located in different geographical regions across Canada. The survey consisted of 35 questions pertaining to the various key road drainage elements and their associated planning, design, and implementation (PDI) steps.

1.2 Scope

The main function of a road drainage system is to convey storm water efficiently and effectively from the road surface and pavement structure while minimizing the accumulation of standing water on the roadway. This provides for the safe passage of traffic and pedestrians, and assists in providing a cost-effective design life for the road surface and reduced life cycle costs. This document addresses the considerations taken into account when developing a road drainage system and the factors leading to a best practices approach in the PDI steps.

The scope of considerations given to best practices in road drainage design is limited to the drainage of water from the road surface and granular base and the drainage of water, (i.e., storm water and snowmelt) from the road right-of-way. It should be noted that drainage from external sources outside these limits has many implications for road drainage, some of which are discussed here. This guide, however, is primarily limited to the scope discussed above. Storm sewer design and maintenance is discussed within the storm and waste water (SWW) set of best practice guides, and does not constitute the scope covered under the municipal roads (MR) guides.

1.2.1 Issues Related to Drainage

For the purposes of the development of this best practice, a series of key drainage issues or items that are typically considered and influence the approach that is used in the planning, design, construction, and maintenance of roadways are covered:

- developing an overall drainage plan (Section 3.2.1);
- selecting drainage criteria to be applied (Section 3.2.2);
- applying closed drainage systems (Section 3.2.3);
- applying open drainage systems (Section 3.2.4);
- providing road surface drainage/right-of-way drainage (Section 3.2.5); and
- structural design of the pavement structure (Section 3.2.6).

The main function of a road drainage system is to convey storm water efficiently and effectively from the road surface and pavement structure while minimizing the accumulation of standing water on the roadway.

1.2.2 Planning, Design, and Implementation Cycle

This guide discusses the various issues related to road drainage within the context of the steps that should be followed in a best practice approach for roadway design and implementation. The steps are illustrated on Figure 1–1 and include planning, design, construction, operation and maintenance (O&M), quality control, monitoring and assessment, and rehabilitation.

These steps are referred to in this guide as the PDI steps, with the implementation steps including the construction, O&M, monitoring, and rehabilitation phases.

This document provides road drainage practices for use in both rural and urban areas in municipalities of various sizes. It should be used in conjunction with the recently issued *Centre for Expertise and Research on Infrastructures in Urban Areas (CERIU) Compendium*. The Compendium, originally issued in French as the *Classeurs du CERIU*, is designed to educate and increase awareness among urban infrastructure professionals with respect to the various facets of the latest investigation and rehabilitation technologies used in underground infrastructure and municipal pavements (CERIU, www.ceriu.qc.ca, internet, last accessed in October 2003). In addition to the Compendium, there are a number of best practices that provide supplemental information, including:

- *Repair and Replacement of Utility Boxes in Pavements;*
- *Construction of Utility Boxes in Pavements; and*
- *Source and On-Site Controls for Municipal Drainage Systems.*

Through the information covered in this guide, a number of principles are addressed that form the basis of a best practices approach.

- Ensure that a drainage function is provided that meets basic road service levels. Design geometry to facilitate drainage.
- Recognize the dual drainage system in design (major and minor drainage). Ensure conveyance levels exist for the different road classifications, and flood and property protection for major systems. Maintain emergency functions for safety.
- Consider life-cycle costs as the basis for design selection. Consider construction, life duration, and operation and maintenance costs of alternative road and drainage systems.
- Provide for storm water management (SWM) in the design. Recognize the impact of road drainage and SWM opportunities in rights of way.
- Recognize opportunities presented by replacement and rehabilitation. Ensure service levels and design standards can be upgraded.
- Use hydrograph techniques (models) in the design.
- Ensure road safety as it relates to effective drainage.
- Address environmental concerns.
- Consider the full life cycle of roads from initial construction through stages of pavement preservation, and then the planning and design for reconstruction.
- Look at how best practices have evolved through advances in road design.
- Integrate structural and performance assessments of drainage infrastructure into pavement rehabilitation programs.

1.3 General Health and Safety

The design and location of drainage structures should receive as much attention from a safety point of view as other roadway features such as geometry, lighting, signing, and guardrail elements, since the main objective of road design is to provide a safer environment for all right-of-way users. Road drainage systems must be designed to minimize the potential for accidents and uncomfortable riding conditions for all travellers (including cyclists), minimize the potential for snowmelt refreezing, minimize ponding in ditches to prevent drowning hazards, and minimize any splashing of pedestrians using the right-of-way.

The elements of a drainage system should enhance the safety of roads without sacrificing the main function of these elements, which is removing storm water from road surfaces. The major safety concerns associated with drainage systems are the location and condition of these features. These systems should be located, modified or, wherever necessary, protected (shielded) to create the least possible hazard. The location of underground storm water conveyance structures is discussed in further detail in the best practice guides *Repair and Replacement of Utility Boxes in Pavements* and *Construction of Utility Boxes in Pavements*. Appendix A provides a summary of generic safety treatments and issues to be considered as part of road drainage.

1.4 Glossary

Boulevard — An area within the road right-of-way not used as part of the driving surface. It is usually separated from the driving surface by a physical barrier and contains landscaping.

Catchment — An area of land where runoff can flow to a point (e.g., inlet or outfall structure) in the drainage system.

Closed drainage system — A system where the storm water conveyance components (i.e., pipes) are located below the frost line, protected from the atmosphere.

Distributed runoff control (DRC) — A system that can accommodate the variable control of peak flows at various levels to meet specific flow or design criteria.

Drainage — Natural or artificial means of intercepting and removing surface or subsurface water (usually by gravity).

Drainage system — A system of catch basin inlets, pipes, overland flow paths, open channels, culverts, and detention basins used to convey runoff to receiving waters.

Environment — The biotic and abiotic elements and systems and their interactions, including effects on human quality of life. Environmental elements and systems include: land (including flora), water, air (including noise, light) and soil.

Erosion — (1) The wearing away of the land surface by moving water, wind, ice, or other geological agents, including such processes as gravitational creep. (2) Detachment and movement of soil or rock fragments by water, wind, ice, or gravity. (i.e., accelerated, geological, gully, natural, rill, sheet, splash, or impact, etc.).

Groundwater — The water below the ground surface, and typically below the groundwater table.

Impervious area — The area within a drainage catchment that is impermeable to groundwater infiltration.

Infiltration — The slow movement of water into or through a soil or drainage system.

Life cycle — The consideration of all phases of roadway design (i.e., planning, design, construction, operation and maintenance, quality control, monitoring and assessment, and rehabilitation/replacement).

Life-cycle costing — A method of expressing cost in which both capital costs and operations and maintenance costs are considered in comparing different alternatives.

Major storm — The design storm with an average recurrence interval selected on the basis of satisfying requirements for flood immunity and safety. Design may vary in accordance with local authority guidelines.

Major drainage system — The major drainage system includes ditches, channels, and sewers designed for the 100-year flow or the regulatory storm flow, whichever is the adopted criteria.

Minor drainage system — The minor drainage system includes curbs and gutters, roadside channels, inlets, underground drainage, junction pits or access chambers, and outlets designed to contain and convey the minor storm.

Minor storm — The design storm with an average recurrence interval selected on the basis of satisfying requirements for convenience and safety of pedestrians and vehicles. Design may vary in accordance with local authority guidelines.

Open drainage system — A system where the storm water conveyance components (i.e., ditches) are located above grade and are exposed to the atmosphere.

Outlet — The point at which water discharges to a stream, river, lake, tidewater, or artificial drain.

Overland flow path — Open space floodway channels, road reserves, pavement expanses, and other flow paths that convey flows typically in excess of the capacity of the minor drainage system.

Rational method — A design method for calculating peak flows based on the runoff coefficient, drainage area, and rainfall intensity. This method is adequate for small drainage areas (i.e., <65 ha).

Runoff — That portion of the water precipitated onto a catchment area, which flows as surface discharge from the catchment area past a specified point.

Storm water management (SWM) — Drainage practices implemented to protect natural waterways and receiving waters from urban impacts. Controls used include peak flow control for flood control, peak flow and volume control to mitigate erosion impacts, and water quality controls for water quality impacts.

Sub drains — Small diameter perforated pipes placed in trenches with granular backfill, at the edges of roadways to facilitate subsurface drainage.

Swale — A shallow channel, often grass-lined, which is used to transport storm water, sometimes as an alternative to the curb and gutter system, or as a pre-treatment to other measures. Swales are generally characterized by a high top width to depth ratio and gentle grades.

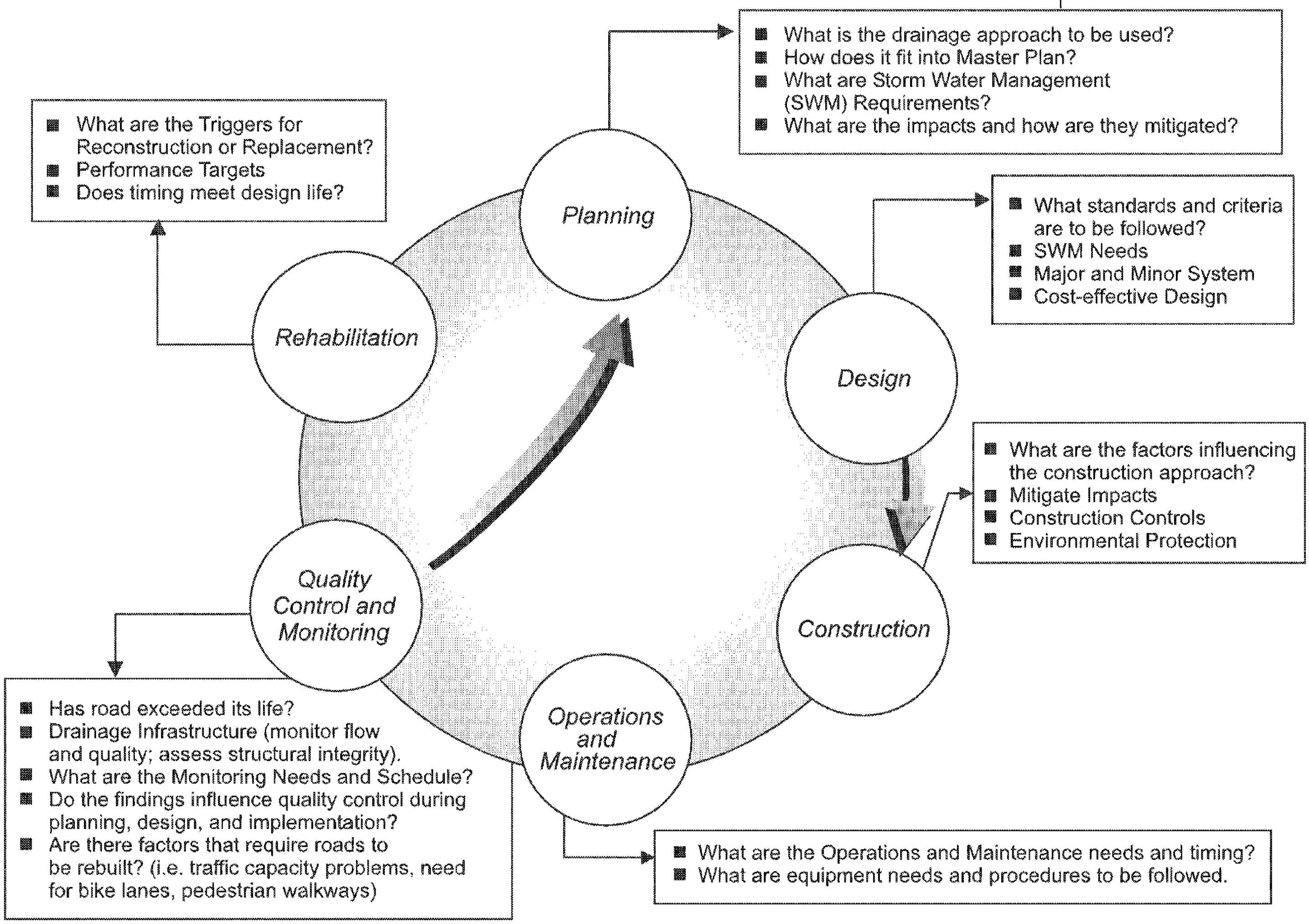
Tail water — The downstream water level that, if high enough, could influence the capacity/water levels in a conveyance system.

Watercourse — A river, creek, or stream in which water flows permanently or intermittently in a natural or artificial channel.

Glossary based on InfraGuide's Glossary of Terms *(www.infraguide.ca).*

Figure 1–1
Concerns in the planning, design and implementation steps

Figure 1–1: Concerns in the planning, design and implementation steps



2. Rationale and General Background

2.1 General Concerns of Right-of-Way Drainage

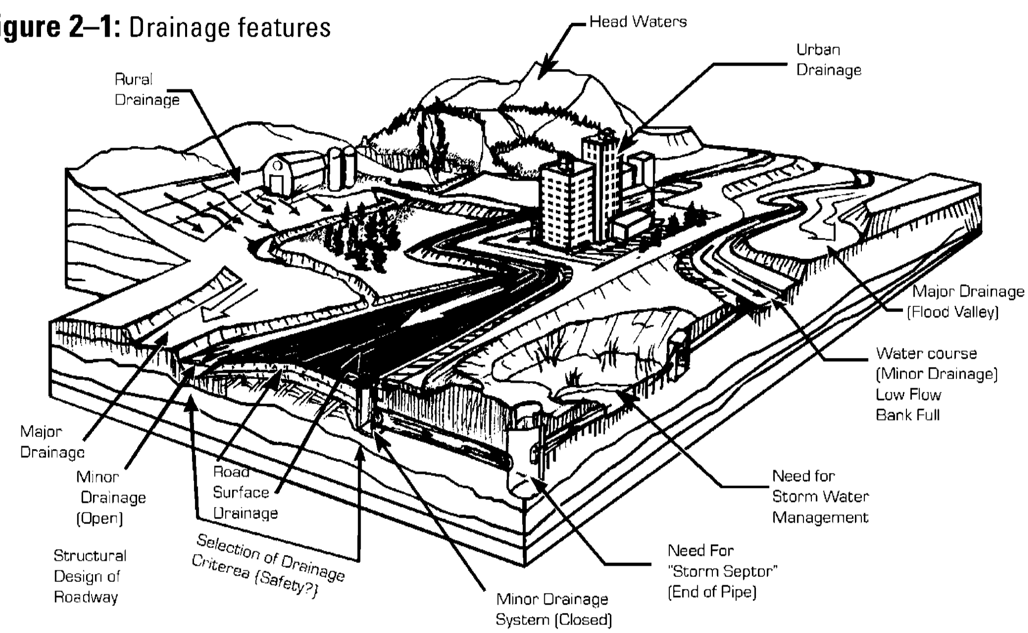
In past years, the key objectives of road drainage were generally considered to be the best and quickest means of removing water from a road surface in order not to impact the ability to travel on the roadway safely. This was rooted in the fact that the primary function of a road design was to provide for the safe conveyance of vehicles and, in many cases, roadside pedestrians and cyclists. Over time, it has been recognized that a number of concerns with regard to drainage can result in conflicting and overlapping objectives. These have typically included the following.

- How does road drainage fit into the overall master drainage planning of an area?
- Will the road drainage disrupt drainage patterns in a manner that affects overall servicing in an area or that creates flooding in upstream or downstream areas?
- Will the road drainage system impact on adjacent lands or the environment through impacts on water quantity (flow regime, peak flows, timing, volume) or water quality (e.g., pollution, siltation, habitat degradation, eutrophication, toxicity, oxygen depletion)?
- What is the most efficient way of providing drainage in the road right-of-way during major (flood) events and minor events?
- How will drainage be provided for during construction while protecting the environment?
- What are the operating, maintenance, and monitoring needs?
- What is the design life? When will rehabilitation or reconstruction be needed?
- What are the drainage needs to protect the road infrastructure (i.e., subsurface drainage)?

The practice of providing for only quick removal of water from the roadway often resulted in high investment requirements or, by sacrificing the level of service, poor performance. The use of storm water management (major and minor flow systems) emerged in the 1960s and 1970s, and provided the opportunity for cost-effective servicing and for satisfying many other objectives. Figure 2–1 shows the drainage features of a road right-of-way, how they interact with the surrounding environment and how they play a role in the drainage of waters from the entire watershed.

Over time, it has been recognized that a number of concerns with regard to drainage can result in conflicting and overlapping objectives.

Figure 2–1: Drainage features



At the quality control, monitoring, and assessment steps, the road designer/evaluator must decide whether the road can be rehabilitated to function properly.

2.2 The PDI Approach

Road right-of-way drainage treatments have evolved to meet the concerns and resulting demands on the drainage system. These demands or requirements span the PDI steps of a drainage system, from planning through to the maintenance and rehabilitation stages. This document discusses best practices for each of the six PDI steps (see Figure 1–1).

The six PDI steps are valid for the construction of new roads as well as the rehabilitation of existing roads. At the quality control, monitoring, and assessment steps, the road designer/evaluator must decide whether the road can be rehabilitated to function properly. If rehabilitation is not acceptable, the road will have to be reconstructed, and the cycle of the PDI steps begins again.

The physical limit of the right-of-way is often the main constraint in the development of a road drainage system. In some cases, the right-of-way drainage system may accommodate, or share facilities with, an external system. However, this is not typical since the road authority will need to have ownership or jurisdiction over the drainage system. Although integration is the norm, in cases where there are separate jurisdictions, efforts to integrate could be made where it is cost effective. A number of the issues or concerns that arise are through the potential impacts on drainage systems, lands, or the environment outside the road right-of-way. For this reason, the physical constraints of a road right-of-way may put limits on the ability to deal with drainage issues or needs outside the right-of-way.

The external drainage issues or the needs external to the road right-of-way are primary factors that have influenced drainage design significantly over recent years. Concerns over the potential impacts of flooding and erosion, or environmental impacts (typically water quality) have resulted in the need to provide conveyance, and manage or control storm water in a manner that will mitigate these impacts.

The need to practise SWM as part of road right-of-way drainage is discussed in more detail in the best practice *Source and On-Site Controls for Municipal Drainage Systems.* However, the concepts are discussed here, in the context of how they coincide with drainage design considerations. The need for SWM on road drainage is typically considered as quantity and/or quality control.

2.3 Storm Water Runoff Management and Controls

Storm water management refers to the control of storm water to satisfy both local and downstream objectives, in terms of quality and quantity. A variety of objectives may be considered, as described in Table 2–1.

Table 2–1: Storm water management objectives and design considerations

Objective	Design Consideration	Application to Road Drainage
Protect sewer system from flooding basements and causing sewer overflows	Reduce volume and peak rate of runoff	Inlet controls limiting flow; allowance for on street ponding; conveyance system storage.
Protect against downstream flooding and erosion in watercourses	Reduce peak rate of runoff	Conveyance system storage.
Protect surface water from spills and sediment	Capture sediments and oil	Catch basin design with sumps for sediment capture; use of GOSS traps; oil-grit separators used as inlets or in the conveyance system. Street sweeping and catch basin cleaning. Detention/retention in an SWM pond.
Protect water quality	Capture pollutants	Use of filtration system in the right-of-way (as part of road rehabilitation or reconstruction); oil-grit separators used as inlets or in the conveyance system. Managed road salting and sanding practices. Use of retention ponds or wetlands.
Maintain natural hydrology	Allow for infiltration	"Leaky pipe" exfiltration system in the right-of-way (as part of a road rehabilitation or reconstruction); conventional roadside ditches; enhanced roadside ditches; catch basin infiltration designs. Avoid direct connection of roof drains to storm sewers.

Road and highway design must take account of requirements for SWM. The road system and storm drainage system or conveyance system are intermediate in the overall urban drainage system. Lot drainage ends up in the conveyance system, usually constructed as part of the road right-of-way as either underground pipes (storm sewers) or open ditches. Usually, if required, downstream SWM facilities are constructed outside of the road right-of-way.

SWM is typically incorporated into a design to mitigate the impacts of development (including roadways) and/or to meet downstream constraints. The SWM needs and resulting criteria can be categorized as follows:

- quantity control for flood and erosion protection, and maintaining groundwater infiltration; and
- quality control for protection of streams and/or aquatic environments, and groundwater quality protection.

Further details on the typical impacts of storm water, the need for controls, and the typical approach are outlined in Appendix C.

A separate best practice document deals with source and on-site controls for storm water (*Source and On-Site Controls for Municipal Drainage Systems*). This document includes a description of source controls that occur on the road, such as street sweeping and catch basin cleaning. These measures are also described in the *Storm Water Pollution Prevention Handbook* (TRCA, 2001).

Other available documents describe downstream controls, such as SWM ponds, in great detail (MTO, 1995-1997).

3. Best Practices for Road Drainage

3.1 Framework for Best Practices

Best practices in road right-of-way drainage systems have evolved out of concerns regarding road drainage and the goal of providing more efficient and effective drainage systems that will meet these concerns.

A number of items in each of the drainage issues described here lead to the development of best practices. These issues are related to the PDI steps discussed previously and are summarized in Table 3–1. The best practices that have evolved out of each of the elements and corresponding issues are discussed in the following sections.

3.2 Drainage Elements and Best Practices

3.2.1 Overall Drainage Plan

The development of an overall drainage plan for the roadway and external drainage areas requires careful consideration of the criteria that will influence drainage, existing local criteria (capacity and SWM) and an approach that will meet the short- and long-term requirements of the roadway. If the proper approach is not given careful consideration, significant problems will exist. For example, if providing conveyance under major storm events is not considered, there could be a significant impact on traffic safety and flooding of private property during severe events.

Development of the overall drainage plan is usually considered in the planning stage of a drainage system (see Table 3–1); however it is also considered in the design, construction, and monitoring phases.

In the planning stage, the overall drainage plan must ensure that all external drainage areas are taken into account. Both existing and future land use conditions must be considered.

The drainage system should be planned to accommodate both minor (i.e., within the drainage system) and major (i.e., extreme flood events) flows.

Under major storm conditions, criteria can be set for either maximum allowable depths of surface flooding or, at the very least to identify the flood potential.

The road authority should work with the drainage authorities to identify criteria to be used for both the capacity and SWM criteria to mitigate any external impacts.

Under the design stage, an approach must be developed to ensure the drainage criteria are being met both for capacity and SWM.

In the planning stage, the overall drainage plan must ensure that all external drainage areas are taken into account.

Table 3–1: Drainage Considerations Leading to Best Practices

Drainage Issues/Items	Planning, Design and Implementation (PDI) Steps					
	Planning	Design	Construction	Operations and Management	Quality Control, Monitoring and Assessment	Rehabilitation
Overall drainage plan (Section 3.2.1) Major/minor systems Need for SWM	Accounting for external drainage. Is a master plan needed? Any current flooding and erosion? What are the overall drainage needs? Has provision been made for major drainage?	What are the criteria? What are the SWM needs?	Are there any environmental protection needs?	Can staff, equipment, and procedures be met by current resources?	Are performance targets being met?	Protect and enhance natural features (i.e., wetlands/streams). Have the ability to mitigate downstream effects.
Selection of drainage criteria (Section 3.2.2)	What level of service/safety is needed? What are the current criteria and is there a need for change? What are the watershed or environmental protection needs?	What are the criteria?		What are operating requirements (e.g. sediment removal frequency)?	Has the overall criteria been met?	
Closed drainage system (Section 3.2.3)	Are there provisions for major/minor drainage? Are there ways to meet quantity/quality control?	Material selection? Drainage criteria? Groundwater levels? Local site conditions (i.e. soil)?	Have local site conditions (i.e., soil) been considered?	What procedure is to be set? Can operations and maintenance be carried out safely?	What is the frequency of monitoring? Are there performance monitoring specifications? Has sediment control been considered?	What is the design life? Have new criteria or opportunities for upgrade been considered?
Open drainage system (Section 3.2.4)	Have provisions been made for major/minor drainage systems? Are there ways to meet quantity/quality Control? Safety concerns? Aesthetic concerns? Ownership/maintenance?	How to handle driveway crossings? Need for under drains? Dealing with safety/aesthetic issues? Landscaping approach?	Selection of materials? Maintenance approach?	Maintenance needs and by whom? Actual costs?	Frequency of Monitoring? Performance monitoring specs? Sediment control? Vegetation control?	What is design life? New criteria or opportunities for upgrade?
Road surface drainage/right-of-way drainage (Section 3.2.5) Geometric design standards	How to set objectives? Setting right-of-way needs?	Criteria for geometry? Criteria to meet winter conditions? Landscaping criteria? CBs spacing location on roadway curb cuts.		Winter maintenance needs? Preservation of trees?		New criteria or opportunities for upgrade?
Structural design of roadway (Section 3.2.6)	Loading /use restrictions?	Meeting local conditions, soils, groundwater. Subsurface drainage needs/conflict with drainage? Adverse conditions (i.e., Permafrost) Base/sub base design Location of other buried infrastructure.	Changes to meet conditions found?	Scheduling of O&M? Methods used? Specific problems (i.e., rutting, snow clearing	Monitoring program details and scheduling	

During the construction stage, the criteria needed to provide for both interim drainage and environmental protection are to be identified and incorporated in the construction documents to ensure controls are properly implemented. Interim drainage can include temporary channels, piped systems, or pumping. Environmental controls typically include silt control, as well as barriers around vegetation or other environmental features.

As part of the monitoring program, the protocol is set to evaluate the performance of the drainage system against the criteria. The monitoring can range from identifying sediment deposits and their potential to reduce the capacity of the drainage system, to monitoring the performance of the SWM facilities to meet targets for flow control, infiltration, and water quality control (i.e., pollutant removal).

3.2.2 Selection of Drainage Criteria

The performance standards and level of service provided by a roadway with respect to drainage are established through the drainage criteria selected. The level of service is usually defined by the return period (frequency) of the rainfall events the minor and major systems must handle. Other level-of-service criteria (e.g., materials, configuration, and geometric requirements) can be defined as well. In some regards, the drainage criteria can also affect the level of safety since it will include the allowable depth and duration of ponding on the road surface or in the open conveyance system. In most cases, drainage criteria are not set by the road authority alone, but typically include input from the local drainage authority, as well as provincial and possibly federal agencies.

A number of factors are typically taken into account in setting criteria for drainage. These include:

- the level of service to be provided;
- acceptable risk to safety (as related to ponding of water on the road surface);
- cost of drainage works as compared to benefit provided;
- currently established local and provincial criteria;
- other uses of the right-of-way; and
- constraints or protection needs for the receiving system (quality, quantity, and other environmental controls).

As the design of drainage systems has evolved, best practices now include a comprehensive set of drainage criteria to be included beyond the historic approach of addressing only the capacity of the drainage system.

Drainage criteria components typically included in road design and their link to road design are noted in the Table 3–2.

As well as being used for design, the established criteria can be used to set performance targets and applied in a monitoring plan. This will generally apply to the capacity of the drainage system and SWM criteria.

Table 3–2: Drainage criteria and their relativity to road design

Criteria	Relation to Road Design
Conveyance system capacity	Criteria to follow in designing road drainage conveyance elements
Road crossing capacity	Criteria to follow in designing conveyance (and free board) of road crossing over a waterway (generally varies with class of road)
Maximum depth of flooding on road	Can relate to flows along roadway during major design event or flow over the road at a watercourse crossing Depth and location restrictions to protect pedestrians from splashing and ensures safe travel for cyclists
Free board between roadside ditch and road base	To protect the road base from saturation and structural damage to the road surface
SWM criteria for quantity, quality control, and infiltration	To protect the receiving stream and environmental conditions
Maximum surface/gutter flow velocity	Pedestrian safety
Grating requirements for inlet and outlet structures	Public safety
Other environmental protection	Protection of specific vegetation, stream conditions, or characteristics and habitat conditions

A closed drainage (i.e., storm sewer) system is characterized by a system of connected pipes or conduits located below the frost line, as a minimum, which collect storm runoff based on gravity flow.

3.2.3 Closed Drainage Systems

A closed drainage (i.e., storm sewer) system is characterized by a system of connected pipes or conduits located below the frost line, as a minimum, which collect storm runoff based on gravity flow. Closed drainage systems are almost always designed to collect runoff from the minor storm event only (i.e., one year up to a 10-year event in Southern Ontario) and consist of curbs, gutter, catch basins, maintenance holes, pipes, and services. Typically, the 25-year storm event is used to design major trunk sewers in Southern Ontario.

A closed system is usually selected to drain road rights of way in lieu of an open system (i.e., ditches) for the following reasons.

- In urban environments, right-of-way widths are an important consideration, and open ditches with depth and side slopes require more land.
- Open ditches are perceived to be more of a hazard to traffic, although for higher speed roadway facilities, ditches with suitable slope treatments are recognized as an area of attenuation for errant vehicles.
- Roadside ditches may experience ponding waters and, as a result, can be perceived to provide lower functionality by the public.
- The critical configuration of a storm sewer system tends to have fewer constraints than a ditch system. (Ditches are constrained by grading limitations.)
- In areas of steeper grades, a storm sewer system is independent of erosion and stability factors, which are considerations for an open ditch system.
- There may be expectations/demands by adjacent property owners in terms of landscaping and aesthetics.

Planning Considerations

The section of roadway being considered must always be planned within the context of its role in the major drainage system. This is discussed in general terms in Section 2.1.

Major drainage considerations in planning must include the following.

- Provisions must be made for some external drainage inflows. Have these been identified?
- Does the preliminary design provide for a continuous overland flow route for storms greater than the closed system design storm, particularly in sag areas where limited ponding/flooding will be permitted?
- Do the roadway's other systems, safety barriers, and noise barriers interfere with the major system flow configuration?
- Is the receiving system (i.e., storm sewer, watercourse, channel) appropriate and suitable with regard to capacity, acceptance of higher peak flows, more flow erosion, and other impacts?

Selection of Design Criteria

The discussion on criteria presented here is largely based on the Ontario, Ministry of Transportation drainage management manuals. Road designers must consult the governing guidelines applicable to their province/municipality.

Design Capacity for Flow

The design capacity for flow generally varies from the 1:1 to 1:10 year frequency (i.e., return frequency of design event to be used). The selection of a lower design capacity will result in a smaller, less expensive system; however, the major (i.e., overland) flow routes will be in use far more frequently, and may be perceived to be more hazardous by the public. The selection of the drainage criteria is therefore based on a balance between the cost of the drainage system and the level of risk the agency is prepared to accept. A five-year design capacity is most commonly selected.

Road designers can conduct a formal documented decision-making process, which includes a risk analysis, before selecting their drainage criteria. Further information regarding the decision-making process is provided in the decision making and investment planning (DMIP) set of best practice guides.

System Criteria

System criteria (i.e., the approach to be used in selecting drainage system components) is typically based on broad-based criteria including:

- safety (vehicular and pedestrian);
- operations and maintenance requirements;
- cost; and
- design life.

System criteria depend heavily on the type of materials selected. A variety of materials with different coefficients of friction are available. The coefficient of friction of the material chosen will affect the capacity of the pipes chosen.

Typical criteria used in the system selection include the following.

Minimum flow velocities

- 0.75 m/s in smooth walled pipes to 0.9 m/s in corrugated pipes.
- Lower minimum velocities will provide for less self-scour and potentially more maintenance.

Maximum flow velocities

- 5.0 – 10.0 m/s
- Higher velocities may result in more scour and cavitation, and reduce the service life of the sewer.

Minimum pipe size

- 250 mm
- Smaller diameter pipes have the potential for more frequent clogging, and are subject to freezing.

Manhole spacing

- 100 – 150 m for smaller pipe sizes (i.e., less than 1200 mm diameter), 200 – 350 m spacing for larger diameter.
- A shorter spacing provides more access and potentially less difficult maintenance operations. Conversely, the presence of more manholes in the pavement surface will adversely affect vehicular riding conditions.

Inlet spacing

- Optimum locations for inlets include sags, upstream of intersections, upstream of pedestrian crossings, upstream and downstream of bridges, at locations of pavement cross-fall reversals, at boulevard locations in low lying areas, and in locations to collect snow melt.
- Many municipalities use a rule of thumb (i.e., minimum spacing) for locations. Where entrances are located in immediate proximity to theoretical inlet locations, the locations should be shifted to upstream of the entrance.
- Spacings can be calculated based on inlet capacity, gutter capacity related to grade, the maximum acceptable depth of gutter flow, and the allowable encroachment of flows or spread into the travelled lane. Computation methods include the use of Mannings Equation, empirical charts or special software (e.g., MTO CBSpace, *MTO Drainage Management Manual*, Part 2, Chapter 4: Pavement Drainage Design, 1995-1997).

In some cases “inlet restrictions” are used to reduce the inflow to the storm drainage system. This is common if either the receiving system has limited capacity or if the storm drainage system (combined or separate) is connected to adjacent buildings through foundation drains or other services. This practice can lead to road safety problems through excessive ponding of storm water on the road surface through either the reduced capacity or blockage of the inlet control. This application is still feasible, provided the potential depth and duration of street ponding is calculated during design, and maintenance procedures are established to check for and minimize the potential for blockage.

Minimum grades for catch basin connections

- 1.5 percent
- Where inlets must accommodate unusual drainage areas, the connections must be designed individually.

Curb Selection

The treatment at the edge of pavement can vary from no treatment (gravel) to a concrete or asphalt curb. Curb types can also vary from mountable to barrier types. A mountable curb essentially provides a means of facilitating drainage with a minimal height to allow for driving access over the curb. A barrier type curb allows for conveyance of water along the curb

The selection of the type of curb will depend on cost, durability, drainage provided, and integration with catch basins or drainage outlets.

at a greater depth, and also protects traffic from hazards in the boulevard. Various treatments for curbs, compiled by the Transportation Association of Canada (TAC) in the *Geometric Design Guide for Canadian Roads,* are illustrated in Appendix D. The selection of the type of curb will depend on cost, durability, drainage provided, and integration with catch basins or drainage outlets.

Concrete gutters are generally provided adjacent to curbs to facilitate roadside drainage, since their flow capacity is significantly greater than the adjacent pavement. Gutters are not considered to be part of the driving pavement width and provide for additional space from the traffic lanes to the face of the curb to enhance safety.

Installing perforated-pipe sub-drains (wrapped in filter fabric) in granular trenches under the curbs will facilitate drainage at the low edges of the granular layers underlying the asphalt pavement. The sides and bottoms of the sub-drain trench can be lined with geotextile to prevent contamination of the permeable granular backfill.

Materials Selection

A variety of precast types of maintenance holes, catch basins, and ditch inlets are available for installation. Some municipalities are now specifying side (curb) inlet catch basins on road bike lanes. However, this type of catch basin is not compatible with subsequent pavement overlays.

Various types of catch basin grates are available with diagonal or "herringbone" and curved patterns that are more "bicycle friendly" and still provide satisfactory inflow capacity (Toronto, 2002). In addition, some manufacturers have developed catch basin grates with a wavy surface designed to prevent debris from completely blocking the grates. Some municipalities have adopted a fish grate design to remind the public of the direct link of the storm sewer to the natural environment.

However, as with other components, a municipality's maintenance history and experience with various types of appurtenances will significantly influence its range of acceptable products.

Design Considerations

The design of the road drainage system includes the analyses of both hydrologic and hydraulic functions. The hydrologic analysis includes calculation of design flows, as well as the design of SWM for quantity and quality control. The hydraulic analysis is necessary for the design of the conveyance system, as well as possible input to SWM facility design.

Hydrology

Hydrologic analysis can be carried out through relatively simple analysis tools or more comprehensive computer models. The most common simple analysis approach includes the rational method, which uses a runoff coefficient, time of concentration (and resulting rainfall intensity), and the corresponding drainage area to calculate design flows. Computer models are more complex, but use the same basic principle of simulating the runoff characteristics for the drainage area and expected rainfall to provide a design flow or design hydrograph. The difference in the computational methods is generally in the detail used in analyzing runoff response characteristics. Details regarding analysis and modelling methods are available in various publications.

The general principles to be followed include the following.

- The Rationale Method is primarily for the calculation of peak flows. The use of this method to calculate runoff should be limited to simple pipe sizing in small drainage areas without stormwater management. Elsewhere, the use of hydrologic models is required.
- When designing SWM facilities, hydrologic models should be used.
- The modelling tools should always be developed to reflect local conditions, including the selection of design events (including rainfall and snowmelt) to be applied.

Hydraulics
The analysis and design of conveyance systems require the use of hydraulic analysis methods for either determining the capacity of existing systems or designing new drainage systems (open or closed). Similar to hydrologic analysis, methods can range from relatively simple analysis methods (using charts and calculations) to more complex models providing the ability to develop a more detailed analysis of hydraulic processes. These are typically used for conveyance systems that vary in type or complexity.

Sewer Design
Sewers should be designed on the basis of the following major considerations:

- pipe flow at 90 percent full under sub-critical conditions;
- free outlet;
- careful review of critical or super-critical flows;
- modelling of hydrographs and a hydraulic grade line along the sewer to identify surcharge impacts and provide for basement protection if downstream outlet pipes are undersized or submerged; and
- ensure the acceptability of outlets for appropriate capacity, so water levels will not be increased to the detriment of other inflows to the receiving pipe or watercourse, and to determine the extent of energy dissipation and erosion protection required.

Construction and Quality Control
Sewer systems located under pavement areas in particular, must be properly constructed, since repair costs, including societal costs due to delay and traffic infringement, will be significant.

Quality control must focus on:

- bedding, backfill, and compaction around appurtenances;
- pipe bedding, laying, and jointing to minimize flow exfiltration (Both infiltration and exfiltration may result in migration and collapse of cover materials and the pavement structure.); and
- backfill and compaction.

Operation and Maintenance
Many municipalities use a geographical information system (GIS) to manage maintenance records and programs for their sewer systems.

Surface maintenance activities generally focus on street sweeping in the fall and spring. A regular street cleaning program is important for both maintaining drainage on the roadway as well as protecting water quality. Regular catch basin cleaning to remove leaves and other debris prevents ponding of surface water. As well, research has shown that regular street cleaning and catch basin cleaning are effective in protecting the quality of receiving streams and water bodies.

The use of trenchless technologies are an emerging trend in more municipalities for repair/rehabilitation to minimize disruption to vehicular traffic. This includes sewer lining.

Municipalities are considering storm sewer maintenance in conjunction with, and integrated with, the maintenance cycles of other infrastructure renewal (i.e., sanitary sewers and water systems, bridges, and culverts), in addition to road works.

3.2.4 Open Drainage Systems

An open drainage system has traits, which can lead to more flexibility in design (i.e., capacity) as well as a lower potential impact on the receiving systems. However, open systems have their own particular concerns with regard to maintenance needs, operational limitations, and aesthetics.

Open drainage systems incorporate primarily ditches as opposed to pipes and conduits.

Ditch systems offer a range of advantages over closed systems including the following.

- Ditches could be viewed as more environmentally friendly. They allow for infiltration, water quality management through "filtering" of pollution, and reduced peak flows and volume through reduced flow velocities.

Sewer systems located under pavement areas in particular, must be properly constructed, since repair costs, including societal costs due to delay and traffic infringement, will be significant.

The application of soil bioengineering techniques integrates drainage, geotechnical, environmental, vegetation, and landscape architectural expertise to address flow conveyance, erosion, fisheries, and aesthetic concerns.

- They address the transitional period by accommodating drainage for the initial construction of roadways that are identified for future widening.
- Ditches can be designed for major, as well as minor drainage systems.
- Since they are not constrained by curb and inlet systems, ditches more easily facilitate structural overlays for routine maintenance.
- Snow management is less expensive.

However, open drainage systems usually require more right-of-way width than closed systems to accommodate the ditch depth and the resulting side slopes.

Planning Considerations
Similar to closed systems, open systems must provide for the major system considerations, such as maintenance of an overland flow route, the consideration of external drainage areas, and the suitability of the receiving system.

Selection of Design Criteria
Design storm
Open systems are generally designed to the same design storm as closed systems. Components may also be designed to convey the major system, as well as minor system flows.

System Criteria
Minimum flow velocity
- 0.3 – 0.5 m/s
- Lower velocities will result in sedimentation.

Minimum grade
- 0.3 – 0.5 %
- Flatter slopes will result in ponding and, possibly, sedimentation.

Maximum flow velocity
- Variable
- Progressively higher velocities will require different channel liners to withstand the flow's shear forces. Liner types vary from grass (lower velocities) to concrete.

Free board (major storms)
- 0 – 0.3 m, as measured from the top of the bank, and the maximum possible water elevation in the ditch.

Free board (minor storms)
- Water surface elevations to be set below the pavement structure and, where applicable, below the inverts of the pavement sub-drains and inletting swales.

Materials Selection
A variety of ditch lining products are available, and should be selected on the basis of the shear strength due to the flow they must accommodate, as well as maintenance, and aesthetic and fish habitat (if any) considerations. For moderate and higher flow velocities, where grass-lined slopes are no longer adequate, lining materials can vary from rip-rap to concrete block and armour stone, to concrete.

The application of soil bioengineering techniques integrates drainage, geotechnical, environmental, vegetation, and landscape architectural expertise to address flow conveyance, erosion, fisheries, and aesthetic concerns. This requires a careful comprehensive multidisciplinary approach.

Design Considerations
The design of open drainage systems requires the application of hydrologic and hydraulic methods as with closed drainage systems. Hydraulic analyses must consider the presence of culverts for roadway and driveway crossings, since these facilities usually provide the most significant head loss. Analysis and design methods are discussed in Section 3.2.3.

Alternative ditch cross sections can be tested using a variety of channel design software. Unless self-evident, cross-section selection should begin with a grass-lined, V-shaped ditch and then step up to trapezoidal channels, as required. Ditches designed for both minor and major storm flow conveyances generally incorporate a smaller low flow trapezoidal channel for minor flow at the bottom of a larger trapezoidal cross section. Ditch characteristics should provide for minor flow velocities large enough to avoid siltation/deposition and velocities under major storm conditions that can still be addressed through cost-effective erosion protection measures.

The performance of the ditch system in conjunction with design flows, proposed cross section and geometry, tail water elevation, can be modelled to generate a water surface elevation over the system using hydraulic computer models. This simulation will be particularly applicable if the outlet of the ditch system is submerged and conditions impede performance.

Construction and Quality Control
Quality control aspects of open ditch construction will normally focus on:

- longitudinal grade tolerance to avoid ponding;
- proper construction at confluence points;
- the timing and installation of interim erosion and sedimentation control measures such as check dams; and
- the construction scheduling of ditch lining to ensure stability over the immediate seasons.

Operations and Maintenance
Open ditch systems tend to collect garbage and debris, which must regularly be cleaned out for aesthetic, health/safety, and functional reasons. Maintenance implications include insect breeding habitat hazards, which must be treated.

Mosquito control and the spread of West Nile Virus are evolving as an issue in open ditch systems. A consistent approach to minimize the spread of the virus has not yet been developed, although various methods are being considered and used, such as larvicides to control mosquitoes, providing habitat to encourage natural predators, and using a design approach to avoid ponding water.

Areas of ponding must be carefully considered for ditch cleanout to address safety and aesthetic concerns. However, these objectives must be reconciled with storm water quality objectives, which are enhanced when storm flow velocities are reduced and ponding is increased to facilitate pollutant removal.

When ponding persists and becomes long term, "wetland" characteristics can develop which could increase approval requirements for cleanout and modifications. One recommended procedure for ditch cleanout includes the Lower Third Method, used by the Ministère des Transports du Québec, where the bottom one third of the ditch is cleaned of sediment and the vegetation lining the upper two thirds of the ditch is left in place. The vegetation on the upper portion of the ditch remains intact, to maintain its function of sediment removal and velocity reduction (Quebec, 1997). Ditch systems may require mowing several times annually, depending on local policies and the concerns of adjacent landowners.

If the objective is to minimize the chance of ponding in a ditch system, under drains can be added to provide an additional outlet. These can consist of a granular material to facilitate drainage, or a perforated pipe below the ditch invert to collect and discharge water.

Depending on the design, open ditch systems may have a number of driveway culverts, which will also require maintenance. During winter months, these can be prone to freezing which will require de-icing through steam injection or other similar methods.

3.2.5 Road Surface Drainage/ Right-of-Way Drainage

The design elements of the road and right-of-way cross section need to be considered to provide for an effective and efficient overall drainage system. One primary objective of road surface (geometric) designs is to ensure that storm flow is directed away from pavement areas as quickly as possible.
For curbed roads, this requires incorporating minimum longitudinal slopes (0.3 to 0.5 percent) and minimum cross fall (1.5 to 3.0 percent). The selection of gutters in conjunction with curbs (wider gutters), and the selection and spacing of catch basins will also facilitate the removal of runoff from pavement surfaces.

The design elements of the road and right-of-way cross section need to be considered to provide for an effective and efficient overall drainage system.

For example, in some colder climates, road designers use the upper end of the range of cross falls suggested above to facilitate rapid drainage under winter conditions.

The integration of all these elements becomes critical when:

- the longitudinal grade of the roadway is minimal to begin with, and additional lanes and pavement widening are introduced;
- intersecting pavement profiles must be integrated, pedestrian crossings, radius curbs, and aesthetics must be considered in intersection areas; and
- transitions are super-elevated, particularly in conjunction with flat longitudinal grades.

In these conditions, the pavement elevation fabric must be considered in multiple directions, including the review of multiple profiles along curb and gutter lines, and along vehicular turning paths, to ensure storm runoff flows from the pavement surface quickly, especially in areas of higher potential accident locations, such as intersections.

Road designers must consult the governing guidelines applicable to their province/municipality. For example, in some colder climates, road designers use the upper end of the range of cross falls suggested above to facilitate rapid drainage under winter conditions.

In the case of areas with very low topographic relief, it may be necessary to promote roadway drainage by introducing a “rolling” profile design. This is provided through a series of rising and falling minimum longitudinal grades, with a high point in between and catch basins placed in the low points. The road takes on a series of regularly spaced high and low points leading to the “rolling” terminology used.

For rural cross sections, longitudinal grades are not as critical. However, cross fall on pavement and shoulders and super-elevation transitions are very important considerations.

Although not as critical, boulevard areas must be designed to facilitate runoff and minimize ponding. Boulevards are ideally graded to drain over curbs into catch basins. Grades of less than 0.5 percent on boulevards, are not practical or achievable under current construction industry conditions.

Where areas in boulevards are lower than the curbs, ditch inlets or catch basins should be incorporated, and their connections designed with the same principles as storm sewer lengths. Boulevard inlets should also be considered in areas where concentrated snow storage/snowmelt is anticipated. Sheet flow drainage from boulevards or adjacent areas behind the sidewalks will be excessive and should be collected first, using a swale system with ditch inlets to intercept flow before it reaches the sidewalk or the curbs.

Boulevard drainage designs must always carefully consider any runoff contributed by abutting lands, particularly older residential areas.

In areas of low traffic volume (i.e., parking lots, etc.), centre-draining roadways may be used. Centre-drained roads eliminate the need for two separate storm water conveyance systems located on either side of the roadway, and therefore, significantly reduce capital costs. Since there is only one conveyance system in this design, its capacity must accommodate drainage from both sides of the roadway. In terms of maintenance, it is imperative that the drains located in the centre boulevard are cleaned regularly and allow for drainage. In many cases, it is difficult to maintain the centre drainage boulevard, since access to the boulevard typically impedes vehicular traffic. There are certain safety hazards also associated with the centre-drained roadway, since standing water or ice could be located on the roadway, and could impede vehicle passage.

3.2.6 Structural Design of Roadway

The approach used can impact the structural integrity, stability, and life of the road surface, especially in terms of whether or not the drainage of the sub-layer is considered. Ineffective drainage of the road sub-base can result in premature failure of the road surface.

Appropriate roadside and subsurface drainage must be provided to maintain structural integrity. Varying frost conditions throughout the country necessitate the requirement that the pavement structure be effectively drained to eliminate frost action and damage, minimize maintenance potential, and prolong pavement life.

For rural cross sections, ditches should be located immediately adjacent to shoulders, with free board to ensure that water levels do not reach the bottom of granular levels under minor storm conditions. Where deep ditches cannot be accommodated and only shallow or "perched" ditches can be provided, it may become necessary to incorporate sub-drains interfacing directly with the granular layer. Unless porous highly pervious native soils are present, sub-drains located under, or behind the curbs are usually incorporated in urban sections, as discussed in Section 3.2.3.

The underlying granular layers of pavement structures should be sloped at 2% minimum or 3% where conditions permit, and drained by suitable open ditches or sub-drains.

Granular surfaces are typically used only for low volume roads. Although initial construction costs are significantly lower than paved roads, there are greater recurring annual maintenance requirements.

For rural cross sections, ditches should be located immediately adjacent to shoulders, with free board to ensure that water levels do not reach the bottom of granular levels under minor storm conditions.

4. Applications and Limitations

4.1 Strategic Approaches for Effective Implementation

Road drainage is a subset of a larger set of systems designed to manage storm water, and is a mandatory component of the design and operation of every road. Proper design and maintenance is critical for the basic safe functioning of the road and to reduce adverse impacts on the natural and social environment adjacent to, upstream, or downstream from the road.

A life cycle systems approach should be adopted for road drainage, which explicitly recognizes the functions of road drainage in the overall management of storm water and all appropriate costs over the life cycle of the road infrastructure and the road drainage components within it.

There are four fundamental steps in establishing an effective life cycle systems approach to road drainage.

1. Understand the planning and regulatory context.
2. Sustain an engineering capability.
3. Establish an asset management framework.
4. Set priorities and integrate them into operations and capital works programs.

While oversight of SWM might best be delineated by watershed boundaries, the reality is that there may be several jurisdictions at the municipal, provincial/territorial, and federal levels with varying responsibilities for, or interest in, SWM. Consequently, road designers must understand the planning context for drainage design – the availability of master drainage plans for watersheds and sub-watersheds, regulatory obligations for quality and quantity flow management, and applicable engineering design criteria for the road and drainage infrastructure. Proper planning provides the necessary guidance to road designers to develop and assess alternative engineering system solutions for road drainage. With a long-range plan, the requirements for drainage improvements are better understood and opportunities for new road drainage systems or improvements to existing road drainage systems can be more effectively assessed and implemented.

Best practices in the engineering design functions for roads and road drainage draw on three fundamental and essential resources:

- sound engineering knowledge and skills;
- appropriate technical reference manuals or guidelines; and
- supporting analytical and evaluation tools.

Municipalities should have an asset management framework in place for their entire infrastructure inventory. For road drainage purposes, this requires:

- a road inventory that includes a record of needs identifying where drainage problems exist;
- an inventory of drainage infrastructure assets;
- a regime for regular condition and performance assessment of those assets; and
- supporting analytical and evaluation tools for needs assessment and improvement selection.

Proper design and maintenance is critical for the basic safe functioning of the road and to reduce adverse impacts on the natural and social environment adjacent to, upstream, or downstream from the road.

An important analytical tool within this framework, which assists in the selection of the optimum design treatment and its timing for implementation is life-cycle cost analysis. The use of life-cycle cost analysis is recommended. Improvements to the drainage infrastructure (maintenance, enhancement, rehabilitation, reconstruction, or replacement) should be implemented in concert with other planned operations and capital works improvements.

4.2 Key Applications and Limitations

Table 4–1 highlights additional applications and limitations associated with the use of this guide.

Table 4–1: Guide Applications and Limitations

Subject Area	Guide Application and Limitations
Geologic/topography	Applicable in most geologic and topographic environments. Special considerations are required in circumstances, such as presence of rock close to the surface; presence of clays and unstable soils; flat terrain with poor drainage outlets; high water tables; adjacent wetlands; presence of cold water fish habitat receiving waters. Severe vertical topographic relief may accentuate soil erosion problems. Certain chemical characteristics of soils (e.g., acidity) may impact the selection of engineering materials for use in conveyance systems.
Urban/rural	Applicable to urban and rural areas within municipalities. Existing infrastructure upstream and/or downstream may dictate or limit the nature and extent of the conveyance system design. Redevelopment and reconstruction of adjacent lands and/or of road rights-of-way may allow for the phased adoption of best practices to replace underperforming and inadequate systems over time.
Water quantity and quality	Applicable to the management of water quantity issues in the planning design, construction, operations and maintenance of municipal roads. Does not address water quality management issues.
Road classification	Applicable to most municipal road classifications except controlled-access divided highways.
Municipality size	Applicable to municipalities of various sizes but may be of greater benefit to municipalities with limited engineering and technical resources.
Climactic/seasonal	Applicable in most climatic conditions. Extended periods of ground frost may accentuate problems associated with surface runoff and/or snowmelt conditions by increasing runoff quantities and velocities.
Regulatory/planning	The preparation of master drainage plans and watershed plans provides the best context for cost-effective road drainage design and the application of this guide. Storm water quantity and quality management goals and requirements should be defined. In their absence, conveyance design solutions may not meet performance goals.
Engineering	This guide is suitable for most engineering applications. A coherent set of engineering standards and specifications should be developed and/or adopted for municipal road design and the associated drainage design; manuals and procedural guidelines should be available. While the guide is a useful reference, it should not be seen as a substitute for appropriate technical reference manuals for engineering design purposes. Restricted site conditions may impose limitations on the geometric design characteristics of the road and the drainage systems. The treatment of the pavement cross fall requires particular attention with wider/more lanes and at intersections of major roads. Road safety is a key consideration in design of road and roadside infrastructure. Aesthetic considerations in design (e.g., open versus closed systems) must be balanced to meet the requirements and expectations of travellers and adjacent property owners.
Asset management	This guide will be most effective where a sound asset management framework for road infrastructure is in place and is used. Life-cycle costs can be optimized and will promote effective priority setting for proposed improvements to the drainage infrastructure. Coordination with capital works including those by others, such as utility operators, and integration of operations and routine maintenance, with periodic rehabilitation and major reconstruction works can be undertaken.
Operations and maintenance	This guide is applicable to the operation and maintenance of municipal roads. Municipalities are encouraged to have maintenance standards and operating procedures. Effective road drainage performance can be optimized by operations management information and feedback. Performance monitoring specifications should exist for vegetation, sedimentation, and erosion control, beaver dam control, ditch and inlet cleanout, and culvert inspection and clean-out.

Appendix A:
Safety Issues and Safety Treatments

Table A–1
Examples of Safety Issues and Safety Treatments

Table A–1: Examples of Safety Issues and Safety Treatments

Drainage Features	Safety Issues	Safety Treatments
Curbs (barrier curbs, mountable curbs)	Higher curbs may drag on the underside of some vehicles.	Height of 150 mm for barrier curbs. Maximum height of 100 mm for mountable curbs.
	Desirable on roads with posted speeds of 90 km/h or higher.	Errant vehicles may overturn or become airborne on impact with them.
	Obstruction.	In urban conditions, a minimum horizontal clearance of 0.5 mm.
Transverse culverts	Obstacles to vehicles that run off the road.	Traversable design is accomplished by matching the inlet or outlet slope of drainage structure to the embankment slope.
	Obstacles to vehicles that run off the road.	Extension of structure for a culvert is not traversable; an option is to extend the structure so the obstacle is located at or just beyond the appropriate clear zone.
	Obstacles to vehicles that run off the road.	Shielding: in cases where the two above treatments are not available, it may be necessary to shield the obstacle with traffic barrier.
Parallel culverts	They represent a significant obstacle, because they can be struck head on by errant vehicles.	Traversable design: the primary goal is to maintain a traversable slope and to match the culvert opening with the slope. Suggested slope is 6:1 for areas with high-speed impacts. A steeper slope can be used for lower volume and lower speed facilities.
	They represent a significant obstacle because they can be struck head on by errant vehicles.	Relocate the structure: some parallel drainage structures can be moved laterally further from the travel area. This treatment gives the design engineer the opportunity to flatten the transverse embankment slope within the selected clear zone distance of the roadway under design.
	They represent a significant obstacle because they can be struck head-on by errant vehicles.	Shielding: in cases where the two above treatments are not available, it may be necessary to shield the obstacle with a traffic barrier.
On roadway inlet	Does not constitute a safety problem to errant vehicles. Increase safety hazard to maintenance workers.	Installed flush with the pavement surface.
Off roadway inlet	Is an obstacle to errant vehicles.	They should be designed and built to be flush with the channel bottom on which they are located.
Drainage inlets/outlets	Public safety due to accessibility	Gratings to prevent access.
Roadside channel	Sections which fall outside of shaded region are less desirable.	Is acceptable for projects having the following characteristics: restrictive right-of-way, rugged terrain, reconstruction projects, low volume, or low speed roads.
	Sections which fall outside of shaded region are less desirable.	Should be considered for either conversion to a closed system (culvert) or shielding by roadside barrier.

Appendix B:
Storm Water Quantity Control

Storm water runoff quantity is typically viewed as the criteria that will influence the capacity of the drainage system provided. Road drainage systems can impact on the drainage systems both upstream and downstream of the road right-of-way. Road drainage systems must accommodate external drainage upstream of the roadway and safely convey it downstream. InfraGuide best practice entitled *Assessment and Evaluation of Storm and Wastewater Collection Systems* (in development) describes in further detail, methods used to select the appropriate storm sewer, in terms of structure and capacity.

Road systems, as part of the design approach, can affect both flood potential in the immediate area, as well as the potential for erosion, including the fluvial geomorphologic characteristics of a stream system.

Flooding

Road right-of-way drainage can influence flooding in two ways.

- The increased impervious area and concentrated flow in the drainage system can increase peak flows and flow volume in downstream receiving systems, increasing flood potential.
- The size of the roadway drainage system and/or road crossing over a watercourse can constrict flows and increase flood potential upstream of the roadway.

Road structures may impede the passage of flow in a watercourse and increase upstream water levels significantly. This can introduce floodplain storage in a watercourse that could reduce peak flows and associated flood potential downstream. The controls may include either the control of peaks to pre-development levels or over control to the capacity of the downstream receiving system.

SWM is, therefore, a common requirement by drainage authorities to mitigate any flooding impact. Similarly, drainage authorities require input on the drainage design criteria chosen to avoid upstream flooding impacts.

Erosion

Road right-of-way drainage can impact the overall rainfall response characteristics (flow regime), including runoff volume. This is not only an impact on flood potential, but can also increase the potential for erosion in receiving streams and influence fluvial geomorphologic processes. As a result, drainage authorities will often require that SWM be practised to mitigate potential erosion impacts. This could include various controls of peak flows at specific flow or design levels (referred to as distributed runoff control/DRC), the retention or detention of a specified volume of water for a long duration (usually a minor storm event), or the use of infiltration to reduce runoff volumes.

Appendix C:
Storm Water Quality Control

Urban land uses generate residual and waste material from a myriad of individual and group activities. Each type of land use has unique characteristics that result in the generation of pollutants and runoff volume. Density or intensity of the land use and percent imperviousness also plays a part. Table C-1 presents a summary of different storm water quality pollution sources originating from different land uses.

Table C–1: Pollution Sources

Source of Pollution	Description
Vehicular traffic	Accounts for much of the buildup of contaminants on road surfaces. Wear from tires, brake and clutch linings, engine oil and lubricant drippings, combustion products and corrosion, all account for buildup of sediment particles, metals, and oils and grease. Wear on road surfaces also provides sediment and petroleum derivatives from asphalt.
Lawn and garden maintenance	In all types of land uses including residential, industrial, institutional, and parks, road and utility right-of-way design should account for additions of organic material from grass clippings, garden litter, and fallen leaves. Fertilizers, herbicides, and pesticides all can contribute to pollutant loads in runoff.
Air pollution	Fallout of suspended solids accounts for a buildup of sediments contaminated from traffic, industrial sources, and the wind erosion of soils.
Municipal maintenance	Activities including road repair and general maintenance (road surface treatment, sanding, salting, dust control, etc.).
Industrial and commercial	Activities can lead to contamination of runoff from loading and unloading areas, raw material and by-product storage, vehicle maintenance, and spills of petroleum products.
Illicit connections of sanitary services or industrical connections to storm sewers	Causes contamination of storm water with organic wastes, nutrients, bacteria and industrial effluents.
Illicit disposal of household hazardous wastes	Introduces waste oil and a multitude of toxic materials to storm sewers.
Transportation spills	Accidents can occur anywhere, particularly on local commercial industrial streets.
Construction activity	Introduces heavy loads of sediment from direct runoff, construction vehicles, and wind-eroded sediment.
Animal feces and litter	Introduces organic contamination, nutrients, and bacteria.
Combined sewer overflows (CSOs)	Contain a mixture of sanitary, commercial, and often industrial waste, along with surface drainage. CSOs can contain high levels of nutrients, suspended solids, metals, organic contaminants, oxygen-demanding substances, and dangerous bacteria and viruses.
Runoff from residential driveways and parking areas	Can contain driveway sealants, oil, salt, and car care products.

C. Storm Water Quality Control

Pollutant Impacts

The receiving water quality impacts of municipal discharges vary depending on the quality and quantity of the wastewater and the assimilative capacity of the receiving water body. Potential water quality concerns resulting from CSOs and storm water include:

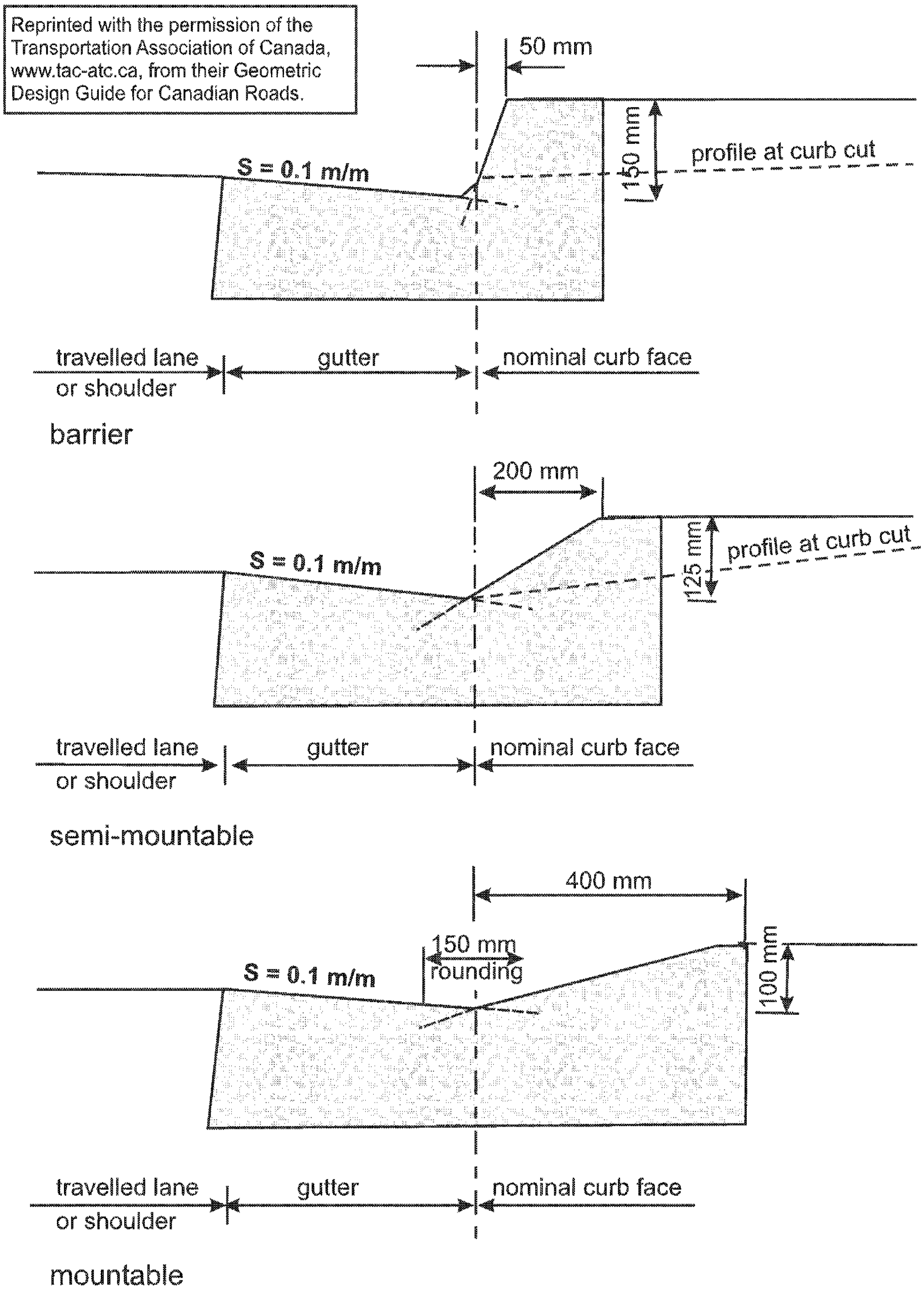
- pathogenic micro-organisms associated with fecal pollution and contributing to restrictions on recreational water use (i.e., beach closures);
- nutrient enrichment, from nitrogen and phosphorous compounds, which can lead to nuisance growths of algae in the receiving water body;
- deposits of contaminated sediments, which can lead to degradation of benthic (i.e., bottom-dwelling) organisms and restrictions on dredging;
- toxicity from ammonia, metals, and organic compounds present in the runoff and overflows and potential human endocrine disruption from pesticides;
- oxygen depletion potential (oxygen demand or BOD) of the wastewater from biodegradable organic material, which can lead to oxygen deprivation to the organisms in the receiving water body;
- temperature changes caused by heating of urban runoff on impervious surfaces;
- aesthetic impacts from floatable matter and sediments (i.e., litter, grass clippings, sanitary items, soil erosion, etc.);
- contamination of groundwater with soluble organic chemicals, metals, nitrates, and salt; and
- damage to roadside and downstream vegetation due to road sand and sand usage.

The need for SWM for quality control will vary significantly, depending on the criteria set by local agencies and the sensitivity of the receiving system (i.e., concerns regarding environmental impacts). A wide variety of control measures are available, with their selection and application depending on the criteria to be met. Further details are provided in the best practice guides dealing with SWM.

Appendix D:
Typical Curb Illustrations

(Extracted from TAC Geometric Design Guide for Canadian Roads)

Figure D–1: Curb and Gutter Types



References

AASHTO (American Association of State Highway and Transportation Officials) (1991) *Model Drainage Manual.*

CERIU (Centre for Expertise and Research on Infrastructures in Urban Areas) (2002) *Centre for Expertise and Research on Infrastructures in Urban Areas (CERIU) Compendium.* December. Available at <www.ceriu.qc.ca/Bienvenue_ang.htm>.

Ontario, MTO (Ministry of Transportation Ontario) (1989) *Drainage Management Technical Guidelines.*

Ontario, MTO (Ministry of Transportation Ontario) (1997) *Drainage Management Manual.*

Quebec, Ministère des Transport (1997) "Summer Maintenance Drainage System Ditch Cleaning," Environmental Promotion Record FPE-01, August.

TAC (Transportation Association of Canada) (1999) *Geometric Design Guide for Canadian Roads.*

Toronto, City of (2002), "Chapter 4: Bicycle Friendly Streets," *Toronto Bike Plan*, December.

TRCA, (2001) *storm water Pollution Prevention Handbook.*

Notes