Underground Stormwater Infiltration

Best Practices for Protection of Groundwater Resources in British Columbia

BRITISH COLUMBIA

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Summary of recommended practices for underground stormwater infiltration

Component	Recommended Practices
Design Approach: Properly site and design underground infiltration facilities to minimize risks to water supply aquifers	☑ Use qualified professionals for facility siting and design. ☑ Design facilities to prevent contamination of drinking water supply aquifers. ☑ Coordinate with local authorities and comply with local design and permitting requirements.
Source Analysis: Characterize the type of pollutants potentially generated by the project, the risks they pose to groundwater and measures to reduce their input into stormwater	☑ Identify site-specific pollutants of concern. ☑ Identify surface and groundwater resources that potentially receive pollutants of concern. ☑ Evaluate the migration potential for pollutants of concern in soils and groundwater, and characterize risks to groundwater quality. ☑ Select appropriate source control measures.
Facility Siting: Evaluate the feasibility of underground infiltration facilities based on proximity to existing infrastructure and environmental conditions	☒ Do not use underground infiltration in watersheds with a potential to generate high levels of pollutants and pollutants that pose a high risk to groundwater quality. ☑ Locate facilities at least 60 m from water supply wells and at least 30 m from septic systems, or as required by local agencies. ☒ Do not use underground infiltration where there is a potential to cause or contribute to slope failure. Have qualified professionals evaluate all potential geotechnical hazards. ☑ Locate facilities at least 50 m up-gradient and 25 m down-gradient from foundations with no footing drains. ☑ Consider human and ecosystem uses of groundwater resources in facility siting and design.
Hydrogeological Assessment: Evaluate the feasibility of underground infiltration facilities based on hydrogeological conditions at the site	☑ Determine the type of geologic materials below the full span of the infiltration facilities. ☒ Do not use underground infiltration in geologic materials with a potential for rapid migration to groundwater, such as fractured bedrock, karst formations, and well-sorted gravels and cobbles. ☑ Determine the annual high water table elevation. Ensure infiltration facilities are a minimum distance above the annual high water table to provide for pollutant attenuation within the unsaturated zone (see **Table 4**, page 28). ☑ Estimate a design infiltration capacity based on geologic conditions of the entire site, incorporating a factor of safety. Conduct a groundwater mounding evaluation as needed to ensure mounding will not restrict infiltration or cause the direct release of stormwater into the aquifer.

Component	Recommended Practices
Pre-Treatment Evaluation: Determine the necessary type of pre-treatment facilities based on the pollutant loading potential	☑ At a minimum, always include sedimentation facilities such as sedimentation manholes to remove coarse sediment and debris from stormwater prior to conveyance into the infiltration facilities. ☑ Use higher levels of pre-treatment in watersheds with large pollutant loads or pollutants that pose a greater risk to groundwater (see **Tables 5 and 6**, pages 29 and 30).
Facility Design: Consider design elements for protection of groundwater quality	☑ Always consider adequate and safe access for maintenance inspection and sediment removal from pre-treatment and infiltration facilities. ☑ Consider additional design elements for added protection of groundwater resources, such a spill protection, bypass and overflow capacity and groundwater observation wells.
Maintenance and Monitoring: Provide for ongoing facility maintenance and site monitoring	☑ Determine and document maintenance requirements, responsible parties, and record keeping of maintenance activities (see **Table 7**, page 33). ☑ Develop a plan for ongoing monitoring of the watershed and facility conditions. Consider groundwater monitoring in high risk areas.

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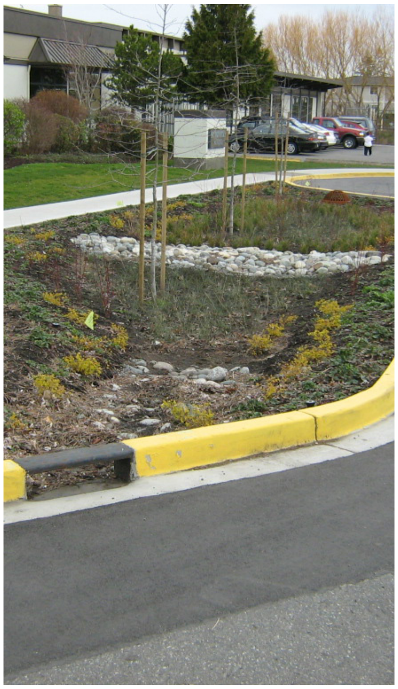
Purpose and Contents

Stormwater management (also called rainwater management) is a key consideration in urban development and redevelopment projects. In British Columbia (B.C.) there is a strong awareness of the connection between stormwater[1] management and watershed health and protection. To protect streams, wetlands and aquatic ecosystems, development projects routinely use stormwater infiltration facilities to reduce the volume of runoff and the level of pollutants that flow to receiving streams.

Common types of stormwater infiltration facilities include swales, rain gardens, bioretention[2] planters, and infiltration basins. These types of vegetated infiltration facilities promote stormwater infiltration at the ground surface. Another approach is to use sumps, shallow percolation systems or wells to infiltrate stormwater below the ground surface. These types of underground infiltration systems pose a risk to groundwater resources if they are not properly designed, operated and maintained.



Rain garden.
Photo: Jeremy Gye

The goals of this guidance document are:

1. To increase awareness of groundwater resources in stormwater management, and
2. To protect drinking water aquifers by reducing risks of groundwater contamination from underground stormwater infiltration systems.

To address these objectives, this document describes:

- Common infiltration practices in stormwater management;
- The regulatory context for stormwater infiltration;
- Risks to groundwater resources from infiltration practices; and
- Recommended best practices for design and operation of underground stormwater infiltration.

1 In this document stormwater refers to all forms of urban runoff, including runoff that originates from precipitation, snowmelt and dry weather runoff.

2 Bioretention planters and rain gardens are landscaped depressions or shallow basins used to slow and retain stormwater runoff, and to remove pollutants from stormwater through a combination of physical, chemical and biological processes.

Background and need for guidance

Stormwater management practices in B.C. are founded on the 2002 document *Stormwater Planning: A Guidebook for British Columbia* (*Stormwater Planning Guidebook*). This document initiated a shift in the way stormwater is managed in the province. The traditional 'collect and convey offsite' approach was replaced with a focus on the ability of the landscape to absorb rainfall and retain stormwater on-site in order to protect aquatic ecosystems.

This guide has been prepared for homeowners, land developers, design professionals, and local government staff who are involved in the use or review of underground stormwater infiltration systems

Local governments throughout B.C. have embraced the principles in the *Stormwater Planning Guidebook*. Many municipalities have established bylaws that require retention of stormwater on the development site. An outcome of these bylaws is the increased use of underground infiltration systems as a means for meeting on-site retention requirements. However, the *Stormwater Planning Guidebook* did not address the use of underground infiltration or emphasize the need for protecting groundwater resources in stormwater management, and until now there has been no provincial-level guidance that addresses the design and use of underground infiltration systems.

The Ministry of Environment (MoE) is concerned about the growing use of underground infiltration systems because these systems can provide a pathway for pollutants to travel from the ground surface to underlying aquifers. This increases the risk of contaminating groundwater resources and drinking water supplies if infiltration facilities are designed and operated without fully considering the types and sources of pollutants, the hydrogeologic[3] conditions and the groundwater uses.

This document addresses concerns for groundwater protection in two ways:

1. Increasing the awareness of stormwater infiltration practices and the potential threats to groundwater; and
2. Providing guidance on best practices for designing and operating underground infiltration systems.

The target audience includes homeowners, land developers, design professionals, and local government staff who are involved in the use or review of underground stormwater infiltration systems.

3 Hydrogeology refers to the interaction of groundwater movement and geology, including the hydrologic, physical, chemical, and biological processes that may influence the distribution and movement of groundwater.

Photo: Judith Cullington

Importance of protecting groundwater

British Columbians have an interest in protecting our groundwater resources. Groundwater is a source of drinking water for 25 percent of B.C.'s population, including both rural and urban areas. Groundwater is an important economic resource for agriculture, manufacturing, mining, and aquaculture throughout the province. Many riparian systems also depend on groundwater flows to function as healthy ecosystems.

The water quality of drinking water aquifers is vitally important to human health and economic development. An aquifer with degraded water quality will trigger concerns about the immediate and long-term human health consequences for domestic and municipal water users, as well as the suitability of the water supply for agricultural, commercial and industrial uses. To address these concerns, the pollutant sources and the risks posed by contaminants must be assessed. Costs are incurred if water quality treatment is required for human uses or if it is necessary to remediate aquifers because of contamination. In extreme cases, the groundwater may no longer be usable for water supply. Protecting groundwater quality for drinking water and economic development should always be a key consideration in the design of stormwater infiltration systems.

In many watersheds, groundwater inflows to streams comprise the majority of dry season low flows. In these watersheds, groundwater flows to streams can be crucial for aquatic habitat, providing both adequate flow and temperature refuge for sensitive fisheries during summer and winter low flow periods. Stormwater management policies that protect the quantity and quality of groundwater resources supports natural groundwater recharge and infiltration conditions that are central to healthy riparian habitat.

Infiltration Practices in Stormwater Management

Importance of infiltration

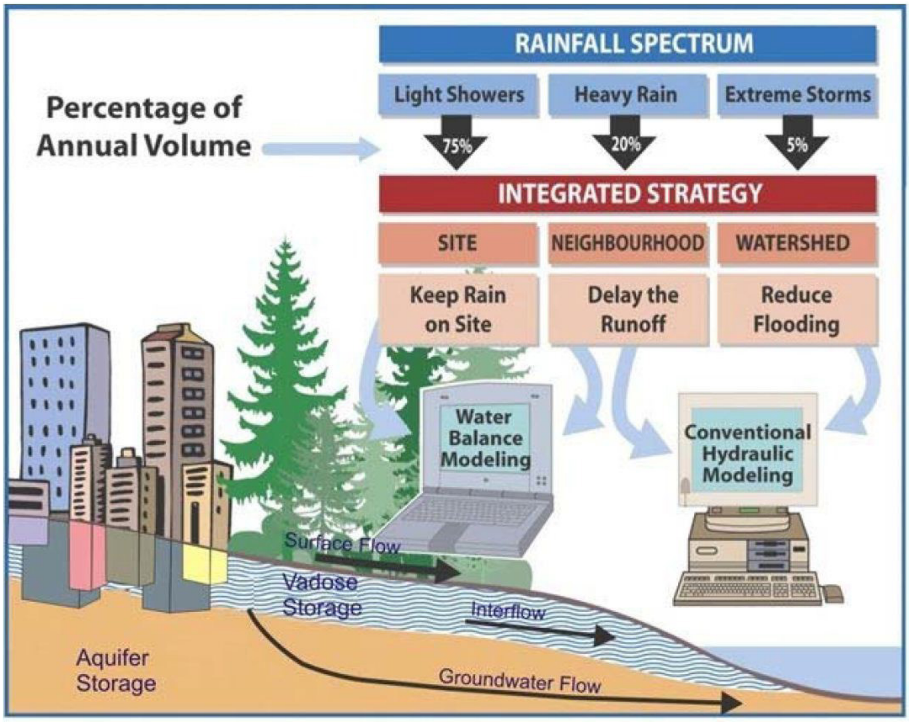
Urban development changes the natural hydrologic processes of the watershed as shown in **Table 1**. Urban development greatly increases stormwater runoff in two ways:

1. Removing vegetation reduces interception, evaporation and transpiration; and
2. Creating impervious surfaces reduces infiltration.

Table 1: Impact of urban development on the hydrologic water balance

	Natural Conditions	Developed Conditions
Evaporation & transpiration	45% of precipitation	30% of precipitation
Stormwater runoff	<1% of precipitation	25% of precipitation
Infiltration and Interflow (lateral flow in shallow soils)	45% of precipitation	35% of precipitation
Deep groundwater recharge	10% of precipitation	<10% of precipitation

Adapted from Stormwater Planning: A Guidebook for British Columbia (2002)



Source: *Stormwater Planning: A Guidebook for British Columbia*, 2002

A guiding principle for effective stormwater management is to design developments that preserve the natural hydrologic balance of the site. This fundamental concept is rooted in a science-based understanding of factors that impact watershed and stream health. The concepts and principles are described in *Stormwater Planning: A Guidebook for British Columbia* (2002), and are actively applied in stormwater management bylaws throughout the province.

To preserve or restore the natural water balance of a development site, the volume of stormwater runoff must be reduced, as shown in **Table 1.** The most common and economical approach for reducing offsite stormwater runoff is to increase on-site infiltration through the following practices:

- Directing runoff from impervious to pervious areas;
- Selecting soils with high infiltration and storage capacity;
- Using construction practices that limit soil compaction; and/or
- Constructing infiltration facilities that increase on-site infiltration.

Stormwater management practices should endeavour to protect the water quality of all receiving waters, including both surface water and groundwater. When properly designed, infiltration facilities can reduce runoff volume and reduce the levels of pollutants that can potentially contaminant surface and groundwater resources.

Surface infiltration practices

The most common and cost-effective infiltration practices are surface infiltration facilities that promote infiltration at the ground surface. They are typically vegetated facilities that can provide both effective runoff reduction and pollutant removal (**Figure 1**).

Figure 1: Bioretention areas (left) and swales (right) are common surface infiltration practices

Photos: Judith Cullington

Common surface infiltration facilities include:

- Rain gardens and bioretention areas;
- Swales and filter strips;
- Infiltration basins; and
- Pervious pavements.

Other types of stormwater control facilities such as extended detention basins, wet basins and constructed wetlands can also provide some incidental reduction in runoff volume via infiltration. However, infiltration is not a primary design goal of these facilities, which are used mainly for flow attenuation and water quality treatment.

What is an underground stormwater infiltration system?

An underground infiltration system has its point of infiltration to the environment below the ground surface. Underground infiltration systems encompass a wide variety of configurations and design approaches. Most systems are low-tech designs that rely on gravity to convey runoff into a sump, pit, chamber, gravel bed, percolation system, or borehole, where it gradually infiltrates into the native soils over time.

Underground infiltration systems are typically more costly to construct and maintain than surface infiltration facilities. They are also susceptible to clogging, which requires diligent maintenance to mitigate. For these reasons underground infiltration system are not as common as surface infiltration systems. The advantage of underground infiltration systems is they provide a means for reducing offsite runoff on development sites where the available surface area for stormwater management is limited.

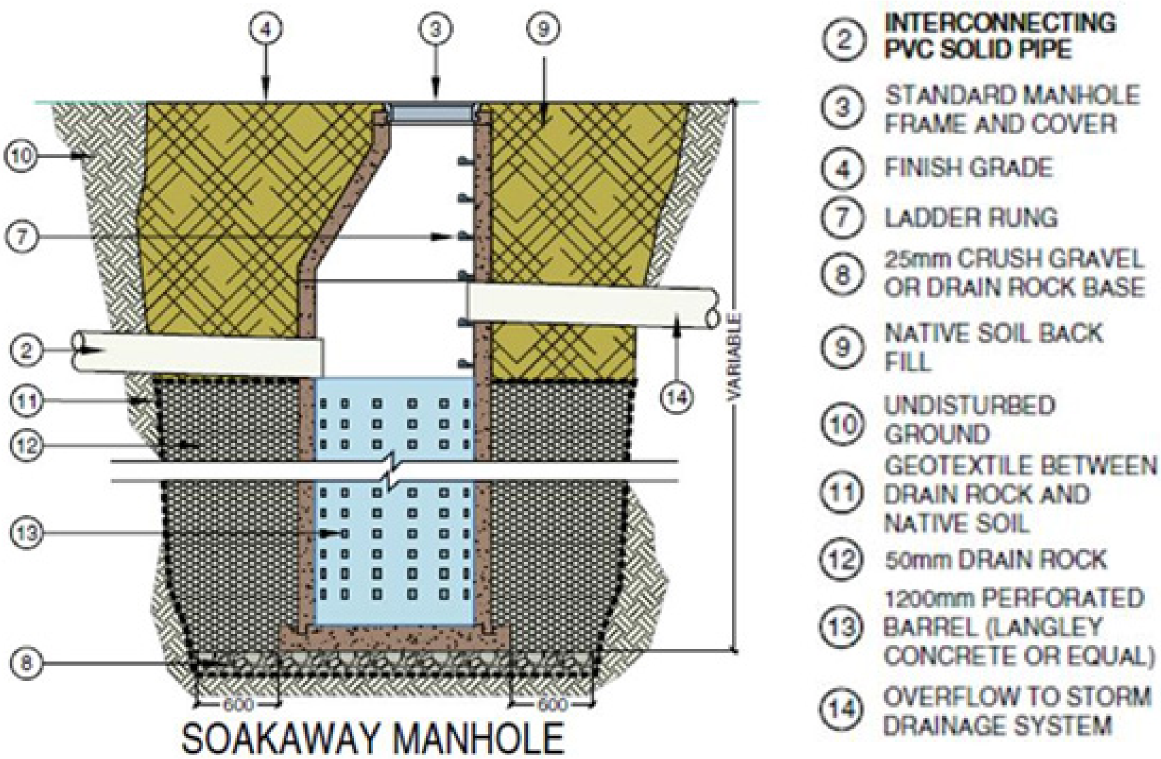
Underground infiltration practices

Perforated manholes

Perforated manholes, also known as soakaway sumps or dry wells, are a common type of underground infiltration system. They include sections of perforated concrete pipe that are installed vertically into the ground, allowing runoff to gradually percolate into the surrounding soils (**Figure 2**). These structures are non-proprietary and widely available in various sizes from vendors of concrete pipe and precast catch basins and manholes. They typically have low to moderate cost and have modular components for flexibility in design and construction.

Metro Vancouver provides guidance on infiltration trenches and soakaway manholes. http://www.metrovancouver.org/about/publications/

Figure 2: Perforated manholes are a common underground runoff conveyance practice



Source: GVRD 2012 Stormwater Source Control Design Guideline

Perforated manholes should only be constructed in the unsaturated zone above the groundwater table, where they are designed to receive, store, and slowly percolate runoff into the native soils. They are sized to drain over a period of hours to days, typically between 24–72 hours. To limit clogging, properly designed systems will include coarse drain rock placed around the outside of the manhole and a sedimentation sump to remove sediment and trash from the runoff prior to conveyance into the perforated manhole.

In the City of Kelowna, groundwater recharge systems must be utilized to the maximum extent possible as determined by a qualified professional experienced in this field, in order to promote interception of pollutants and reduction in downstream impacts. City of Kelowna Design Standards http://www.kelowna.ca

Perforated manholes.
Image source: Kon Kast Products
http://konkast.com/drywells.html

Underground percolation systems

Shallow percolation systems such as infiltration trenches and pits are an accepted source control method in Metro Vancouver and are included in the Okanagan Basin Water Board's Homeowners Drainage Guidance: Slow it. Spread it. Sink it! An Okanagan Homeowner's Guide to Using Rain as a Resource (2011).

Percolation systems are shallow underground infiltration facilities that include a network of drainage pipe and/or chambers to distribute runoff throughout an infiltration gallery (**Figure 3**). These systems are commonly less than a few metres in depth and can be constructed in a wide variety of configurations and materials.

Infiltration trenches and infiltration pits are common non-proprietary percolation systems. They are shallow excavated trenches, or pits of any shape, which are filled with clean coarse gravel or drain rock. A perforated drainage pipe network disperses stormwater into the drain rock. The pore spaces provide storage, allowing the stormwater to gradually infiltrate into the surrounding native soils. To reduce the potential for clogging, designs should include sedimentation facilities to capture sediment and trash prior to conveyance into in the percolation system.

Figure 3: Infiltration trenches are non-proprietary underground percolation systems

Source: Coastal Site Design http://www.coastalsitedesign.com/images/Verizon_infiltrationtrench008.jpg

Proprietary underground percolation systems are commercially available as an alternative to infiltration trenches and pits. Manufacturers have developed a wide variety of design approaches using different material types (**Figure 4**). Many have advantages of low cost, modular design and simple construction. Many can also be integrated with pre-treatment facilities and include maintenance access to support long-term design level operation.

Figure 4: Example of proprietary underground percolation systems

Image source: Contech Engineered Solutions http://www.conteches.com

Boreholes and drilled wells

Any borehole or drilled well with a perforated casing could potentially be used for underground infiltration of stormwater. However, there are significant limitations and risks associated with the use of boreholes and drilled wells for stormwater infiltration. Such practices are uncommon and discouraged.

Infiltration well systems can have high costs. Drilling costs can be expensive depending on the well depth and geologic conditions, and additional drilling costs may be required to evaluate the hydrogeology of the site and/or to install groundwater observation wells. Higher project costs may also be incurred for high-levels of pre-treatment, as well as more comprehensive planning and design to assess and mitigate potential impacts.

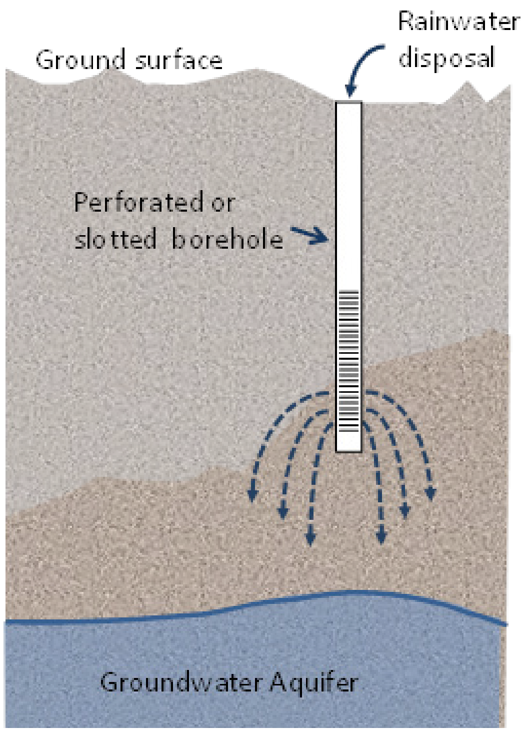
Infiltration well systems are susceptible to clogging, causing reduced infiltration capacity or well failure. Particulates present in stormwater can clog the well screen and adjacent geologic formations over time. Infiltration well systems should include a high-level of pre-treatment to remove sediments from runoff prior to conveyance into the well and the pre-treatment facilities should be diligently maintained. Clogging of the well screen or geologic formation may also occur from the buildup of microbes, chemical precipitates and gases. Once clogged, it can be difficult to rehabilitate the well, or replacement infiltration wells could be required.

A significant concern of boreholes and drilled wells for use as stormwater infiltration well systems is the increased risk they pose to groundwater quality. Boreholes can intercept many types of geologic materials and groundwater zones, providing a direct connection between the surface and groundwater aquifers. For these reasons, use of boreholes and drilled wells for infiltration of runoff requires careful planning, evaluation and design, which should be closely coordinated with local officials.

The use of boreholes and drilled wells for stormwater infiltration into drinking water supply aquifers is discouraged, particularly for conveyance into confined drinking water supply aquifers.

In most cases, use of boreholes and drilled wells for stormwater conveyance will not be practical or feasible for the reasons above. These systems may only be viable for large-scale developments where common types of surface and underground infiltration systems are not feasible, where there are favorable geologic conditions, and where there may be secondary objectives for groundwater recharge.

Figure 5: Use of boreholes and drilled wells for runoff conveyance is uncommon due to cost and risks to groundwater quality



Source: Provincial Observation Well Program

Photo: B.C. Ministry of Environment

Regulatory Context for Stormwater Infiltration Systems

Stormwater management regulations

The regulatory responsibility of stormwater management in B.C. occurs at the municipal level under authority of the *Local Government Act*. Municipalities and regional governments typically define local stormwater management goals in a Liquid Waste Management Plan (LWMP) and/or in an Integrated Stormwater Management Plan (ISMP). MoE developed guidance for the preparation of LWMPs in 2011.

To assist municipalities and to unify stormwater management practices, the Province in collaboration with Environment Canada released the document *Stormwater Planning: A Guidebook for British Columbia* in 2002. This document launched the water balance methodology for integrated stormwater management, which has been adopted by local governments throughout B.C. The Partnership for Water Sustainability has prepared a "Beyond the Guidebook" initiative and a series of technical guidance documents that further assist local governments with stormwater management.

In unincorporated areas, the Ministry of Transportation and Infrastructure regulates and approves drainage and stormwater management requirements for development projects. The Ministry's requirements for drainage design and stormwater management are detailed in the 2007 Supplement to TAC Geometric Design Guide. These guidelines provide the Ministry of Transportation and Infrastructure with the capability to align its efforts with municipalities and to support a consistent watershed-based approach to stormwater management.

Regulations and legislation applicable to underground stormwater infiltration

Regulatory oversight for the design and operation of underground stormwater infiltration systems occurs at the municipal level or by the Ministry of Transportation and Infrastructure. Owners and operators of underground infiltration facilities are responsible for identifying and meeting all applicable local regulations and requirements.

Provincial regulations governing the siting and design of underground stormwater infiltration system are limited. The B.C. Ground Water Protection Regulation (GWPR) addresses the construction, maintenance, and decommissioning of boreholes, drilled wells and dry wells for stormwater conveyance. The GWPR defines a recharge well as "a class of well used to convey water into a geologic formation without the aid of a pump." Stormwater infiltration wells are recharge wells that are subject to requirements under the GWPR. These requirements include obligations for decommissioning recharge wells that are determined to pose a threat to groundwater aquifers, as well as obligations and procedures for decommissioning abandoned recharge wells.

The *Water Sustainability Act* (WSA) was passed in 2014 and will come into force after supporting regulations are developed and finalized. Once implemented, the WSA will replace the current *Water Act* and will include the licensing of groundwater use and additional requirements in the GWPR. These legislative initiatives will further strengthen the protection of groundwater.

In addition to the regulatory requirements in the GWPR, other provincial legislation may indirectly affect the siting and design of stormwater infiltration systems. This includes:

- Conformance with established liquid waste management plans;
- Ensuring infiltration facilities do not cause or contribute to pollution in accordance with the *Environmental Management Act*;
- Ensuring infiltration facilities do not cause a health hazard in accordance with the *Public Health Act*; and
- Ensuring infiltration facilities do not cause contamination to a drinking water source in accordance with the *Drinking Water Protection Act*.

Petroleum hydrocarbons associated with vehicles are a pollutant of concern. Photo: Judith Cullington

Risks to Groundwater Resources

Groundwater aquifers, especially shallow aquifers, are susceptible to contamination from incidental human activities or by accidental or intentional spills. A contaminated aquifer can pose health hazards if pollutants are undetected. Often, use of groundwater from a contaminated aquifer is curtailed or may require special treatment. Once contaminated, it can be difficult and costly to clean up the aquifer.

Stormwater pollutants

Common pollutants of concern in stormwater runoff are:

- Suspended sediments from numerous sources including un-stabilized soils, human activities and atmospheric deposition;
- Trace metals, primarily copper, lead, zinc, and cadmium. The sources include exposed metals (e.g., galvanized metals for roofing, pipe and guard rails) or metals associated with compounds exposed to the environment, such as paints and wood preservatives;
- Nutrients, primarily nitrogen and phosphorus, from landscaping activities, automobile exhaust and atmospheric fallout;
- A wide variety of petroleum hydrocarbons associated with vehicles and other human activities;
- Pesticides, herbicides and fungicides used in residential, commercial and municipal landscaping activities;
- Salts used for roadway de-icing; and
- Pathogens and pathogen indicators associated with human waste, animal waste and natural watershed sources.

Suspended sediments are a principal pollutant of concern for all sites because many other pollutants tend to adhere to particulates, and because they can clog infiltration facilities, diminishing their performance.

Pollutants with greater risk factors

While all pollutants have the potential to contaminate groundwater, pollutants that are more soluble pose a greater risk because they are more mobile and easily transported through the soil pores.

Many pollutants commonly found in stormwater (such as metals and oils) have low solubility in water. Such pollutants will tend to adsorb[4] to sediments or will degrade and breakdown over time. Consequently, they tend to be filtered and attenuate to varying levels as stormwater percolates through the soil pores. For example, many metals commonly found in stormwater may only be transported a few centimetres beneath surface infiltration facilities. Pollutants with low solubility generally pose a lower risk to aquifers.

De-icing salts are highly soluable. Image source: http://www.houffs.com/DesktopDefault.aspx?tabid=45

Other pollutants are highly soluble, such as nitrate in fertilizers and manures and salts used for roadway de-icing. Highly soluble pollutants are not filtered or strongly impeded by soils. They are mobile and readily transported to the aquifer as stormwater percolates through the soil. These pollutants pose a higher risk to groundwater quality.

While solubility is one important risk factor, other site-specific factors can also dictate risks to groundwater quality, such as:

- The chemical and sorption properties of site-specific pollutants, stormwater and soils;
- The size of the pore spaces in the site-specific geologic materials and their ability to transmit water. For example, large fractures or gravelly soils may allow rapid pollutant transport to the aquifer; and
- The site-specific pollutant levels and infiltration system design.

The transport potential of pathogens is complex because the longevity of pathogens within the soil and the likelihood of bacteria, protozoa or viruses reaching a drinking water aquifer is affected by a number of factors. It is highly dependent on the capacity of the soil media to adsorb the pathogens (factors such as soil pH, water content and temperature), as well as the length and time of travel of the flow path from the source of contamination to the aquifer. While bacteria such as *E. coli* may be short-lived in the soil, protozoa and viruses can travel significant distances and remain infectious for a longer period of time. Consequently, the risks posed by pathogens in the subsurface can be difficult to assess.

4 Adsorption: The adhesion of a chemical species onto the surface of particles." From http://chemistry.about.com/od/chemistryglossary/g/adsorption.htm.

Image source: U.S, EPA http://www.epa.gov/region9/water/npdes/stormwater-feature.html

Risks to groundwater quality from surface infiltration facilities

With increasing use of surface infiltration facilities, the fate of pollutants in these systems has received considerable attention in the stormwater literature. **Table 2** provides a general assessment of the risks to groundwater quality from surface infiltration practices based on literature information.[5] Site-specific conditions can increase or decrease risks.

Literature information indicates that for most pollutants, surface infiltration facilities do not pose a high risk to groundwater resources when the facilities are properly sited and designed. This is because many stormwater pollutants are present at low levels, and because many common pollutants are subject to adsorption, degradation and filtration in the infiltration systems.

A few pollutants, notably nitrate, dissolved solids (salts) and some organic compounds, are poorly removed in infiltration facilities and pose a greater risk to groundwater. While use of organic compounds is pervasive in urban areas, monitoring studies indicate they are often not detected or are present at low levels in stormwater runoff. Similarly, the levels of nitrate and salts are typically low in stormwater runoff, and when excessive levels are detected, they are often associated with land use practices that include heavy use of these compounds. A watershed source analysis to assess the potential for soluble pollutants in stormwater should be routinely conducted during feasibility and design studies for all infiltration facilities.

5 Pitt et al., 1994; Clark and Pitt, 2007; Weiss et al., 2008.

Table 2: Qualitative assessment of risks to groundwater quality from stormwater infiltration facilities

Stormwater pollutant	General characteristics from literature information	Methods to reduce risk	General risk to groundwater quality
Sediments	• Suspended sediment is common in stormwater. It is a primary pollutant of concern by itself, and also because many other pollutants are associated with sediments • Highest sediment loads are in watersheds with exposed and un-stabilized soils, such as construction sites • Infiltration facilities effectively remove sediments by filtration • Sediment loads are a concern because they can cause clogging, thus reducing the infiltration capacity and system performance	☑ Include pre-treatment facilities to remove sediments ☒ Do not use infiltration in watersheds with high sediment loads, such as construction sites	• Not a risk to groundwater quality as sediments are readily filtered by the soil matrix • The main concern is the potential to clog infiltration facilities
Trace metals	• Often present in stormwater at concentrations below the Canadian Drinking Water Guidelines. • A large fraction of metals are bound to sediments, which are subject to removal in pre-treatment facilities or by filtration • Dissolved fractions are subject to adsorption, particularly in fine-grained, organic-rich soils • The majority of metals are retained in the upper soil layers of surface infiltration systems, between 10–30 cm	☑ Use pre-treatment facilities to remove sediments ☑ Periodically replace top soil layers to remove accumulated metals	• Low for typical urban watersheds, particularly if sedimentation facilities are used for pre-treatment
Nutrients, (nitrogen and phosphorus)	• Generally present in stormwater at concentrations below the Canadian Drinking Water Guidelines. • Nitrate is the nitrogen form most often evaluated. Due to high solubility, nitrate is poorly removed in infiltration facilities • Phosphorus in stormwater tends to be associated with sediments, which are subject to removal in pre-treatment facilities or by filtration • Dissolved phosphorus tends to be lower in shallow groundwater than surface waters • Some studies found poor removal of phosphorus in infiltration systems, which may be due to internal sources in vegetated systems	☒ Do not use infiltration facilities in areas with a potential for elevated levels of nitrate	• Low to moderate for nitrate and phosphorus, in typical urban watersheds with low runoff concentrations • High for nitrate in watersheds with a potential for elevated runoff concentrations

Stormwater pollutant	General characteristics from literature information	Methods to reduce risk	General risk to groundwater quality
Petroleum hydrocarbons	• A wide variety of hydrocarbons are used in urban areas. Common hydrocarbons of concern for stormwater are oil & grease from cars, as well as polycyclic aromatic hydrocarbons (PAHs), which are produced as combustion by-products such as automobile exhaust • Typically found at very low levels and often not detected in runoff • Many common hydrocarbons have low solubility and will tend to adsorb to sediments. Many are also subject to volatilization and degradation, and do not persist in the environment for long periods	☑ Use pre-treatment facilities to remove sediments ☑ Restrict use of infiltration practices in high source watersheds, such as high capacity roads and industrial areas	• Moderate in high source watersheds or with no pre-treatment • Low for typical urban watersheds with low runoff concentrations, and when pre-treatment is included
Pesticides	• A wide variety of pesticides (including herbicides and fungicides) are used in urban settings. These have a wide range of chemical properties • Pesticides are not routinely monitored in stormwater, and are infrequently detected or detected at low levels. They are most frequently found in runoff from residential areas, especially dry weather flows in landscaping irrigation runoff • Many pesticides have low solubility and strongly partition to sediments, which are subject to removal in pre-treatment facilities or by filtration • Many pesticides are also subject to microbial degradation with most half-lives ranging from days to months in surface soils • Fungicides and herbicides may pose a greater risk to groundwater than insecticides because they are generally more soluble and may have greater use in residential settings • The greatest potential for pesticide mobility is in coarse-grained soils with low clay and organic content, and for more soluble pesticides	☑ Use pre-treatment facilities to remove sediments ☑ Restrict use of infiltration practices in high source watersheds, such as areas that receive dry weather runoff from residential or heavily landscaped areas ☑ Implement source control measures, such as proper storage and application of pesticides. Encourage use of integrated pest management practices	• Low for typical urban watersheds when infiltration facilities are properly sited and include pre-treatment
Salts	• Salts are very soluble and therefore very mobile in the subsurface • Salts are not effectively removed in infiltration facilities. Concentrations often increase as water percolates through soils	☒ Do not use infiltration in watersheds with high levels of salts, such as roadways and parking lots that are subject to snowmelt and de-icing activities	• Low in most urban watersheds. with low levels of salts typically observed in runoff • High in watersheds with de-icing activities

Stormwater pollutant	General characteristics from literature information	Methods to reduce risk	General risk to groundwater quality
Pathogens and pathogen indicators	• Levels of indicator bacteria in stormwater vary, but can exceed B.C. working guidelines for contact and non-contact recreational uses. However, there are many natural and non-pathogenic sources of indicator bacteria in urban watersheds • Pathogens are subject to removal in infiltration systems by straining (similar to sand filters) and by adsorption. Once adsorbed, pathogen survivability depends on many environmental factors including temperature, pH, and presence of other chemicals • Enteroviruses pose a higher risk to groundwater because they are more resistant to environmental factors than enteric bacteria, and due to their small size they may be more mobile in soil systems	☑ Locate infiltration facilities a safe distance from septic fields, septic lines, water supply wells, and areas with a potential for co-mingling of stormwater and wastewater ☒ Do not use infiltration facilities where there is a potential for rapid migration to drinking water supply aquifers	• Low to moderate depending on site conditions including appropriate siting analysis, adsorption potential, pathogen mobility, and pathogen survivability

Figure 6: Underground infiltration practices can be a direct route for pollutant migration between the ground surface and water supply aquifers

Photo: Ian Graeme

Image source: Graf http://www.graf-water.com/stormwater-management.html

Risks to groundwater quality from underground infiltration facilities

Underground infiltration systems behave and perform similarly to surface infiltration when properly sited, designed, and operated. However, underground infiltration systems can also increase the risk of groundwater contamination in comparison to surface infiltration systems by providing a more direct pathway between sources of pollutants at the ground surface and the underlying aquifer. Consequently, pollutants that are accidentally or intentionally spilled at the ground surface, or pollutants present in stormwater runoff, are more able to reach the groundwater aquifer (**Figure 6**). Furthermore, pollutants that reach the aquifer cannot be visually observed and are therefore less likely to be detected and removed than in surface systems.

Factors that can increase the risk of groundwater contamination in underground infiltration systems when compared to surface systems are:

- Accessibility to pollutant sources: locating facilities in watersheds or certain land use types with a high potential for pollutant sources;
- Facility design: designing underground infiltration systems that convey water directly into the saturated zone or close to the aquifer, or do not include appropriate pre-treatment facilities;
- Unfavorable subsurface conditions: locating facilities in certain types of geologic formations that permit rapid movement of water or provide little attenuation of filterable pollutants; and
- Maintenance and operation: inadequately maintaining and monitoring the facilities and the environmental conditions at the site.

By considering and addressing these risk factors, the vast majority of underground infiltration systems can be designed and operated with minimal risk to groundwater.

Best Practices for Underground Infiltration Systems

Guiding principles

Protect groundwater resources
There should be a presumption that all groundwater resources below underground infiltration facilities are actively or potentially drinking water supply aquifers. Protection of drinking water supply aquifers is the foremost issue of concern in the siting, design and operation of underground infiltration facilities. To protect drinking water aquifers, infiltration facilities should be located, designed, operated, and maintained in a manner that will not contribute to contamination of the aquifer at levels exceeding the Canadian Drinking Water Guidelines.

Standards of practice
Underground infiltration systems should be designed in accordance with accepted standards of practice and only by qualified professionals with appropriate background in hydrogeology or geotechnical engineering and who are licensed to practice engineering and geoscience (P. Eng., P. Geo., or Eng. L., Geo. L.). Facility designs should be reviewed by local permitting agencies[6] and should comply with all local bylaws and provincial legislation.

Low risk to groundwater resources
Underground stormwater infiltration systems are presumed to have a low risk to groundwater resources and drinking water supplies if, in the opinion of the approving agency, the siting, design and operation of the facilities adequately address:

- Potential pollutant types, sources, and loadings in stormwater;
- Methods to control sources of pollutants;
- Conformance with local siting and setback requirements;
- Hydrogeologic conditions at the site and the unsaturated zone treatment capacity;
- Use and selection of pre-treatment facilities;
- Conformance with local design standards; and
- Operation and maintenance.

6 Municipality, or Ministry of Transportation and Infrastructure if in unincorporated area.

Pollutant source analysis and source control

Characterize pollutants of concern

A catchment-specific source analysis is essential for properly assessing the risks and feasibility of underground infiltration systems. The source analysis includes:

- Using general water quality characteristics of stormwater to identify potential pollutants of concern based on existing and proposed land use, land use activities, and existing infrastructure. Alternatively, site-specific stormwater quality monitoring should be considered for catchments with high risk factors;
- Identifying specific and potential sources of the pollutants within the catchment to guide appropriate selection and use of source control measures;
- Identifying possible migration pathways and the potential receiving waters for the pollutants of concern, including surface waters, water supply aquifers and groundwater dependent ecosystems; and
- Characterizing key properties of pollutants of concern, including their solubility, mobility and persistence in groundwater, and their treatability in stormwater treatment facilities.

Identify pathways for pollutants of concern. Photo: Kim Stephens

Source controls

Source controls are preventative measures to limit pollutant accessibility to stormwater. They are one of the most efficient ways to reduce stormwater pollutants because it is generally easier to restrict the introduction of pollutants than to treat and remove the pollutants from stormwater.

Source controls should be selected to comply with local requirements and to address those pollutants of concern with a potential to impact groundwater resources (**Table 3**). Source control measures in watersheds that drain to underground infiltration systems are most effective when they target soluble and hazardous compounds, for example ensuring the proper storage and use of soluble fertilizers and pesticides.

Table 3: Potential source control measures for areas that drain to underground infiltration systems

Pollutant	Potential source controls
Sediment	• Limit disturbance of native soils • Actively implement effective erosion and sediment control measures at construction sites
Trace metals	• Limit use of exposed metals such as copper flashing and galvanized roofing materials • Use alternatives to treated lumber
Nutrients (nitrogen and phosphorus)	• Diligent nutrient management, including proper application and storage to limit runoff and leaching • Reduce turf areas and consider alternative landscaping with native plants
Petroleum hydrocarbons	• Develop and implement spill prevention plans • Properly store and dispose of all hazardous materials, lubricants and solvents
Pesticides	• Properly store and apply all pesticides according to manufacturer instructions • Use integrated pest management practices • Use alternative landscaping with native plants
Salts	• Properly store and limit use of salts for de-icing • Use alternative de-icing practices

Facility siting and setbacks

Land-use exclusions

Underground infiltration systems are not appropriate for certain land-use or activity areas with a high potential of contaminant sources. The local approving agency will establish applicable land-use exclusions, which may include but are not limited to:

- Recycling facilities such a salvage yards and metal recycling facilities;
- Fuelling stations;
- Outdoor industrial storage areas (e.g., treated lumber, hazardous materials);
- Industrial facilities where hazardous chemicals are routinely used or transported;
- Vehicle service and maintenance areas;
- Vehicle and equipment washing and steam cleaning facilities;
- High-capacity roadways;
- Runoff susceptible to high levels of coliform bacteria from human or natural sources;
- Commercial nurseries or other sources of heavy fertilizer use or manure storage;
- Catchments prone to significant de-icing activities with salts;
- Catchments with un-stabilized soils that potentially generate high sediment loads, such as construction sites or areas of significant landscaping activities; and
- Sites with contaminated soils or up-gradient from contaminated groundwater where infiltration systems may potentially mobilize contaminants or alter migration pathways.

Underground infiltration systems are not approrpriate for areas with high potential for contamination, such as lumber yards.
Photo: Judith Cullington

Water well setbacks

To reduce potential pathways between infiltration facilities and water wells, underground infiltration systems should meet a minimum horizontal setback distance from all domestic and municipal drinking water supply wells and irrigation wells.

A minimum setback distance of 60 m is recommended, consistent with the Municipal Wastewater Regulation. In general, a protective setback distance will depend on site-specific conditions including the direction and rate of groundwater flow and the vulnerability of the drinking water wells to contamination. Therefore, local municipalities may require greater setback distances based on established bylaws or to address site-specific hydrogeologic conditions.

Capture zone analysis is an alternative approach for establishing a setback distance. Where established, capture zones delineate source areas and travel times to drinking water supply wells. A setback distance based on well-head travel times (e.g., a one-year travel time) should be established through consultation with municipal officials. If capture zones are not established, the B.C. *Well Protection Toolkit* could be used to estimate capture zones.

The design report should document steps taken to identify the location of local water wells. The MoE WELLS database identifies those local wells that have been voluntarily reported to the provincial government. Additional steps may be needed to fully identify all local wells, such as a local well survey and public notices.

Septic system setbacks

Underground infiltration systems should be setback from existing septic systems to avoid adversely affecting performance of the septic system and transporting contaminant to groundwater. A minimum setback distance of 30 m is recommended, consistent with the Sewerage System Regulation and Health Hazard Regulation. However, greater setbacks may be required by local governments, depending on the specific conditions.

Identify local wells.
Photo: Laurie Lyons

Geologic hazard setbacks

Underground infiltration systems should not cause or contribute to slope failure. No system should be constructed above landslide hazard areas, or in any area with identified geologic hazards. Underground infiltration systems are not recommended on slopes steeper than 25 percent (4:1). However, a qualified professional with experience and knowledge of local geotechnical conditions should assess potential geologic hazards for any system contemplated in a sloped setting or near a steep slope, as well as to ensure that all systems comply with local requirements.

Foundation setbacks

Underground infiltration should not adversely affect foundations, footings and underground structures. The recommended minimum setback from foundations with no footing drains is 50 m for systems up-gradient of the foundation, and 25 m for systems down-gradient of the foundation. Footing drains should be used if facilities are located within these setbacks, or as required by local agencies.

Underground infiltration systems may impact surface waters. Photo: Norm Bilodeau

Environmental setbacks

Underground infiltration systems may potentially impact surface waters if they are located in areas where shallow groundwater is conveyed to sensitive surface waters, such as wetlands and groundwater dependent ecosystems. Designers should consider the potential pathways to environmentally sensitive areas, and comply with any applicable setback requirements.

Hydrogeologic assessment

Hydrogeologic characterization

A site-specific hydrogeologic characterization conducted by a qualified professional is necessary for comprehensive and reliable system designs. Key considerations include the following.

Site lithology

Site-specific borings or test pits are needed to determine the type of geologic materials below the point of infiltration. For large sites or long linear trenches, multiple borings are needed to characterize site lithology.

Underground infiltration systems are most suitable in geologic materials with moderate to good infiltration capacity and that provide a high degree of pollutant filtration and attenuation. Good candidates are fine- to medium-grained alluvial materials with some fine and organic content, such as silty sands, and fine to coarse sands interbedded with silts and clays.

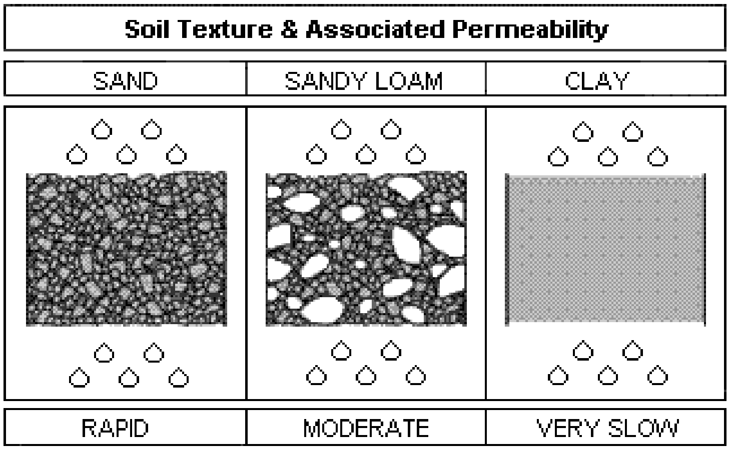


Image source: Ontario Ministry of Agriculture, Food and Rural Affairs http://www.omafra.gov.on.ca/english/engineer/facts/07-035.htm

Geologic materials that rapidly transmit water or provide little pollutant attenuation are poor candidates because pollutants are readily transported to the groundwater aquifer. These materials include fractured bedrock, karst formations, gravels, boulders, and cobbles.

Groundwater elevation

Knowledge of the depth and annual variability of the local groundwater table is needed to ensure infiltration occurs within the unsaturated zone and to meet minimum vertical separation requirements above the seasonally high groundwater level. This is particularly important when the depth to groundwater is shallow, the infiltration depth is close to the water table, and the regional groundwater gradient and soil conductivity are small. For such conditions, a site-specific mounding analysis may be required to ensure any water table rise does not diminish infiltration capacity. Groundwater elevation can be measured by site-specific monitoring, or estimated from nearby well records, if available.

Infiltration capacity

An estimate of the average infiltration capacity or hydraulic conductivity of the geologic materials is needed for facility sizing. Infiltration rates can be estimated from the material type, but are more reliably determined by a double-ring infiltrometer test and borehole infiltration tests. Because infiltration systems are susceptible to clogging, the design infiltration rate should be based on the smallest measured infiltration rates and should incorporate a factor of safety.

Inadequately characterized sites have a greater risk for poor system performance or groundwater contamination. Pay particular attention if available information is variable, is not in close proximity to the site, or suggests marginal site conditions in terms of lithology, groundwater level, or conductivity. Under such conditions, the feasibility of underground infiltration systems is questionable and additional site characterization is warranted prior to system design. If detailed site investigations are not economically feasible, a conservative design approach should be used.

Water table separation

Underground infiltration systems should only be designed to infiltrate stormwater within the unsaturated zone above the groundwater table. In other words, the lowest point of infiltration from the infiltration system should be above the groundwater aquifer. Infiltration into the unsaturated zone provides a level of treatment for pollutants prior to reaching the saturated groundwater zone (aquifer). To ensure a reasonable level of treatment within the unsaturated zone, the lowest point of infiltration from the infiltration system should exceed a minimum separation height above the annual high groundwater elevation.

Table 4 shows the recommended vertical separation between the base of the infiltration facility and the annual high groundwater level. These recommendations are adopted from the Washington State Department of Ecology. They relate the separation distance to the type of geologic materials in the unsaturated zone below the infiltration facility.

Fine grained, poorly sorted materials with high organic content provide a high level of unsaturated zone treatment, allowing lesser separation distances above the water table. Conversely, coarse-grained and well-sorted materials provide a low level of unsaturated treatment, requiring greater separation distances. Fractured bedrock and karst formations that allow rapid migration are not suitable for underground infiltration systems.

Underground infiltration systems should not be designed to convey stormwater directly to groundwater, particularly confined drinking water aquifers. Such designs set up a situation where stormwater and associated pollutants or any accidental spill could flow directly from the ground surface to the water supply aquifer.

Any facility specifically designed to convey stormwater to the saturated zone of a drinking water aquifer requires a high level of design and regulatory approval and ongoing oversight. Such facilities should be carefully designed and operated in close collaboration with local governments and the Province's Regional Environmental Protection and Health Authority staff.

Table 4: Recommended vertical separation distance between the base of the infiltration facility and the annual high groundwater level

Unsaturated zone treatment potential	Minimum vertical separation distance	Description of unsaturated zone soils between the infiltration facility and the groundwater table
High	1.5 m (~5 ft)	• Materials with median grain size < 0.125 mm • A sand to silt/clay ratio of less than 1:1 and sand plus gravel < 50% • Clayey or sandy silt • Sandy loam or loamy sand • Silt/clay with inter-bedded sand • Well-compacted, poorly-sorted materials • Generally includes till, hardpan, caliche, and loess
Medium	3.0 m (~10 ft)	• Materials with median grain size 0.125 to 4 mm • Sand to silt/clay ratio from 1:1 to 9:1 and percent sand > percent gravel • Fine, medium or coarse sand • Sand with interbedded clay and/or silt • Poorly-compacted, poorly-sorted materials • Includes some alluvium and outwash deposits
Low	7.5 m (~25 ft)	• Materials with median grain size > 4 mm to 64 mm • A sand to silt/clay ratio greater than 9:1 and percent sand less than percent gravel • Poorly-sorted, silty or muddy gravel • Sandy gravel, gravelly sand, or sand and gravel • Includes some alluvium and outwash deposits
None	Not suitable for underground infiltration	• Materials with median grain size >64 mm • Total fines (sand and mud) less than 5% • Well-sorted or clean gravel • Boulders and/or cobbles • Fractured rock • Includes fractured basalt, other fractured bedrock and cavernous limestone

Adopted from: Washington State Dept. of Ecology, Guidance for UIC Wells that Manage Stormwater, 2006

Mounding analysis

Groundwater mounding calculations may be required to ensure groundwater mounding will not limit infiltration capacity, that infiltration facilities are correctly sized and will perform at a design level, or to ensure that infiltration does not interfere with or damage other underground structures such as foundations or septic systems. Mounding calculations are warranted in areas where the groundwater table is shallow or flat, soils have low to intermediate conductivity, the distribution area for infiltration is broad, or there are nearby underground structures.

Pre-treatment

Pre-treatment refers to the use of treatment facilities to reduce pollutant levels in stormwater prior to conveyance into the infiltration facilities. Pre-treatment facilities help to keep infiltration facilities functioning properly and are key measures for protecting groundwater resources.

Options for pre-treatment facilities can range from no treatment to high levels of treatment targeting soluble and high-risk pollutants. **Table 5** shows three categories of treatment objectives and associated types of treatment facilities that can be used to achieve those objectives.

Table 5: Pre-treatment options for underground infiltration systems

Treatment category	Target Pollutants	Representative treatment facilities
Pre-settling	• Trash and debris • Coarse sediments	• Sumped catch basins, sedimentation manholes • Oil/water separators
Solids removal	• Treatment exceeding pre-settling • Coarse and fine sediments • A portion of the metals, indicator bacteria and particulate nutrients that are associated with sediments	• Catch basin devices such as tree-well filter, catch basin media filtration systems • Hydrodynamic devices • Media filtration systems
Oil removal	• Treatment exceeding solids removal • Oils and grease • A portion of the more soluble hydrocarbons and pesticides	• Stormwater filtration systems using engineered media • Biofilters: swales, rain gardens

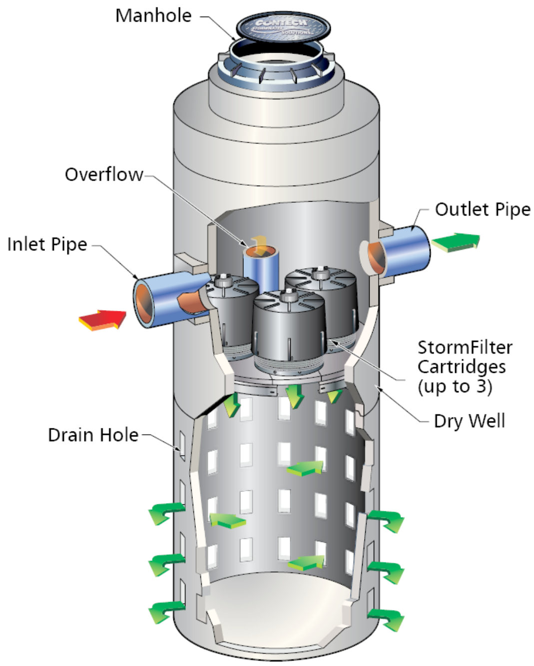
Adapted from: Washington State Dept. of Ecology, Guidance for UIC Wells that Manage Stormwater, 2006

The most common pre-treatment approach is a pre-settling facility that targets removal of coarse sediment and debris. Coarse sediments and debris including organic debris and trash are common in stormwater. The accumulation of sediment and debris is a concern because they can clog infiltration facilities, which degrades the infiltration capacity and overall system performance. Accumulated sediments and debris can also be an internal source of pollutants.

Sedimentation manholes are the most frequently used pre-settling facilities for coarse sediments and debris. Because of the potential for clogging, sedimentation manholes are recommended as a minimum level of pre-treatment for all underground infiltration systems.

A higher level of pre-treatment is warranted in watersheds with a higher potential for pollutant sources. For example, runoff from major roadways and heavily used parking lots often contains higher levels of sediment, particulate metals, and oil and grease in comparison to runoff from residential areas. In such watersheds pre-treatment systems that provide better removals of sediment and pollutants associated with

Example pre-treatment using stormwater filtration configured inside a drywell system.
Image source: Contech Engineered Solutions
http://www.conteches.com/products/stormwater-management/treatment/stormwater-management-stormfilter.aspx#1993310-technical-info



sediments (metals, hydrocarbons, indicator bacteria) are recommended. These could include hydrodynamic systems and various non-proprietary and proprietary media filtration systems.

Other types of pre-treatment facilities, such as vegetated swales, rain gardens and advanced media filters, can provide effective treatment for sediments, as well as some dissolved pollutants. These pre-treatment facilities are recommended in watersheds with a higher potential for soluble pollutant such as some pesticides and hydrocarbons.

The selection of appropriate pre-treatment systems will be based on site-specific conditions, including consideration of the source analysis, the geologic characteristics of the site, the unsaturated zone treatment potential and the local jurisdictional requirements. General guidance for selection of pre-treatment facilities is shown in **Table 6**.

Facility design

Engineers and designers should consider the following design elements as additional measures for protection of groundwater resources in underground infiltration systems.

Spill protection

In watersheds with potential sources of hazardous materials, such as fuels, it is prudent to include spill protection equipment that would prevent or limit the introduction of materials into the underground infiltration system in the event of a spill. This could include spill containment structures, such as hazardous material traps or oil-water separators and shut-off valves.

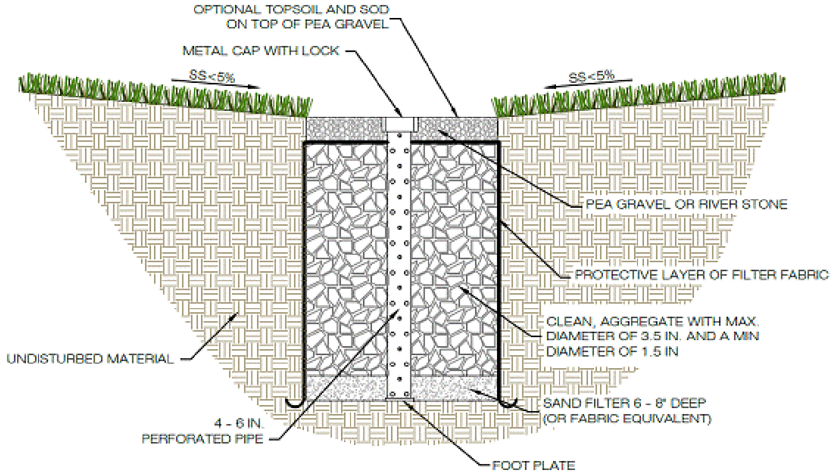
Table 6: General guidance for pre-treatment selection

Pollutant loading potential: (representative land use)	Unsaturated Zone Treatment Potential		
	High	Medium	Low
Low: • Impervious surfaces not subject to road runoff or intensive landscape maintenance • Low density residential areas with limited access roads, residential parking lots • Low traffic commercial area • Low-density collector roads	Pre-settling	Pre-settling	Pre-settling
Medium: • Medium and high density residential areas • Moderate use commercial areas and small to medium use parking lots • Medium use collector and arterial roads, e.g., 7500<ADT< 30000	Pre-settling	Pre-settling	Solids Removal
High: • High density urban areas • High use commercial centers and large parking lots • High use and high capacity arterial roadways	Solids Removal	Solids & Oil Removal	Solids & Oil Removal

Adapted from: Washington State Dept. of Ecology, Guidance for UIC Wells that Manage Stormwater, 2006

Observation wells

Observation wells are recommended to observe groundwater levels and fluctuations below infiltration systems, and to have an ability to assess and track groundwater quality. Observation wells are most valuable in systems that are shallow and close to the groundwater table, in systems with marginal hydrogeologic conditions, and in high risk watersheds that have greater sources of pollutants or are close to water supply wells.



Observation well.
Image source: Virginia DEQ Stormwter Design Specification http://www.vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec8INFILTRATION.html

Inspection and maintenance access

Design of infiltration and pre-treatment facilities should consider safe access to internal and underground spaces necessary for inspections, maintenance, sediment removal, and repairs. For example, manholes should be no more than 5 m from access roads, as the boom of typical vacuum trucks can only reach 5 m. Access manholes should have a minimum diameter of 75 cm to facilitate cleaning.

Bypass and overflow equipment

Underground infiltration systems can be designed as terminal sumps. However, it is prudent to include a bypass mechanism to convey flows that exceed the design capacity or to prevent flooding in the event of clogging.

Maintenance and monitoring

Ongoing maintenance of all structures is essential to ensure facilities perform at a design level, to maintain the infiltration capacity and to reduce sources of pollutants and build-up of contaminants. An effective operation and maintenance program includes the following recommended elements.

- **Maintenance Plan**: Ideally the site will have a documented maintenance plan which includes:
  - an inventory of all structural facilities the required maintenance activities, including a description of maintenance indicators and triggers;
  - a maintenance schedule; and
  - the recording and reporting responsibilities.
- **Responsible Parties**: It can be easy to overlook maintenance requirements of underground facilities. To mitigate this, the maintenance plan should identify responsible parties for all maintenance activities and reporting.
- **Documentation**: All maintenance, monitoring and reporting activities should be recorded in a maintenance log, including periodic digital photographic records of the site and maintenance activities.
- **Review**: The maintenance and monitoring records should be periodically reviewed to assess the maintenance effectiveness in terms of system performance and groundwater protection, and to consider potential changes to the maintenance plan.

Maintenance activities will generally include routine inspections and maintenance, periodic major maintenance activities and repairs, and emergency maintenance if needed. **Table 7** describes potential maintenance activities for underground infiltration systems. Note that this table is not comprehensive. Individual maintenance plans should be tailored to address the local requirements and the site-specific facilities, conditions and sources of groundwater contaminants.

Table 7: Potential maintenance activities for underground infiltration systems

Maintenance Objective	Maintenance Activities
Site Inspection: Regular and frequent inspections to ensure facilities are working properly, to determine the need for maintenance or repairs, and to assess threats to groundwater quality	☑ Check for accumulated sediment, debris, floatables, oil accumulation, or gummy deposits in sumps, vaults, sediment traps, or any other surface pre-treatment facilities by visual inspection or by video inspection. ☑ Check for visible signs of clogging at inlets, racks, outlets, and pipes. Look for bypassing, erosion, channeling, standing water or any other signs of poor drainage through media or overall poor system performance. ☑ Inspect for structural problems, corrosion, undercutting, cracks, and vandalism. ☑ Inspect for vector issues (mosquitoes, burrowing rodents).
Minor sediment cleaning: Periodic removal of minor levels of sediment and debris as needed to address visible accumulation, potential clogging at key locations, or aesthetic concerns	☑ Remove minor accumulations of sediment, trash and debris from inlets and other locations as needed to ensure operation. ☑ Conduct routine sweeping and trash pickup to reduce potential clogging and to address aesthetics.
Major sediment cleaning: Routine removal of sediment from pre-treatment facilities and underground infiltration facilities with maintenance access	☑ Vactor and remove sediment, trash & debris and water from sumps and chambers of pre-treatment facilities, as well as from accumulation points in surface facilities. Use high pressure jets to flush sediments to sumps and access locations in underground facilities as needed. ☑ Properly transport and dispose of all sediments, trash, debris, and water.
Structural repairs: As needed to address structural problems or to correct and improve designs	☑ Fix or replace pipes, manholes, pumps, and other structural stormwater control facilities as needed. ☑ Replace clogged media as needed.
Vector control: As needed to address site-specific issues	☑ Conduct routine mosquito abatement practices. ☑ Pest control for burrowing rodents.
Emergency response: Unscheduled and unanticipated maintenance in emergencies	☑ Unknown activities depending on the nature of the emergency, for example emergency actions to address spills of hazardous materials.

Monitoring encompasses all activities that are conducted to gain information and insights about the operation and conditions of the infiltration facility, the contributing watershed area, and the groundwater resources. Monitoring may address a variety of objectives and may include one or more of the following activities.

- **Stormwater quality monitoring**: Due to cost and generally low risk, stormwater quality monitoring is not commonly conducted. However, stormwater quality monitoring is prudent and recommended in high risk watersheds in order to:

⅄ Evaluate the site-specific stormwater quality;

⅄ Support appropriate selection and design of infiltration and pre-treatment facilities; and

⅄ Assess potential threats to groundwater quality.

- **Start-up monitoring**: Runoff to newly constructed facilities can be prone to high sediment loads, particularly if there are un-stabilized soils or ongoing construction in the drainage area. Frequent visual monitoring is recommended during early operation periods of new facilities, in order to verify they are functioning at a design level and to make sure there are no excessive sediment loads or erosion issues in the drainage area. Visual monitoring should look for indicators of runoff quality such as excessive turbidity or debris, and indicators of system performance such as drainage rates, clogging and flooding. If problems are detected, more quantitative monitoring of runoff quality, system performance or groundwater response should be pursued.

- **Groundwater monitoring**: For sites with observation wells, groundwater monitoring is recommended during start-up and early operation periods, following unusual events or as part of routine monitoring in high risk watersheds. Groundwater monitoring goals include:

⅄ Verifying the groundwater elevation;

⅄ Measuring the change in groundwater levels due to infiltration;

⅄ Verifying the separation distance between the infiltration system and the groundwater table meets the design requirements;

⅄ Verifying the groundwater table rise does not reduce the infiltration capacity; and

⅄ Assessing the changes to groundwater quality due to infiltration.

Summary

This document has been prepared as guidance to promote awareness of groundwater resources in stormwater management and to support the protection of drinking water aquifers. To this end, the recommended practices summarized in **Table 8** are intended to prompt consideration of pollutants that are conveyed into the subsurface through underground infiltration systems, and to provide design and maintenance approaches that will reduce the risks of groundwater contamination from these systems.

Table 8: Summary of recommended practices for underground stormwater infiltration

Component	Recommended Practices
Design Approach: Properly site and design underground infiltration facilities to minimize risks to water supply aquifers	☑ Use qualified professionals for facility siting and design. ☑ Design facilities to prevent contamination of drinking water supply aquifers. ☑ Coordinate with local authorities and comply with local design and permitting requirements.
Source Analysis: Characterize the type of pollutants potentially generated by the project, the risks they pose to groundwater and measures to reduce their input into stormwater	☑ Identify site-specific pollutants of concern. ☑ Identify surface and groundwater resources that potentially receive pollutants of concern. ☑ Evaluate the migration potential for pollutants of concern in soils and groundwater, and characterize risks to groundwater quality. ☑ Select appropriate source control measures.
Facility Siting: Evaluate the feasibility of underground infiltration facilities based on proximity to existing infrastructure and environmental conditions	☒ Do not use underground infiltration in watersheds with a potential to generate high levels of pollutants and pollutants that pose a high risk to groundwater quality. ☑ Locate facilities at least 60 m from water supply wells and at least 30 m from septic systems, or as required by local agencies. ☒ Do not use underground infiltration where there is a potential to cause or contribute to slope failure. Have qualified professionals evaluate all potential geotechnical hazards. ☑ Locate facilities at least 50 m up-gradient and 25 m down-gradient from foundations with no footing drains. ☑ Consider human and ecosystem uses of groundwater resources in facility siting and design.
Hydrogeological Assessment: Evaluate the feasibility of underground infiltration facilities based on hydrogeological conditions at the site	☑ Determine the type of geologic materials below the full span of the infiltration facilities. ☒ Do not use underground infiltration in geologic materials with a potential for rapid migration to groundwater, such as fractured bedrock, karst formations, and well-sorted gravels and cobbles. ☑ Determine the annual high water table elevation. Ensure infiltration facilities are a minimum distance above the annual high water table to provide for pollutant attenuation within the unsaturated zone (see **Table 4**, page 28). ☑ Estimate a design infiltration capacity based on geologic conditions of the entire site, incorporating a factor of safety. Conduct a groundwater mounding evaluation as needed to ensure mounding will not restrict infiltration or cause the direct release of stormwater into the aquifer.

Component	Recommended Practices
Pre-Treatment Evaluation: Determine the necessary type of pre-treatment facilities based on the pollutant loading potential	☑ At a minimum, always include sedimentation facilities such as sedimentation manholes to remove coarse sediment and debris from stormwater prior to conveyance into the infiltration facilities. ☑ Use higher levels of pre-treatment in watersheds with large pollutant loads or pollutants that pose a greater risk to groundwater (see **Tables 5 and 6**, pages 29 and 30).
Facility Design: Consider design elements for protection of groundwater quality	☑ Always consider adequate and safe access for maintenance inspection and sediment removal from pre-treatment and infiltration facilities. ☑ Consider additional design elements for added protection of groundwater resources, such a spill protection, bypass and overflow capacity and groundwater observation wells.
Maintenance and Monitoring: Provide for ongoing facility maintenance and site monitoring	☑ Determine and document maintenance requirements, responsible parties, and record keeping of maintenance activities (see **Table 7**, page 33). ☑ Develop a plan for ongoing monitoring of the watershed and facility conditions. Consider groundwater monitoring in high risk areas.

References and Resources

British Columbia laws, regulations and guidance

B.C. laws and regulations can be found at http://www.bclaws.ca/

Drinking Water Protection Act 2001. http://bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/00_01009_01

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