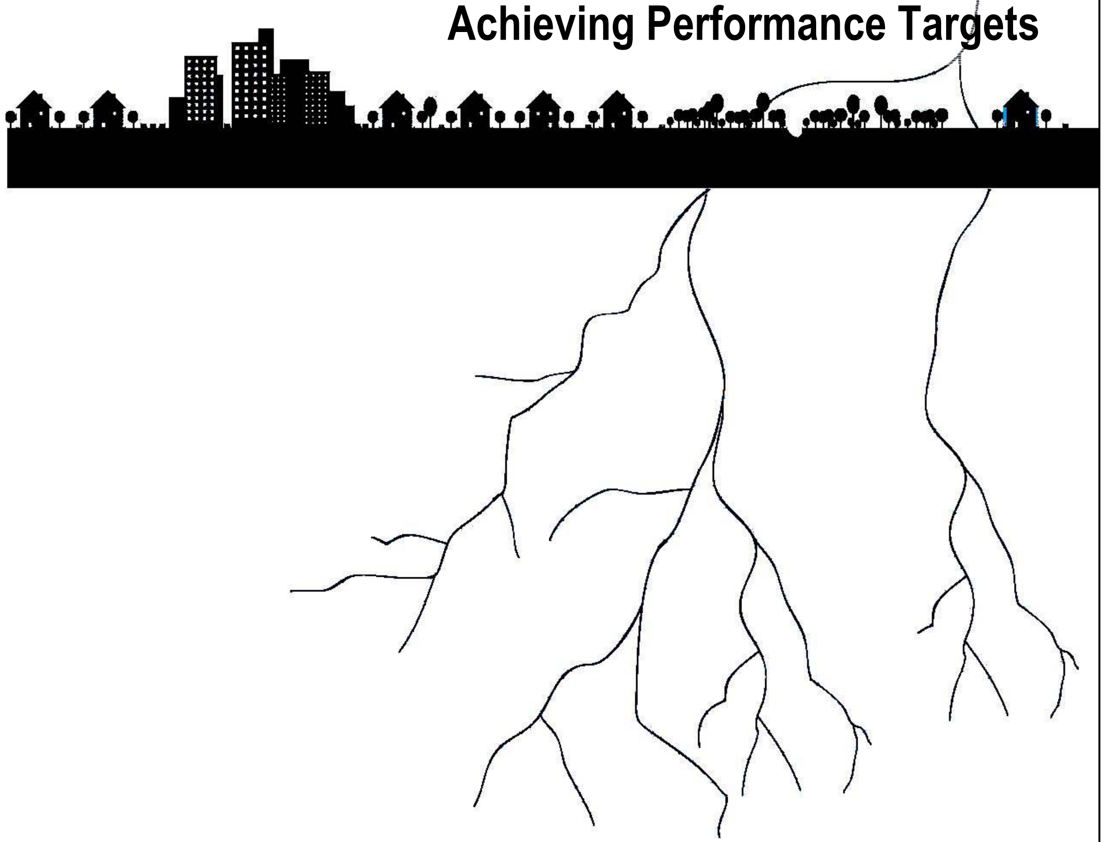
Site Design Solutions for Achieving Performance Targets



Chapter Seven

7.1 Overview of Site Design Strategies for Achieving Performance Targets

Chapter 6 showed how to establish performance targets. This chapter presents site design strategies for achieving performance targets, including:

- **Low Impact Development Practices** that:
  - minimize the creation of impervious cover (i.e. reduce total impervious area (TIA)) and other land cover changes that are detrimental to downstream watercourses, such as clearing of natural vegetation and compaction of soils.
  - preserve natural features that are key to maintaining healthy aquatic ecosystems, such as riparian forests and wetlands.
- **Stormwater Source Control Practices** that capture rainfall at the source (on building lots, road right-of-ways, or in neighbourhood facilities) and return it to natural hydrologic pathways - infiltration and evapotranspiration - or re-use it at the source. Source controls create hydraulic disconnects that reduce effective impervious area (EIA).

Catchment-specific performance targets for rainfall capture and runoff control may be achieved at the site level through some combination of these strategies.

Section 7.2 discusses low impact site design practices, and Sections 7.3 through 7.8 provide guidance for selecting appropriate stormwater source control options.

Section 7.9 shows how to communicate performance targets and related design guidelines to developers so that they can be applied at the site level.

7.2 Low Impact Development Practices

Reducing Total Impervious Area

Runoff from impervious surfaces is the primary cause of drainage-related problems such as stream degradation and flooding risk. Limiting impervious coverage can reduce runoff volume and partially mitigate these problems.

At the Land Use Planning Level

Impervious coverage can be controlled at the land use planning level by controlling where certain land use types are permitted. Limiting the amount of development, or controlling the type of development, in catchments where local and downstream ecosystem values could be negatively impacted, can be a science-based strategy to support stormwater management goals.

However, stormwater is just one of many factors that need to be considered when making land use decisions.

At the Site Design Level

There are a number of site design practices that can reduce impervious coverage for a wide range of land uses, including:

- **Reducing Road Widths** – Paved roadways are often larger than they need to be. Reducing road width not only reduces impervious area, but also reduces motor vehicle speeds, improves pedestrians and bicycle safety, reduces infrastructure costs and allows more of the paved surface to be shaded by overarching tree canopy.
- **Reducing Building Footprints** – Building footprints can be reduced (thus reducing rooftop area) without compromising floor area by relaxing building height limitations. Taller, more slender building forms provide greater flexibility to develop building layouts that preserve naturally vegetated areas and provide space for infiltration facilities. This also has important implications for integrating source control into site design, as discussed in Section 7.5.
- **Reducing Parking Standards -** Reducing parking standards reduces the amount of space devoted to parking (driveways, parking lots and parkades). In compact and/or high density communities where dwelling units are within walking distance to transit and services, parking standards may be reduced to 1.3 or even as low as 1 space per dwelling unit. There are other factors that could reduce the need for parking, including a high proportion of low income housing units, the implementation of transportation demand management strategies, and high parking costs. Reducing parking standards not only reduces impervious area, but also reduces parking-related development cost, and facilitates the provision of affordable housing.
- **Limiting the Amount of Surface Parking** – The more parking provided within the building envelope (e.g. underneath other land uses), the less additional lot area will be needed for parking. For parking outside the building envelope, surface parking typically creates far more impervious coverage than parkades. There is also greater opportunity to mitigate the runoff from parkades using green roofs or rainwater re-use (see Sections 7.6 and 7.7). Generally, underground parking only occurs where land economics favour residential or commercial development over surface parking.
- **Building Compact Communities –** Building compact communities enables more natural area to be preserved, thus reducing impervious coverage at the watershed scale. In a compact community pattern, there can be up to 75% less roadway pavement per dwelling unit. The need for parking is also reduced in compact communities, as discussed previously.

Site design practices that reduce total impervious areas also reduce clearing of natural vegetation and the compaction of natural soils (total site disturbance is reduced).

Reducing Impervious Area Improves Source Control Effectiveness

Reducing impervious coverage on lots and roads can improve the effectiveness of stormwater source controls, particularly infiltration facilities. Less impervious coverage on roads and building lots means that:

- less runoff becomes concentrated into infiltration facilities
- more space is available to locate infiltration facilities

This can significantly improve the effectiveness of infiltration facilities, as discussed in Section 7.5.

Stormwater Source Control – A Key Element of Site Design

Implementing low impact site design practices that reduce impervious coverage is not enough to protect downstream watercourses and prevent drainage-related problems. Even low levels of impervious coverage can cause significant stormwater-related impacts. For example, the volume of runoff from low-density single family land uses far exceeds the target condition for Water Balance management (i.e. the 10% runoff volume target).

Source controls are needed to further reduce runoff from impervious surfaces on development parcels (rooftops, driveways, parking lots) and roads (paved roadway and sidewalks).

Consistency with Other Low Impact Development Objectives

Site design practices that achieve stormwater objectives (reducing impervious area, forest clearing and soil compaction) are highly compatible with other low impact development objectives, including:

- Compact communities and cluster development that encourage walking, cycling and transit use
- Smaller streets that are more pedestrian and cyclist-oriented
- Continuous riparian corridors and open space systems (greenways)
- Preservation of environmentally significant areas
- Tree retention
- Community parks and recreation areas
- Construction practices that minimize soil and vegetation disturbance
- Lower expenditures on infrastructure

Preserving Significant Natural Features

Preserving natural vegetation and soils in their undisturbed state is key to minimizing changes in the natural Water Balance (i.e. loss of evapotranspiration and infiltration capacity). There are certain natural features that are especially important for maintaining the health of aquatic ecosystems, including riparian forests, wetlands, natural infiltration areas and floodplains. These features can also have significant benefits in terms of reducing flood risk.

A key component of an integrated strategy to manage stream health and flood risk is to identify significant key natural features at a watershed scale, and protect these features through growth management, land use planning, and development policies and regulations.

Significant natural features should also be identified at the site design level, and preserved through creative site design practices that integrate significant natural features with community open spaces.

Riparian Forests

As discussed in Chapter 2, riparian forests are key to maintaining the health of aquatic ecosystems. Preserving riparian forests enables overland flow to infiltrate and directly feed stream baseflow, thus helping to maintain the natural Water Balance.

Wetlands

Wetlands play a key role in maintaining natural Water Balance and hydrology. They retain large volumes of water, and promote recharge of the interflow zone and evapotranspiration from wetland vegetation. The vegetation in wetlands also improves water quality by removing sediments, nutrients and other contaminants such as heavy metals. Wetlands are typically very productive ecosystems that provide high quality habitat for waterfowl, fish and other wildlife. Constructed wetlands can be used to manage runoff from developed areas.

Natural Infiltration Areas

Natural areas where large volumes of rainfall infiltrate (e.g. natural depressions with highly permeable soils) are key to maintaining the natural Water Balance and should be preserved. Natural infiltration areas that directly feed stream baseflow (e.g. riparian corridors) are particularly important. These areas may also be used to infiltrate runoff from impervious surfaces.

Floodplains

Natural floodplains provide the space for streams and rivers to expand during periods of high rainfall and/or snowmelt. Floodplains provide natural flood control by dissipating the energy of high peak flows. Confining watercourses using flood protection structures such as dykes prevents this natural energy dissipation, and increases the risk of downstream flooding.

The periodic flooding of floodplain areas is also key to maintaining important ecosystems, including riparian forests and wetlands.

The hydrologic functions of natural floodplains can be preserved by limiting development, or by promoting ‘flood-friendly’ land uses (e.g. types of agriculture that can support periodic flooding, buildings that are flood-proofed) in floodplain areas.

7.3 Stormwater Source Control Practices

The Role of Source Control

Stormwater source control practices can play a key role in achieving performance targets for rainfall capture, runoff control and flood risk management.

The primary objective of source control is to reduce runoff volume (i.e. provide rainfall capture) by managing the Water Balance at the site level. Source control can also have significant benefits in terms of reducing runoff rates (i.e. provide runoff control and flood risk management).

Source controls can be very effective at reducing runoff volumes and at reducing peak runoff rates from relatively large storms (e.g. 5-year storms) or from very intense short duration storms (e.g. 100-year cloudburst). However, the ability of source controls to reduce peak runoff rates from very large, long duration storms (e.g. a 100-year winter storm) is limited. Even with source controls, stormwater systems must be designed to safely convey these extreme events.

The Need for Information on Source Control Effectiveness

In order to select appropriate source control options to achieve catchment-specific performance targets, there is a need for information on how well different types of source controls perform under different conditions (e.g. land use types, soil and rainfall conditions).

There is a lack of scientifically defensible data on the long-term effectiveness and benefits of different types of stormwater source controls. To bridge this information gap, in the Greater Vancouver Regional District (GVRD) commissioned a report titled *Effectiveness of Stormwater Source Controls* (2002) to assess the potential effectiveness of various source control options (as measured by their ability to reduce runoff volume and peak rate).

The GVRD report provides a quantitative reference on the effectiveness of the following categories of stormwater source controls:

- **Type 1 - Absorbent Landscaping -** refer to Section 7.4
- **Type 2 - Infiltration Facilities (on lots and along roads) -** refer to Section 7.5
- **Type 3 - Green Roofs -** refer to Section 7.6
- **Type 4 - Rainwater Re-use -** refer to Section 7.7

Guidance for Selecting Appropriate Source Controls

Sections 7.4 to 7.7 present key information from the GVRD report to show how the hydrologic performance of each source control category (i.e. their ability to reduce the volume and rate of runoff) varies depending on land use type, soil conditions, rainfall characteristics and source control design.

For each source control category, these sections also provide design guidance, discuss cost implications and review operation and maintenance requirements.

The information provided in Sections 7.4 to 7.7 is intended to help local governments:

- identify opportunities to manage stream health and/or stormwater infrastructure by applying various types of stormwater source controls
- determine what can realistically be achieved through the application of source controls
- determine which source control options are worth pursuing, and
- estimate the likely return on investment

This provides a starting point for integrating stormwater source control strategies into:

- long-range land use and infrastructure planning decisions
- the design of stormwater systems at the site level

The most appropriate source control options and source control design features for any given development or re-development site will depend on site-specific conditions.

The selection of source controls to meet catchment-specific performance targets should be flexible to allow for innovation. Local government staff, consulting professionals, or developers that select source control options should consider the need for these options, site constraints to their use, expected performance and benefits, maintenance considerations and costs implications (both positive and negative).

This chapter helps evaluate these factors. For more detailed information on the effectiveness of stormwater source controls refer to the GVRD report.

Modeling the Effectiveness of Source Controls

The commonly used hydrologic modeling applications were developed when flow-based thinking dominated stormwater management and surface water modeling. Therefore, none of these models are well suited for modeling Water Balance volumes at the site level.

The Water Balance Model (WBM), introduced in Chapter 6, was used to simulate the performance of source controls under a range of conditions.

Overview of the Water Balance Model

The WBM provides a continuous simulation of the runoff from a development (or re-development) area, or from a watershed (or sub-catchment) with multiple land uses, given the following inputs:

- **Continuous rainfall data** (time increment of one hour or less) and **evapo-transpiration data** (daily) over a long period of record (at least a year). Historic rainfall data can be modified to create climate change scenarios.
- **Site design parameters** for each land use type being modeled (e.g. road width, rooftop coverage, surface parking coverage, population density).
- **Source control information** for each land use type, including:
  - extent of source control application (e.g. % of road and % of building lots with a certain types of source controls)
  - source control design parameters (e.g. area and depth of infiltration facilities, soil depth for green roofs or absorbent landscaping, volume of rainwater re-use cisterns)
- **Soils information**, including:
  - surface soil parameters (e.g. maximum water content, vegetation rooting depth)
  - sub-surface soil parameters (e.g. saturated hydraulic conductivity)

Scenario Modeling

The WBM was used to generate a series of scenarios that demonstrate how a range of factors (e.g. rainfall, land use type, soil conditions) affect the hydrologic performance of the various source control categories.

The source control modeling was based on the best available knowledge of source control performance, but has not been calibrated with measured hydrologic performance data. Performance monitoring from source control demonstration projects will improve understanding of how well source controls can reduce runoff under a variety of conditions, and provide the data needed to calibrate the source control models.

The source control scenarios presented in this chapter are examples, and do not reflect the complete range of available source control options. The examples are intended to provide a starting point for evaluating the potential for source control application, and should not limit innovation in applying combinations and types of source controls.

Chapter 8 presents the results of scenario modeling for case study watersheds to demonstrate what is achievable at the watershed scale through the application of source controls.

Integrating Source Controls into ISMPs

Source controls are applied at the site level, but must be implemented in the context of an Integrated Stormwater Management Plan (ISMP). At the planning level it is important to:

- **Identify stormwater related issues**
  - significant resources to be protected and/or restored
  - drainage problems, such as high flooding risk
- **Characterize development pressures that could affect aquatic ecosystem values or drainage system performance**
  - are there plans for new development in existing natural areas?
  - are there older development areas where re-development is imminent?
- **Evaluate the opportunities for implementing stormwater source controls to:**
  - avoid further stream degradation
  - avoid worsening of drainage problems
  - improve water quality
  - restore watershed health over time

Performance targets, such as the 10% runoff volume target, provide a reference point based on the characteristics of a healthy watershed. The ISMP process will determine what is achievable and affordable in the context of each individual watershed.

Chapter 8 presents case study examples that show how watershed restoration could be achieved over a 50-year timeline through the application of source controls.

Evaluating the Cost of Source Controls

This chapter discusses cost implications of each source control category and provides order-of-magnitude cost estimates. Detailed cost estimates can only be obtained based on the characteristics of each individual development site.

Site-specific costs should be evaluated relative to the potential benefits gained, in terms of protecting or improving watershed health and/or in terms of flood risk management. The information in this chapter helps evaluate the benefits of using source control options.

Cost estimates can be misleading if they are not considered in the context of the overall development process. For example, there may be excavation costs associated with the construction of an infiltration facility on a particular lot, but much of this cost may be incurred through the site grading process (even without infiltration).

It is also important to consider the potential cost savings of source controls. For example, applying infiltration facilities may reduce the cost of storm sewer pipes needed for a new development project, avoid the need for ongoing maintenance of eroded channels, or avoid the need for drainage infrastructure upgrades.

Ensuring the Long-Term Performance of Source Controls

Source control facilities typically require ongoing maintenance to ensure that they continue to function effectively over the long term. While this report discusses operation and maintenance requirements and costs for each source control category, there is a need for further research to better define the:

- operation and maintenance practices required to maintain source control performance over the long term
- cost of these operation and maintenance practices

To address these research needs and provide further guidance on how maintain the long-term performance of source controls, it is important to continue monitoring the performance of source control demonstration projects over long periods of time and to keep accurate records of ongoing operation and maintenance practices.

Operation and Maintenance Implications

New source control practices raise concerns about associated operations, maintenance and liability issues. It is important during any adoption of new design standards to involve operations and maintenance personnel, and to use their creative and practical talents to anticipate and solve these issues.

Demonstration projects are an excellent way to solve real operations and maintenance problems, and to allay false fears.

Certain types of source control facilities may be operated and maintained by local government staff (e.g. infiltration facilities within road right-of-ways). However, many source control facilities are likely to be on private property (e.g. on-lot infiltration facilities, re-use facilities or green roofs). Responsibility for maintaining these facilities shifts to individual landowners or strata corporations, which places a greater reliance on the conscientiousness of individuals.

An on-lot stormwater system is similar to an on-lot septic sewage system, in that owners must be given basic information about operation and maintenance requirements.

There are potential liability issues related to operation and maintenance responsibility (e.g. who is responsible in the event of a failure?). Local governments should resolve these issues in collaboration with landowners and the development community. There are parallel issues relating to water supply and sanitary sewer systems (e.g. sewer cross connections) that local governments have been dealing with for years and could use as precedents.

Education of local government staff, developers and the general public regarding the need for source controls, as well as their long-term operation and maintenance requirements, is essential to the successful implementation of stormwater source controls.

Section 8 provides further discussion and guidance on how to facilitate the changes in standard practice that are needed to promote the widespread implementation of source controls.

Water Quality Benefits of Source Control

Stormwater source controls capture the first flush of pollutants that wash off from impervious surfaces. This is particularly important for roads and parking areas because pollutants from motor vehicles and road maintenance can accumulate on these surfaces.

Infiltration facilities are particularly beneficial in terms of improving water quality at the source. Absorption of stormwater runoff in the shallow soil zone filters out sediments and many pollutants, thus improving downstream water quality.

This chapter focuses on the effectiveness of source controls at reducing runoff volume and rate, because this information enables source control to be evaluated relative to performance targets for rainfall capture and runoff control. Further research is needed to provide similar quantitative modeling of the effectiveness of source controls for improving groundwater and surface water quality.

This research should start with a good understanding of the source of water quality problems (e.g. runoff from roadways, lawns and agriculture areas). This understanding will enable the selection of appropriate water quality indicators and the development of an appropriate water quality model.

As a parallel example, the evaluation of hydrologic effectiveness presented in this report started with a good understanding of the source of water quantity problems (i.e. an increase in the volume and rate of runoff). This understanding led to selection of appropriate hydrologic performance indicators and development of the Water Balance Model.

7.4 Type 1 Source Control - Absorbent Landscaping

The Importance of Surface Soil and Vegetation

Surface soil structure plays a fundamental role in stormwater management. Minimizing surface soil disturbance and using absorbent landscaping can significantly reduce the volume and rate of runoff from developed areas.

In a natural condition, surface soil layers are highly permeable. Surface plants provide a layer of organic matter which populations of earthworms and microbes stir and mix into the soil. This soil ecosystem provides high infiltration rates and a basis for interflow that supports the baseflow needs of aquatic ecosystems.

In an urbanized condition, it is common practice to remove the surface soil layers, to regrade and heavily compact the site, and then to replace only a thin layer (often 50mm or less) of imported topsoil. This practice creates a surface condition that results in significant amount of runoff from lawn and landscape areas.

Absorbent Soil and Vegetation Characteristics

Vegetation and organic matter improve soil structure and contribute to macropore development. This is essential for promoting and maintaining infiltration and evapo-transpiration capacity. To optimize infiltration, the surface absorbent soil layer should have high organic content (about 10 to 25%). Surface vegetation should be either herbaceous with a thickly matted rooting zone (shrubs or grass), deciduous trees (high leaf density is best), or evergreens.

A range of soil and vegetation characteristics is acceptable depending on whether the area is to be covered by lawn, shrubs or trees. The soils required by the BC Landscape Standard for medium or better landscape will provide the required hydrologic characteristics. Often this standard can be achieved by adding organic matter to existing top soils on a residential site.

Figure 7-1 shows the mixing of soil and organic matter to create a good landscape soil.

A range of acceptable absorbent soil compositions are shown in Section 7.9.

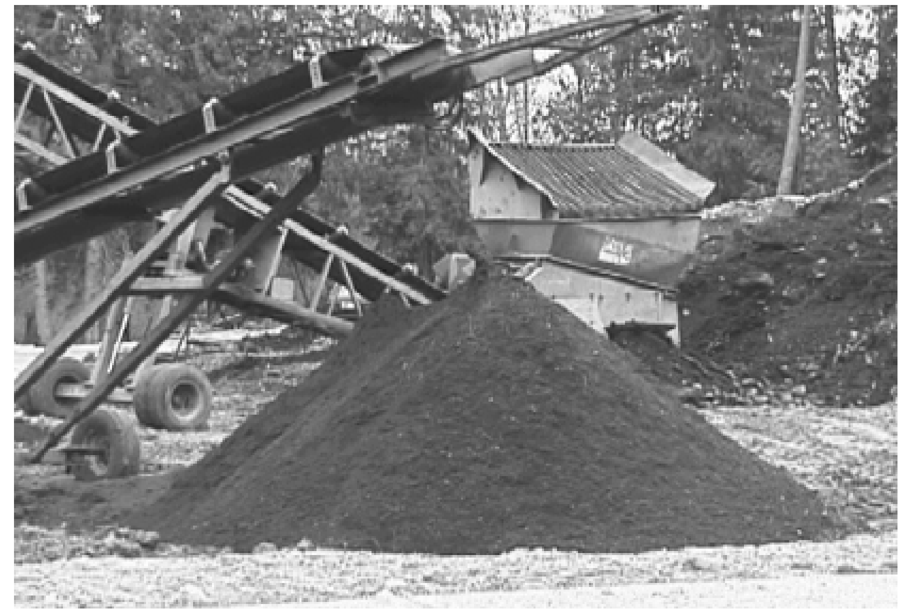


Figure 7-1 Creation of Landscape Soil

Absorbent Soil Depth

Figure 7-2 shows that runoff from landscaped areas can be virtually eliminated by providing a 300 mm layer of landscaped absorbent soil, even under very wet conditions where the hydraulic conductivity of the underlying soil is low.

The Figure assumes that the rooting zone of the surface vegetation extends to the depth of the absorbent soil layer, and that absorbent landscaping covers all undeveloped areas.

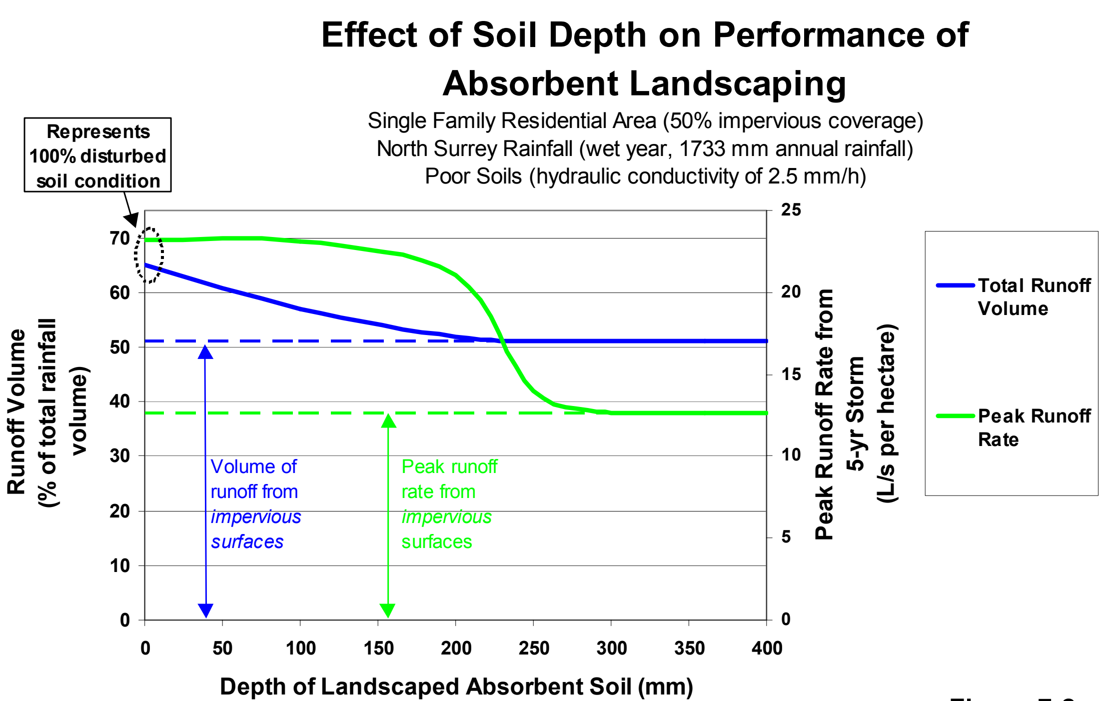


Figure 7-2

The Importance of Forests

Forests are the most effective form of absorbent landscaping. Since trees typically have very deep rooting zones (often in the range of 2 metres), there is virtually no surface runoff from forested areas. Tree canopies that shade impervious surfaces (e.g. roadways) can reduce the runoff from these surfaces by intercepting rainfall.

Preserving and/or restoring as much forested area as possible through implementation of an urban forestry strategy is an effective way to reduce runoff volumes and rates.

The thick layers of absorbent soil in forested areas typically have the capacity to retain and infiltrate large volumes of runoff (in addition to direct rainfall). Dispersing runoff from rooftops or paved surfaces over forested areas can be an effective infiltration strategy, as discussed in Section 7.5.

The Benefits of Absorbent Landscaping for Different Rainfall Conditions

Figure 7-3 shows that absorbent landscaping is most beneficial for high rainfall locations. This is because increased rainfall typically leads to greater volumes of runoff from disturbed soil, but not from absorbent landscaping.

Absorbent landscaping (300 mm soil depth or more) can virtually eliminate surface runoff from undeveloped areas, even in the wettest conditions. This has significant benefits in terms of reducing peak runoff rates from extreme rainfall events, as shown on the following page.

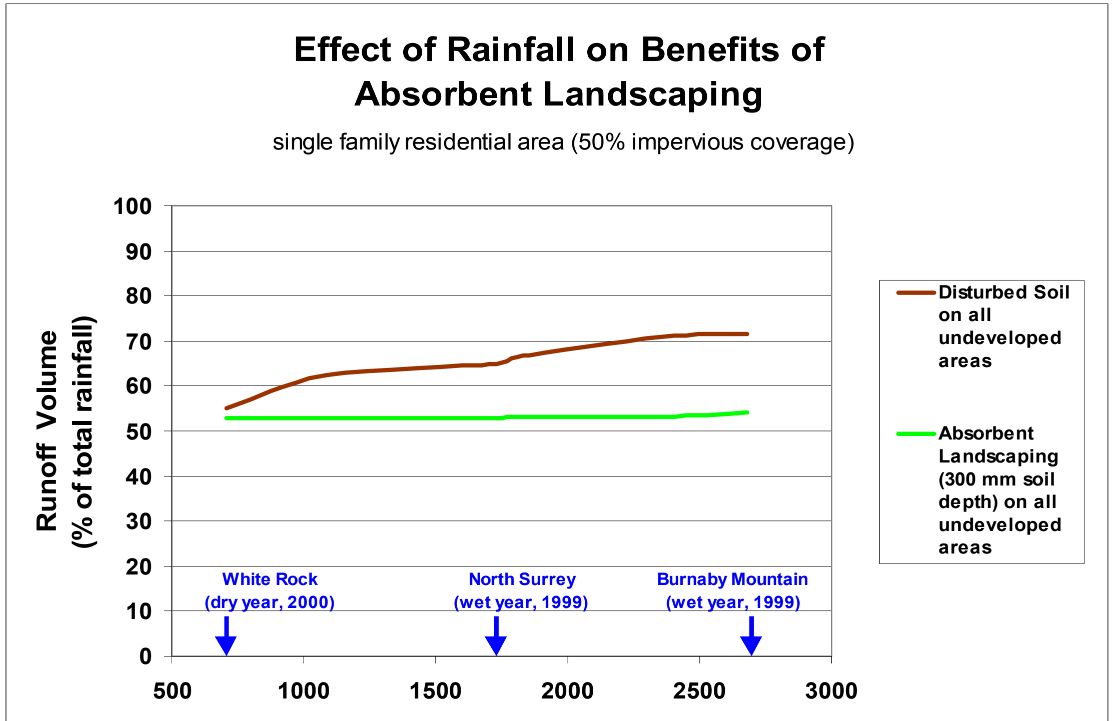


Figure 7-3

Benefits of Absorbent Landscaping for Different Land Use Types

The benefits of absorbent landscaping are more significant for land uses with lower levels of impervious site coverage and higher proportions of undeveloped area (e.g. single family residential), as shown in Figures 7-4 and 7-5.

These figures show the simulated runoff volumes and peak runoff rates during a very wet year (1999) in North Surrey. A total of 1733 mm of rainfall fell during this year, and the most extreme rainfall event was a long duration, wet weather storm with a 5-year return period.

Figure 7-4 shows that absorbent landscaping is particularly beneficial in terms of reducing peak runoff rates. During large rainfall events (e.g. a 5-year storm), disturbed soil can generate nearly as much runoff as impervious surfaces, whereas an absorbent soil layer (300 mm depth) can continue to absorb rainfall. Therefore, absorbent soil can significantly reduce peak runoff rates from large storms, especially for land uses with large amounts of undeveloped space.

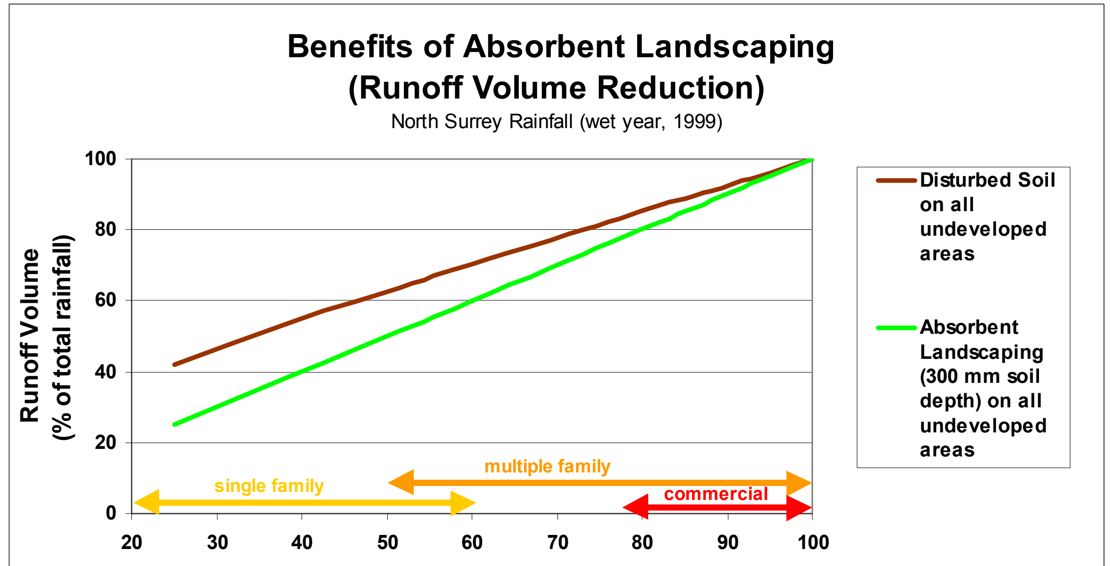


Figure 7-4

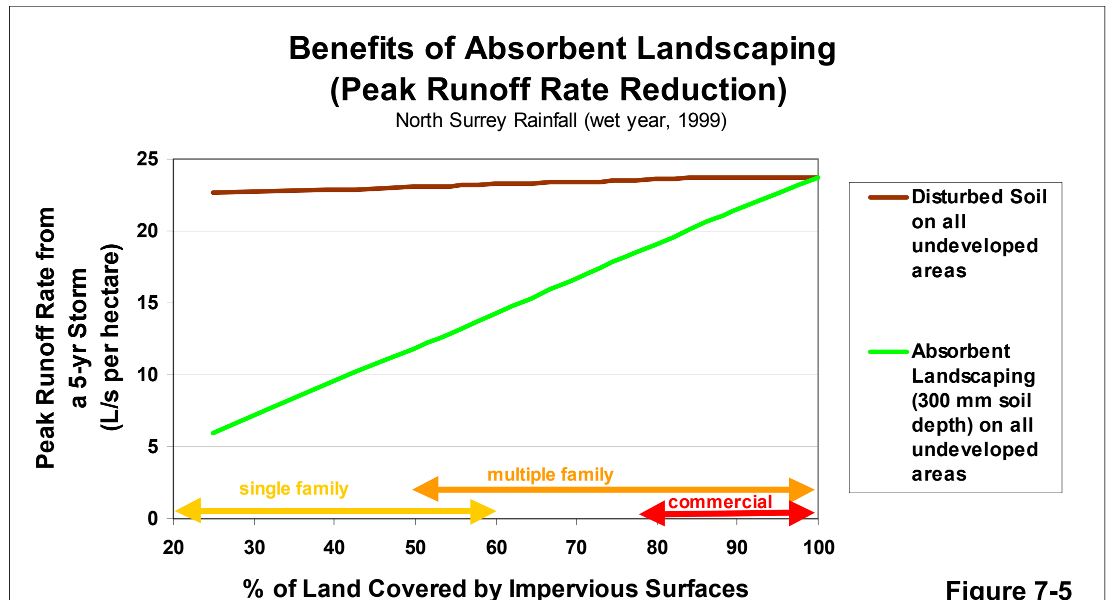


Figure 7-5

Cost Implications of Absorbent Landscaping

The costs of absorbent landscaping are highly variable and depend on site-specific conditions such as vegetation type. This reflects the customized nature of individual site landscaping plans.

Typical costs for absorbent landscaping range from about \$25 - \$70 per m^2. In the lower cost ranges, the absorbent soil depth would be about 150 mm, with turf cover and some trees. In the upper ranges, soil depth would be about 450mm, with shrubs or groundcover and trees.

Maintenance Tips for Absorbent Landscaping

- Maintaining the absorbency of soils is an advantage both to turf and plant health and to stormwater management. Normal landscape maintenance of absorbent soils will generally produce an absorbent landscape surface.
- In shrub beds, regular application of bark mulch, natural leaf drop or other organic inputs will keep burrowing insect populations high and maintain soil permeability.
- In lawn areas, use of proper sandy topsoil will avoid compaction problems. Aerating techniques can assist air and water exchange in locally compacted areas.
- Bare soils should not be left uncovered (e.g. during construction) because rainfall impact can create a relatively impermeable surface crust, even in sandy soils.
- Dry season watering of plants is essential, especially when plants are first becoming established.
- Maintenance requirements (and costs) are typically highest in the first year when plants may require more watering, weeding and some replacement.

Rehabilitation of Disturbed Soil

There are a number of ways to convert a disturbed surface soil layer into absorbent soil that has good hydrologic properties, including:

- Mixing in organic content (e.g. compost); this is the most effective soil rehabilitation technique
- Mechanical tilling or scarifying of the surface soil
- Soil aeration, which requires specialized equipment

Immediate replanting of the surface soil layer is an essential part of any soil rehabilitation project.

7.5 Type 2 Source Control - Infiltration Facilities

The Importance of Disconnecting Impervious Surfaces

Direct runoff from impervious surfaces is the primary cause of drainage-related problems (e.g. stream degradation, flooding risk). This direct runoff can be eliminated to a large extent by infiltrating runoff from impervious surfaces on development parcels (rooftops, driveways, parking lots) and roads (paved roadways and sidewalks).

Figure 7-6a and 7-6b show the runoff volume and rate reduction benefits that can be achieved in one of the wettest parts of the province (North Vancouver) during a very wet year (2355 mm of annual rainfall) by disconnecting impervious surfaces. These figures show that the benefits vary significantly depending on the type of surface and the amount of space available to infiltrate runoff (discussed further on the following pages).

Simple Disconnections

There is very little benefit gained by impervious surface disconnection if the runoff is simply dispersed over an area with disturbed surface soil.

Dispersing runoff over an area with absorbent landscaping can result in significant runoff volume reduction, even if the underlying soils have poor hydraulic conductivity. However, this is not likely to reduce peak runoff rates resulting from large, long duration rainfall events (e.g. a 5-year winter storm). Concentrating runoff from an impervious surface area onto a smaller area of absorbent landscape causes the surface soil to become saturated during prolonged rainfall. There must be an adequate collection and conveyance system (e.g. lawn basins) to ensure that runoff from saturated soils does not cause water damage, nuisance problems, or inconvenience to the public.

The most significant reduction in runoff volume and peak rates can be achieved by dispersing runoff over a forested area. The rooting depth of trees provides significant storage capacity to retain runoff for extended periods of time and allow it to seep into the ground.

Infiltration Facilities

The hydrologic function of a forested infiltration area can be approximated using infiltration facilities (e.g. bioretention areas) that are designed to retain runoff and provide time for it to infiltrate. Different types of infiltration facilities are discussed on the following page.

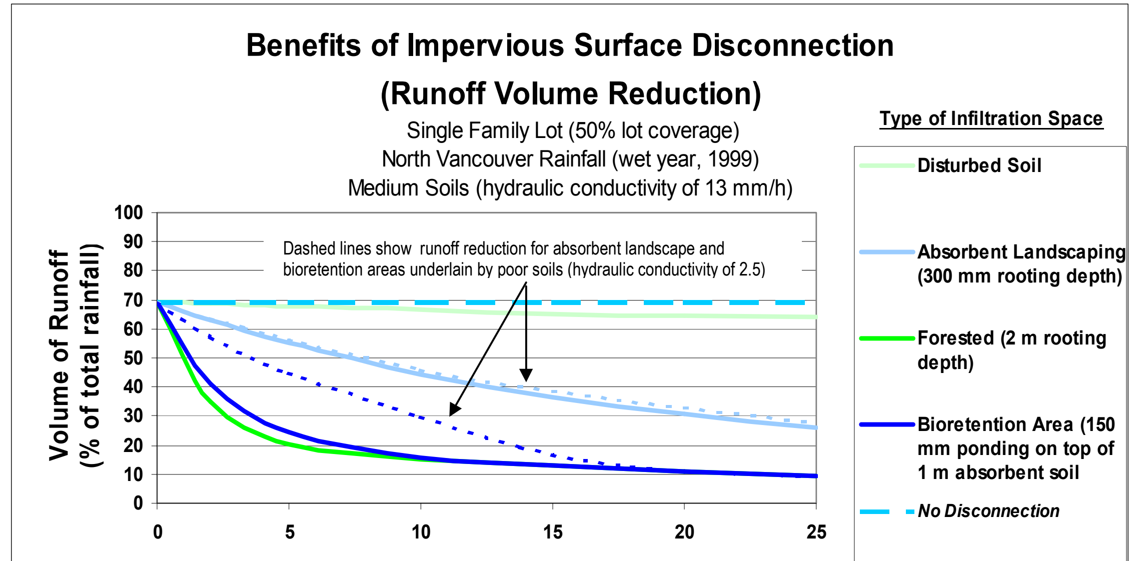


Figure 7-6a

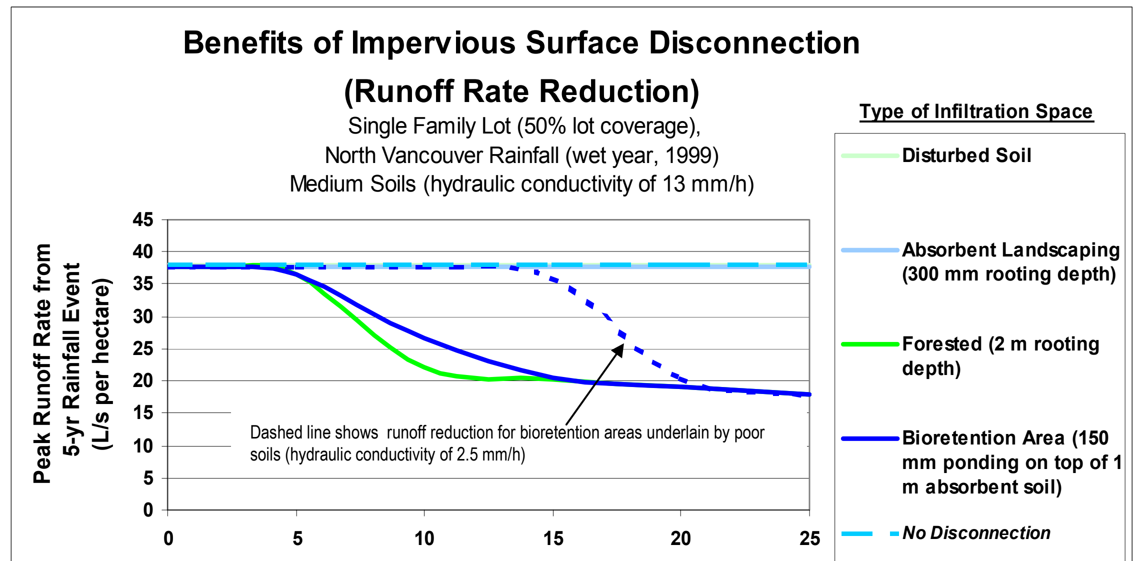


Figure 7-6b

Different Types of Infiltration Facilities

The storage capacity needed to retain impervious surface runoff and allow it to infiltrate can be provided:

- in the void space of absorbent soil, sand or gravel layers
- on the ground surface (i.e. ponding)
- in infiltration chambers (see Figures 7-7a and 7-7b)
- in storage structures, such as cisterns; runoff stored in structures must eventually be released to an infiltration area

Note that the amount of area provided for infiltration is a more important design parameter than storage volume.

There are two general categories of infiltration facilities:

- **Surface Facilities** – Runoff is stored in a layer of absorbent soil, sand or gravel, and/or on the ground surface in a ponding area. Surface facilities can be aesthetically landscaped and integrated into the design of open spaces (often called bioretention facilities or rain gardens). Figure 7-8a shows an example of a bioretention facility in the form of a terraced landscape feature on a hillside. Figure 7-8b shows an example of parking lot runoff draining to linear bioretention areas (landscaped islands in the parking lot). Bioretention can also be applied at the neighbourhood scale (e.g. constructed wetlands serving multiple dwelling units).

  Surfaces facilities can also be infiltration trenches, which store runoff in a layer of clean gravel or stone (see Figure 7-9).

- **Sub-surface Facilities –** Runoff is stored in sub-surface layers of gravel, sand or drain rock and/or in infiltration chambers (e.g. inverted plastic half pipes). Absorbent landscaping can be installed over the surface, and with proper engineering, pavement and light vehicle traffic may be allowed on the surface (e.g. a soakaway pit under a driveway).

Note that infiltration facilities can also be a combination of the two types described above. For example, infiltration swales along roads (see Figure 7-10) may consist of an absorbent soil layer (surface swale) on top of a sub-surface infiltration trench (gravel filled soakaway).

Design, construction, and operation and maintenance tips for different types of infiltration facilities are provided later in this section.

The Need for Escape Routes

All infiltration facilities must have overflow pipes or channels to ensure that runoff from extreme storms can escape to downstream watercourses without posing a threat to property or public safety. Infiltration facilities along roads (e.g. swales and infiltration trenches) must also be designed to convey extreme storms from the development areas they serve (as conventional storm sewers do).

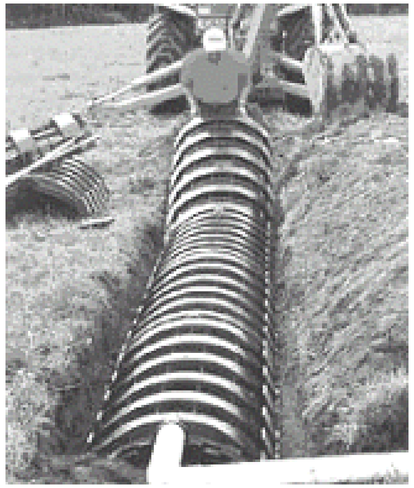


Figure 7-7a
Infiltration Chamber

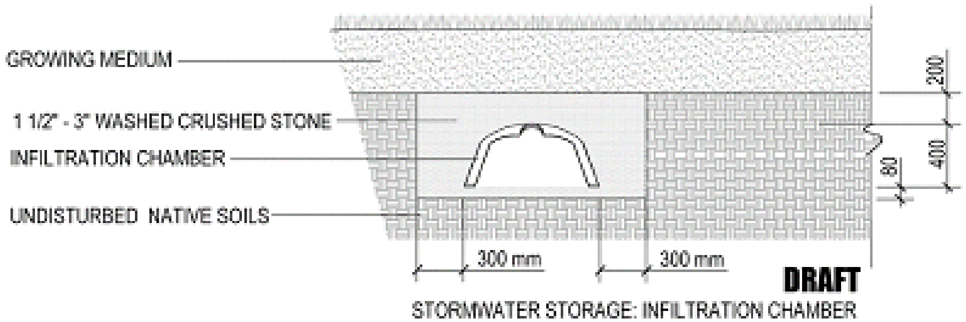


Figure 7-7b

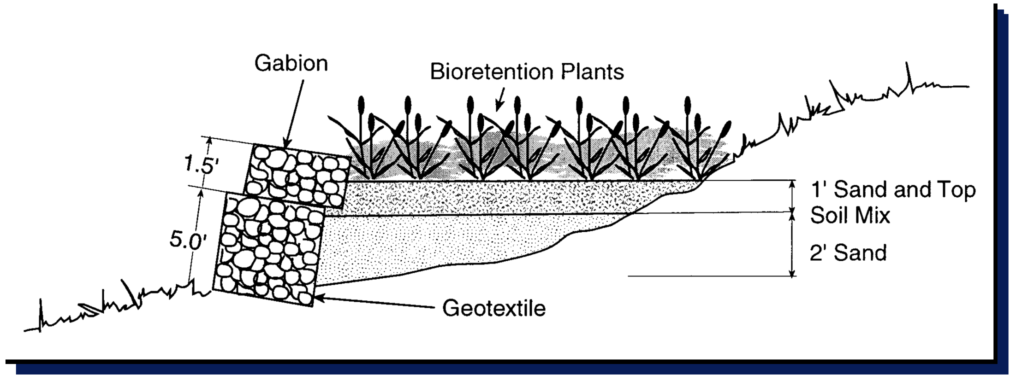


Figure 7-8a Bioretention Landscaping Feature

Figure 7-8b Bioretention for a Parking Lot

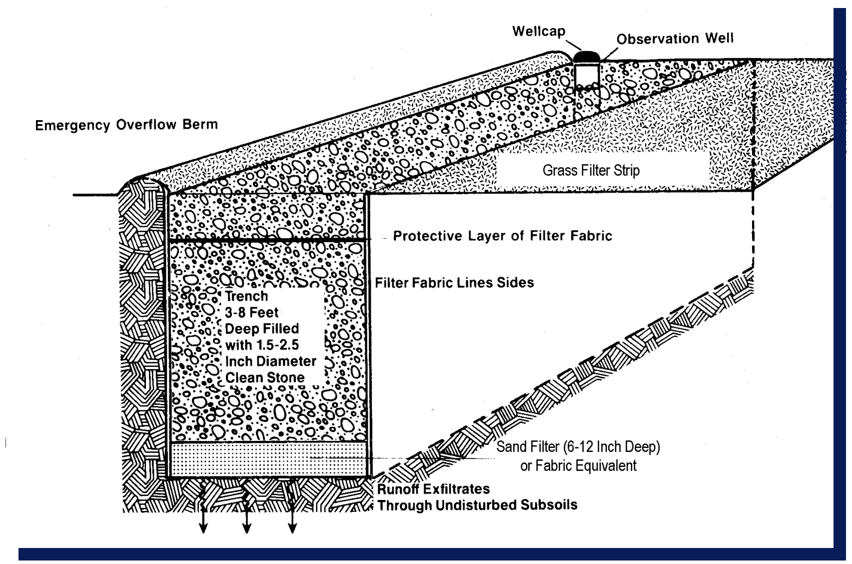


Figure 7-9 Infiltration Trench

Figure 7-10 Infiltration Swale Along Roadway

Factors that Affect the Performance of Infiltration Facilities

The hydrologic effectiveness of infiltration facilities (i.e. amount of reduction in runoff volume and rate) varies depending on the following factors:

- **Land Use Type –** Infiltration is more challenging for land uses with higher levels of impervious surface coverage (e.g. commercial or high-density residential uses). On high coverage land uses there is more surface runoff (thus concentrating more water into infiltration facilities), and less space available to locate infiltration facilities.
- **Soil Type –** The maximum rate at which water can exfiltrate from infiltration facilities is controlled by the hydraulic conductivity of soils.
- **Amount of Area Provided for Infiltration –** Footprint area is the most important design parameter for infiltration facilities. Increasing infiltration area reduces runoff volume and rate by:
  - dispersing runoff over a larger area, and thus reducing the concentration of runoff (governed by the ratio of impervious surface to infiltration area)
  - increasing the rate at which this runoff can exfiltrate
- **Rainfall Characteristics –** The effectiveness of infiltration facilities typically decreases as rainfall increases. This is because more rainfall results in more runoff to be concentrated into infiltration facilities, which leads to more overflow (i.e. greater volumes and rates of runoff).
- **Depth and Type of Infiltration Facility –** Increasing the depth and/or void space for storage in an infiltration facility increases the retention storage capacity, thus decreasing the amount of overflow (i.e. runoff). In general, infiltration area is a more important parameter than depth.
- **Depth to Groundwater –** In order for infiltration facilities to be effective, the bottom of the facility must be a reasonable depth (at least 0.5 m) above the groundwater table. Infiltration facilities are not appropriate in areas where the water table is at or near the ground surface

The graphs presented on the following pages illustrate how these factors affect the performance of infiltration facilities.

The Effectiveness of Infiltration under Different Rainfall Conditions

Figure 7-11 illustrates how the performance of infiltration facilities (in terms of runoff volume reduction) decreases as total annual rainfall increases.

More infiltration area is required to achieve the same level of runoff volume reduction in a wetter location (or year) than in a drier location (or year). For example, in order to reduce the total runoff volume from a typical single family lot (on poor soils) to 10% or less of total rainfall volume (i.e. the target condition):

- in a location where the annual rainfall is around 700 mm, about 3% of the lot would have to be provided for infiltration
- in a location where the annual rainfall is around 1800 mm, about 15% of the lot would have to be provided for infiltration

Variability in soil type and land use also has a big effect on the amount of area required to meet a given volume reduction target (e.g. the 10% target), as discussed on the following pages.

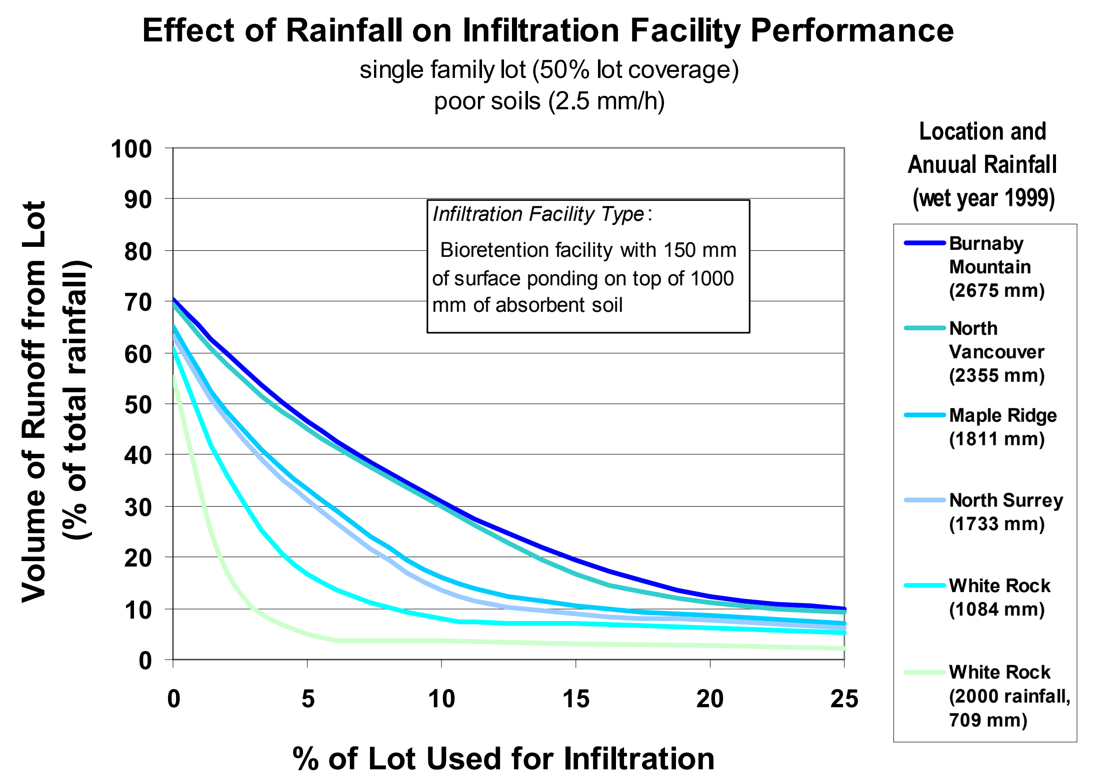


Figure 7-11

Selecting Infiltration Facility Depth

Figure 7-12 illustrates how the depth of an infiltration facility (i.e. distance from the bottom of the facility to the overflow level) increases the level of runoff volume reduction that can be achieved for different types of facilities.

The benefits of increasing facility depth diminish beyond a certain threshold (around 500 mm). Beyond this threshold, the area of an infiltration facility has a much greater impact on performance than its depth (as discussed on the following pages).

It is important to note that shallow infiltration facilities typically provide the best opportunity for recharging the soil interflow zone. In addition, the hydraulic conductivity of soils tends to be higher closer to the surface.

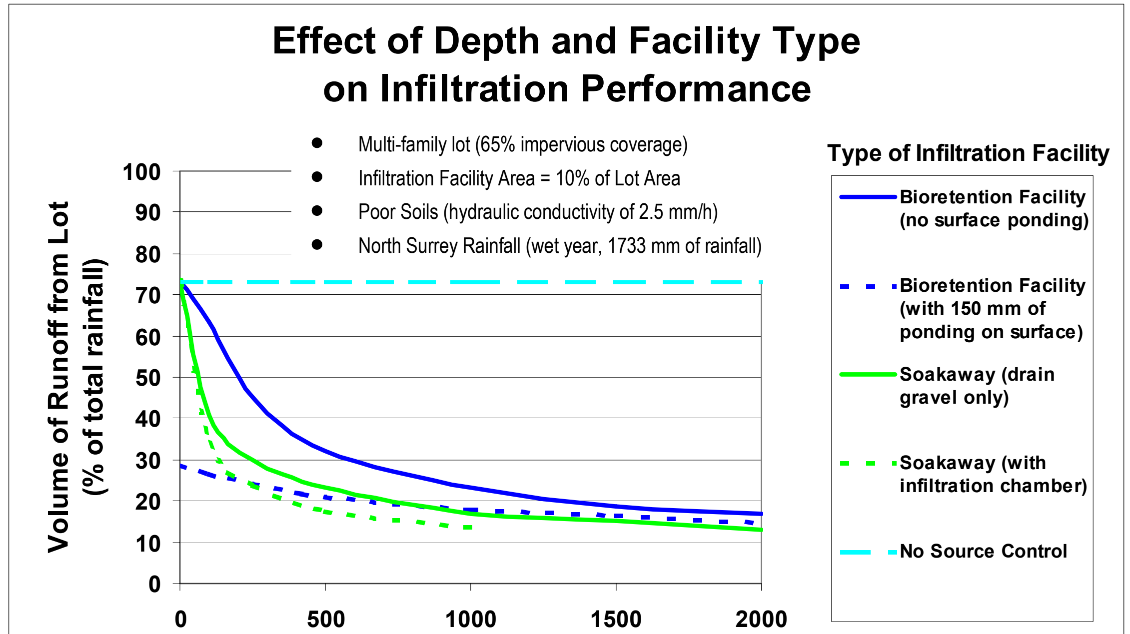


Figure 7-12

Constraints on Facility Depth

Appropriate depths for infiltration facilities must be selected based on site-specific characteristics and constraints.

As noted previously, the bottom of an infiltration facility should be at least 0.5 m above the local groundwater table. The depth to bedrock or to relatively impermeable soil layers may also govern the feasible depth of infiltration facilities.

Appropriate ponding depths for surface infiltration facilities may also be governed by safety or aesthetic considerations.

Comparing Different Types of Infiltration Facilities

Figure 7-12 shows that a soakaway pit would be slightly more effective than a bioretention facility of the same depth (with no surface ponding), because gravel stores more runoff per unit volume than absorbent soil (i.e. it has higher void space storage).

Placing an infiltration chamber in a soakaway trench (as shown in Figure 7-7b) increases its storage volume, and slightly improves its effectiveness. Similarly, surface ponding increases the storage capacity and improves the effectiveness of bioretention facilities, particularly for facilities with fairly low absorbent soil depth (e.g. less than about 500 mm).

The Importance of Infiltration Area and Soil Type

Figures 7-13a and 7-13b show how the level of reduction in runoff volume and rate that can be achieved using infiltration facilities is highly dependent on the hydraulic conductivity of local soils and on the amount of area provided for infiltration.

For example, providing 10% of a single family lot area for infiltration could:

- reduce total runoff to about 10% of total rainfall and reduce the peak runoff rate from a 5-year storm by about 45%, where soils have good hydraulic conductivity (greater than about 13 mm/h)
- reduce total runoff to about 35% of total rainfall but achieve virtually no reduction in the peak runoff rate from a 5-year storm, where soils have very poor hydraulic conductivity (about 1 mm/h)

Note that these graphs are based on Water Balance Model simulations for a very wet year in North Surrey (1999). In locations and/or years with less rainfall, infiltration facilities can be expected to perform better than the graphs indicate (and vice versa).

These graphs assume that all undeveloped areas have disturbed surface soil (i.e. no absorbent landscaping), and that runoff from disturbed soils on building lots is not captured by bioretention facilities.

Determining What is Feasible and Affordable

The size of infiltration facility that can be provided in any given situation will depend on:

- the physical constraints associated with the available undeveloped space (feasibility thresholds), and/or
- willingness to pay (affordability thresholds)

Affordability thresholds will likely govern infiltration facility sizes for lower coverage land uses (e.g. single family residential) and feasibility threshold will likely govern for higher coverage land uses (e.g. commercial land uses).

The affordability thresholds shown on the adjacent infiltration performance curves are for illustration purposes only, and reflect judgement as to what seems appropriate. Further discussion on how to establish affordability and feasibility thresholds is provided on the following page.

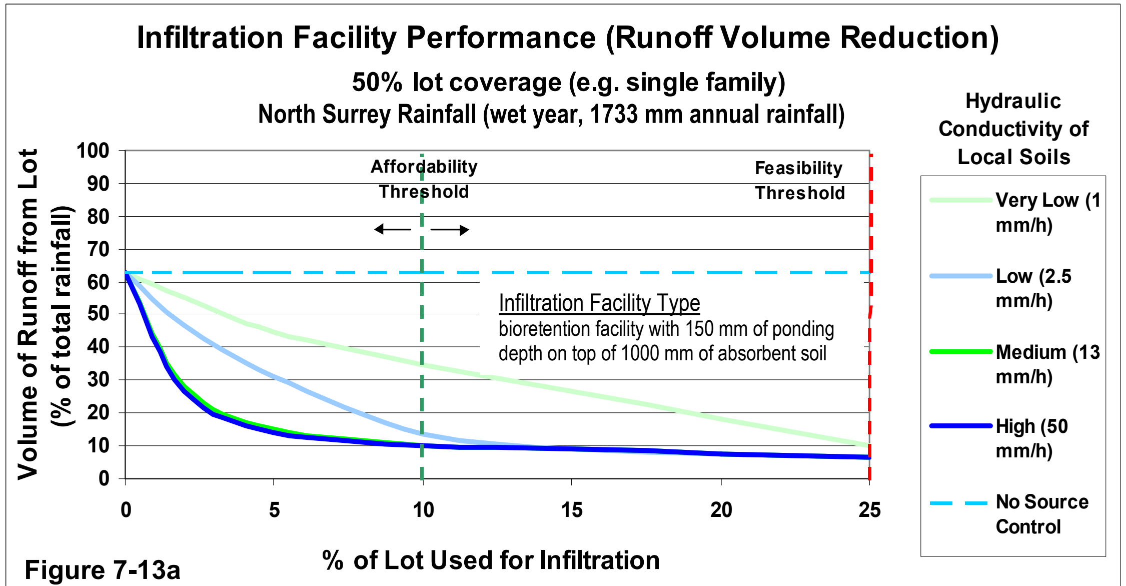


Figure 7-13a

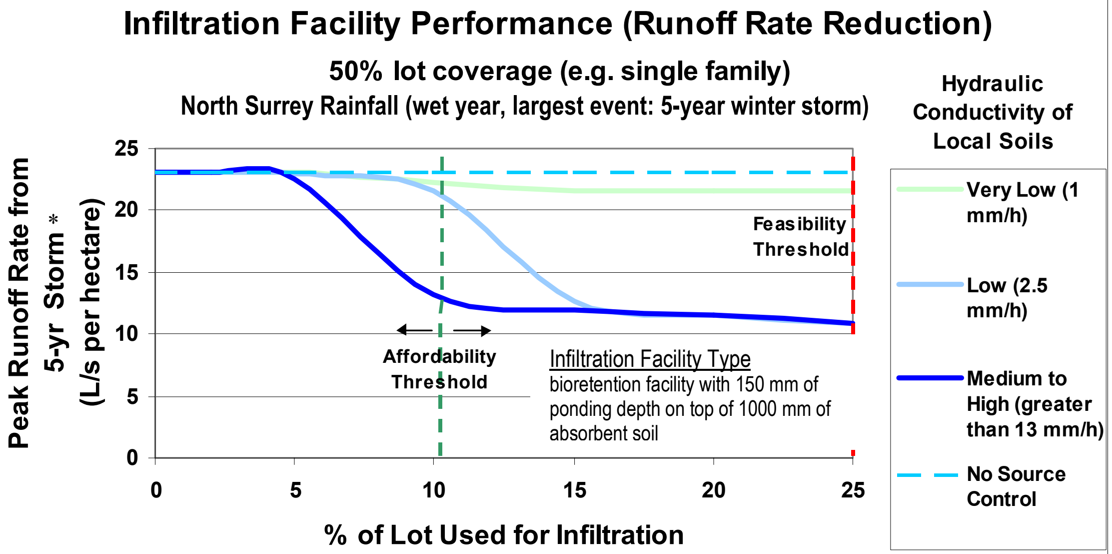


Figure 7-13b

* refers to the rate of runoff from an entire development area (i.e. building lots *and* the roads serving these lots).

Feasibility Thresholds

As lot coverage increases there is less space available to locate infiltration facilities. The feasibility threshold refers to the maximum amount of physical space that could be used for infiltration.

These thresholds will be highly site-specific because they depend on the layout of impervious and pervious spaces within a lot (or road), as well as on soil type.

It is typically not possible to use all undeveloped lot space for infiltration facilities. Feasibility thresholds can be estimated at about 50% of undeveloped lot space to provide a starting point for planning purposes.

Since constant wetting can cause localized expansion of clay soils, a certain amount of clearance between infiltration facilities and building foundations (and property boundaries) is needed to prevent potential damage. A clearance distance of 3 m or more should be used in any soils with significant clay content. For heavy clay soils, the clearance distance should be about 5 m.

With proper engineering, it may be feasible to use nearly all of the undeveloped space within road right-of-ways for infiltration.

Affordability Thresholds

Increasing the size of infiltration facilities improves their effectiveness (as shown in Figures 7-13a and 7-13b), but also increases their cost. Local governments must establish affordability thresholds based on the community's willingness to pay, and on the potential benefits of the infiltration facilities.

Note that reductions in runoff volume and rate are indicators of hydrologic benefits, which translate into benefits for a community in the form of stream protection and restoration, avoided flooding, or other avoided drainage costs.

Establishing Affordability Thresholds

Figure 7-14 shows an example of how order-of-magnitude cost estimates can provide a starting point for answering the questions:

- what can realistically be achieved through infiltration?
- are infiltration source controls worth pursuing?
- what is the likely return on investment?

The costs of infiltration facilities can be highly variable depending on site-specific conditions, such as amount and type of material that needs to excavated. The benefits of infiltration facilities are also highly dependent on site-specific conditions, and therefore, site-specific cost-benefit analyses are essential. The costs and benefits of infiltration facilities must be considered in the context of an Integrated Stormwater Management Plan (ISMP).

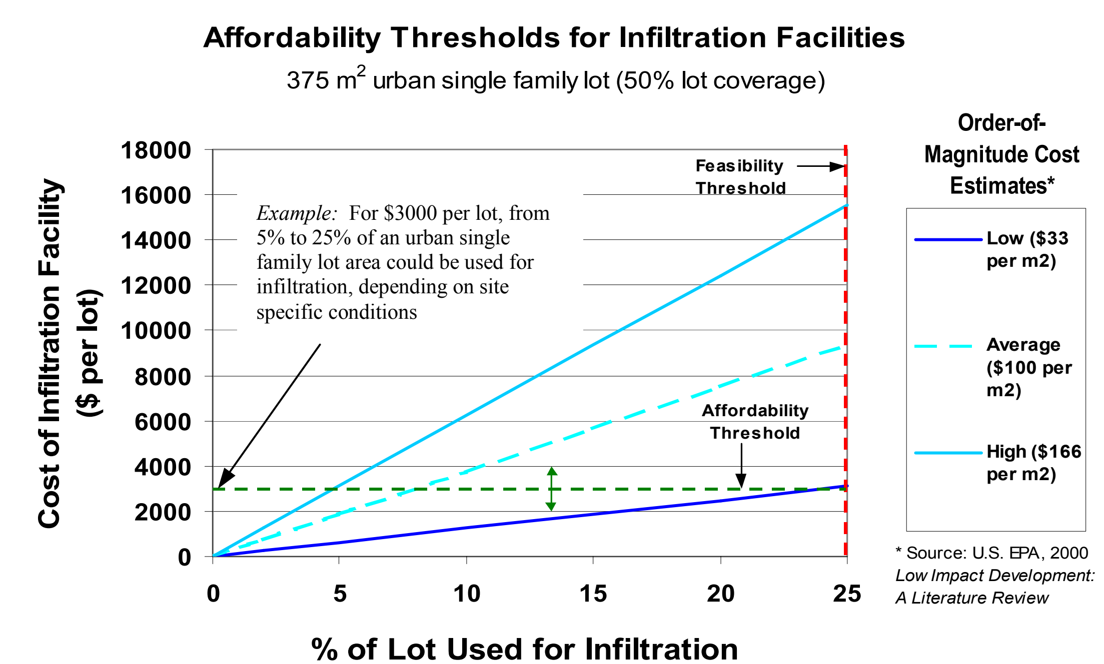


Figure 7-14

Infiltration Facilities for Land Uses with High Impervious Coverage

Figures 7-15a and 7-15b show the level of runoff volume and rate reduction that could be achieved for land uses with relatively high impervious coverage, such as high-density multiple family or commercial land uses.

In this case, the feasibility threshold rather than the affordability threshold governs the amount of infiltration area that can be provided.

By providing the feasible amount of infiltration area (about 7.5% of the lot area), the volume of runoff volume from a high coverage lot could be reduced to:

- about 10% of total rainfall, where soils have good hydraulic conductivity (greater than about 13 mm/h)
- about 60% of total rainfall, where soils have very poor hydraulic conductivity (about 1 mm/h)

The peak runoff rate from a 5-year, long duration winter storm could not be reduced using infiltration facilities on high coverage land uses, even where soils have good hydraulic conductivity. This conclusion does not necessarily apply to lower rainfall locations.

The effectiveness of infiltration facilities on land uses with high impervious coverage can be improved by providing additional storage structures such as cisterns, and releasing stored runoff to infiltration areas at a controlled rate.

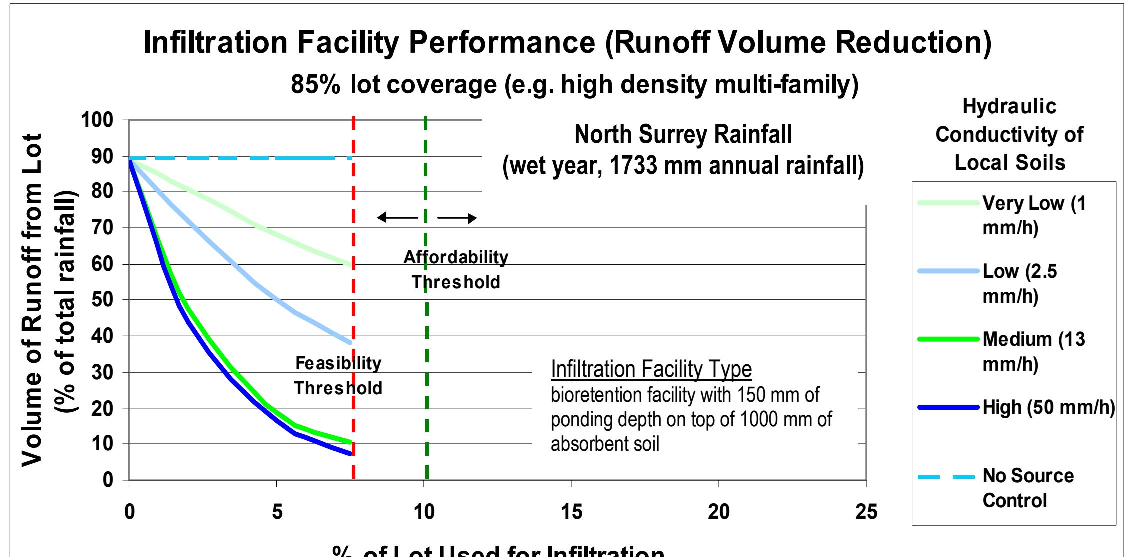


Figure 7-15a

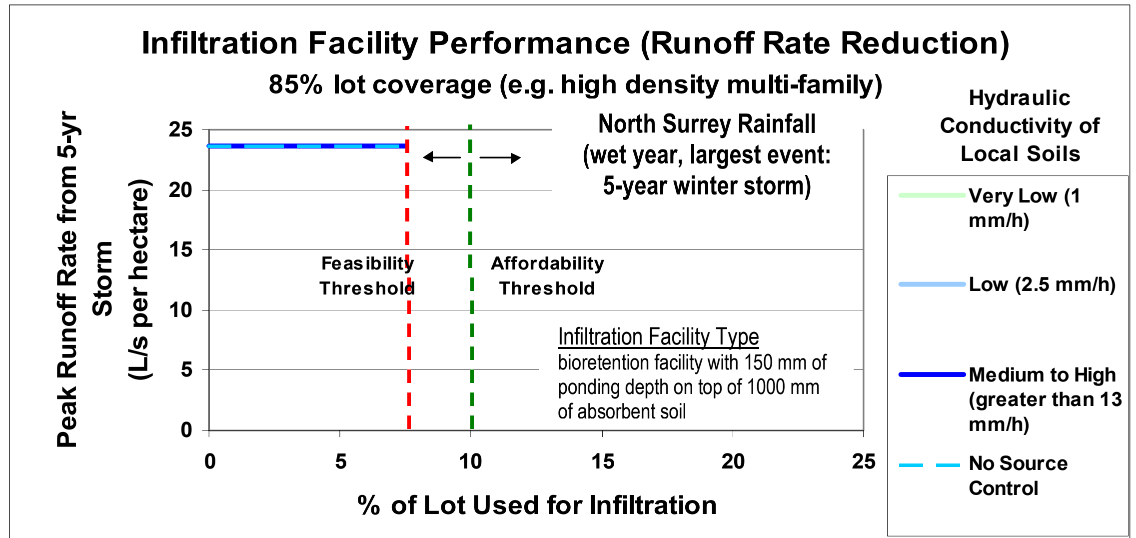


Figure 7-15b

Performance of Infiltration Facilities for a Range of Land Use Types

The GVRD report on the *Effectiveness of Stormwater Source Control* includes infiltration performance curves (similar to Figures 7-13 a-b and 7-15 a-b) for eight different land use types, with total lot coverage ranging from 30% (e.g. low-density single family) to 98% (e.g. town centre commercial).

The GVRD report also provides infiltration performance curves for four road types, with paved roadway widths ranging from 8.5 m (e.g. local roads) to 16 m (e.g. divided arterials). Sample infiltration performance curves for roads are shown on the following page.

For a given land use or road type and soil condition, these curves can be used to estimate the hydrologic benefits (i.e. runoff volume and rate reduction) of providing a certain amount of infiltration area.

Performance of Infiltration Facilities on Roads

Figures 7-16a and 7-16b show the reduction in runoff volume and rate that could be achieved using infiltration facilities on roads. These graphs show the simulated performance of two-layer swale and infiltration trench systems, assuming:

- top layer (surface swale) = 300 mm of absorbent soil
- bottom layer (infiltration trench) = gravel-filled trench with perforated overflow pipe 300 mm above the trench bottom

The performance curves show that the runoff from a typical local road could be virtually eliminated (even during a very wet year) by dispersing roadway runoff to:

- a 2 m wide swale/trench (or two 1 m swales) along the road, where soils have very good hydraulic conductivity (around 50 mm/h)
- a 4 m wide swale/trench (or two 2 m swales) along the road, where soils have good hydraulic conductivity (around 13 mm/h)

Even where soils have very poor hydraulic conductivity (around 1 mm/h), a 4 m swale/trench could reduce the volume of runoff from a typical local road to about 25% of total rainfall.

In general, infiltration facilities along roads are more effective than on-lot infiltration facilities because there is typically less concentration of runoff (i.e. the ratio of impervious area to infiltration area tends to be lower).

Note that the affordability thresholds shown on Figure 7-16a and 7-16b are provided for illustration purposes only. Local governments should establish their own thresholds by evaluating costs, benefits and willingness to pay.

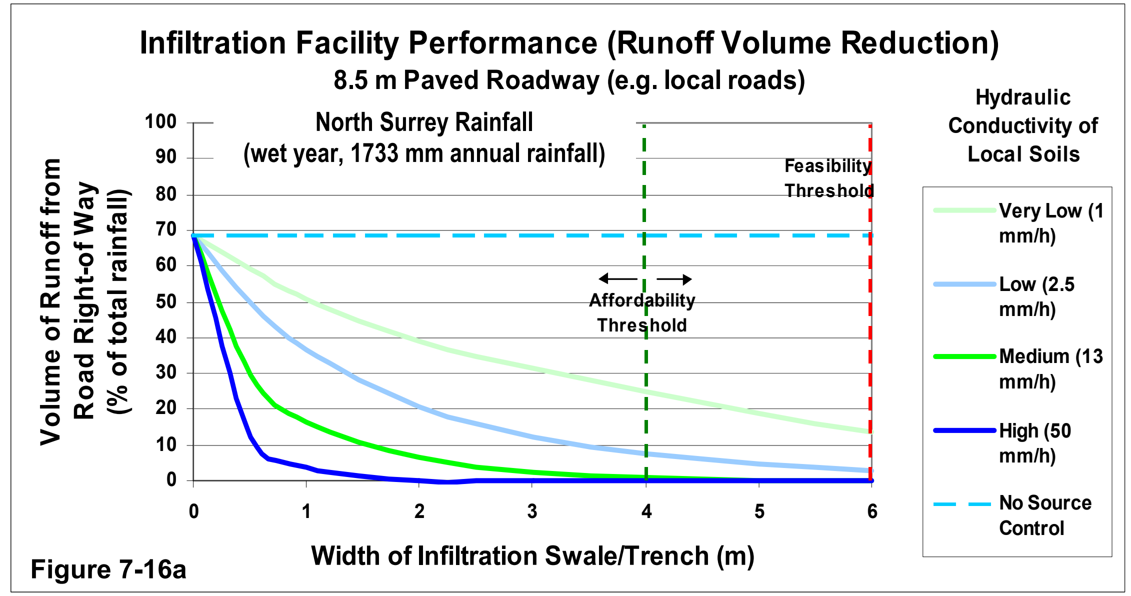


Figure 7-16a

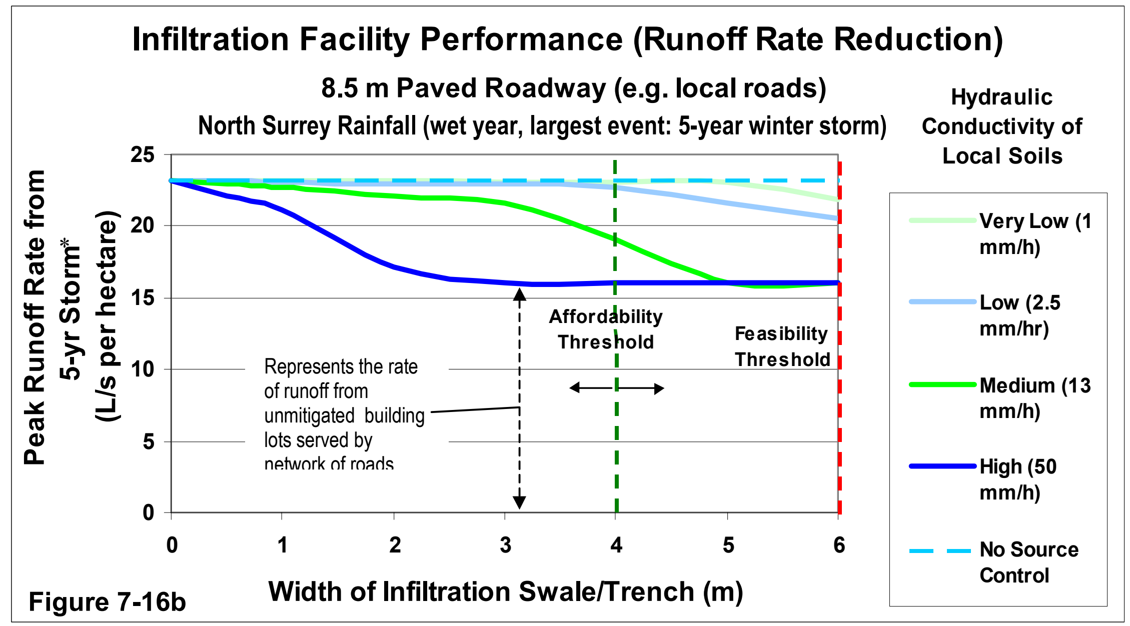


Figure 7-16b

* refers to the rate of runoff from an entire development area (i.e. building lots *and* the roads serving these lots).

Achievable Level of Runoff Volume Reduction for Different Land Use Types

Figure 7-17 provides an estimate of the level of runoff volume reduction that could be achieved using infiltration facilities (during a wet year in the South Coast climate) for a range of land use types, under different soil conditions. This figure assumes that infiltration facility size is based on the governing threshold for each land use type (i.e. either feasibility or affordability).

Where soils have medium or better hydraulic conductivity (greater than about 13 mm/h), runoff volume could be reduced to about 10% of total rainfall (i.e. the target condition for a healthy watershed) for all but the highest coverage land uses (high density multiple family or commercial).

To achieve the 10% target for lower coverage single family land uses, absorbent landscaping would be required in addition to infiltration facilities. This is because lots with lower impervious coverage typically have more runoff volume from disturbed soil (Figure 7-13 assumes that undeveloped areas are covered by disturbed soil).

Significant levels of runoff volume reduction can also be achieved in soils with poor conductivity (around 2.5 mm/h), for all but the highest coverage land uses. Even where the hydraulic conductivity of soils is very poor (around 1 mm/h), runoff volume can be reduced by about 40 to 50% on single family and low to medium-density multiple family land uses.

Note that greater levels of runoff volume reduction would likely be achievable in locations and/or years with less rainfall (and vice versa).

Typical hydraulic conductivity ranges for different soil types are provided below for reference purposes.

Soil Type	Typical Hydraulic Conductivity Range*
Sands and gravels	> 50 mm/h
Sandy loams	10 – 50 mm/h
Silty loams	5 – 40 mm/h
Clay loams	2 – 6 mm/h
Clays	< 2 mm/h

* Source: Soil Texture Triangle: Hydraulic Properties Calculator, Washington State University (http://www.bsyse.wsu.edu/saxton/soilwater/)

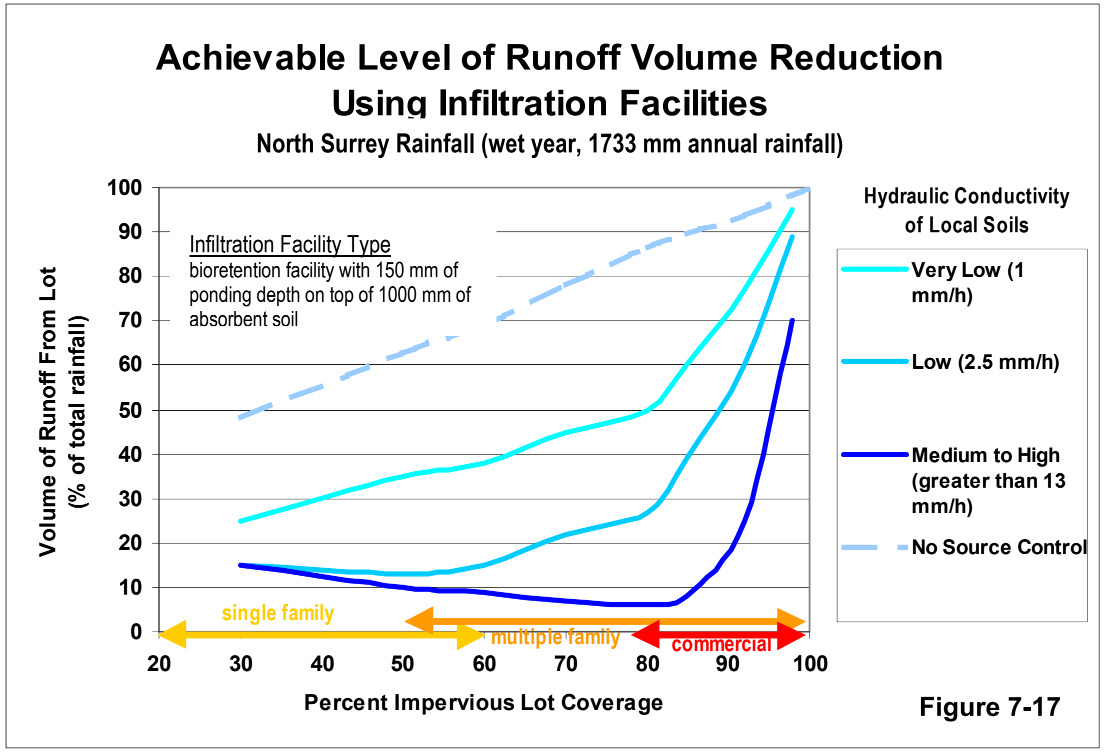


Figure 7-17

Creating Hard Surfaces that Infiltrate

Pervious Paving

Runoff from paved surfaces can be virtually eliminated by replacing impervious pavement with pervious pavers that allow rainwater infiltrate through cracks between the pavers. Figure 7-18 shows an example of pervious paving.

Pervious pavers are placed over a reservoir base course of fractured drain rock (similar to railway ballast), which can be sized to store a given design storm. For example, to store a 60mm storm, the reservoir part of the base course would have to be about 180 mm deep (33% void space).

Pervious paving can be applied on areas with light (or no) vehicle traffic (e.g. driveways, shoulders of roadways, sidewalks, overflow parking areas).

Figure 7-19 provides an example of how pervious paving options for roadways can reduce runoff volume.

Since pervious paving effectively reduces the impervious coverage on lots or road right-of-ways, applying pervious paving can also improve the effectiveness of infiltration facilities (by reducing the concentration of runoff discharged into these facilities).

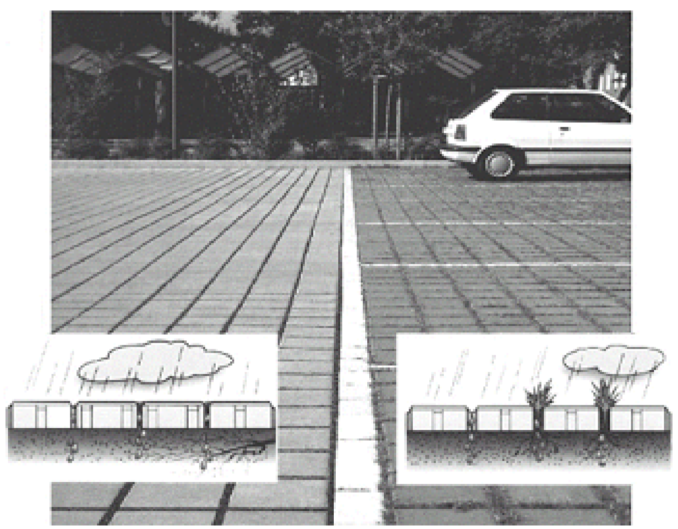


Figure 7-18 Pervious Pavers

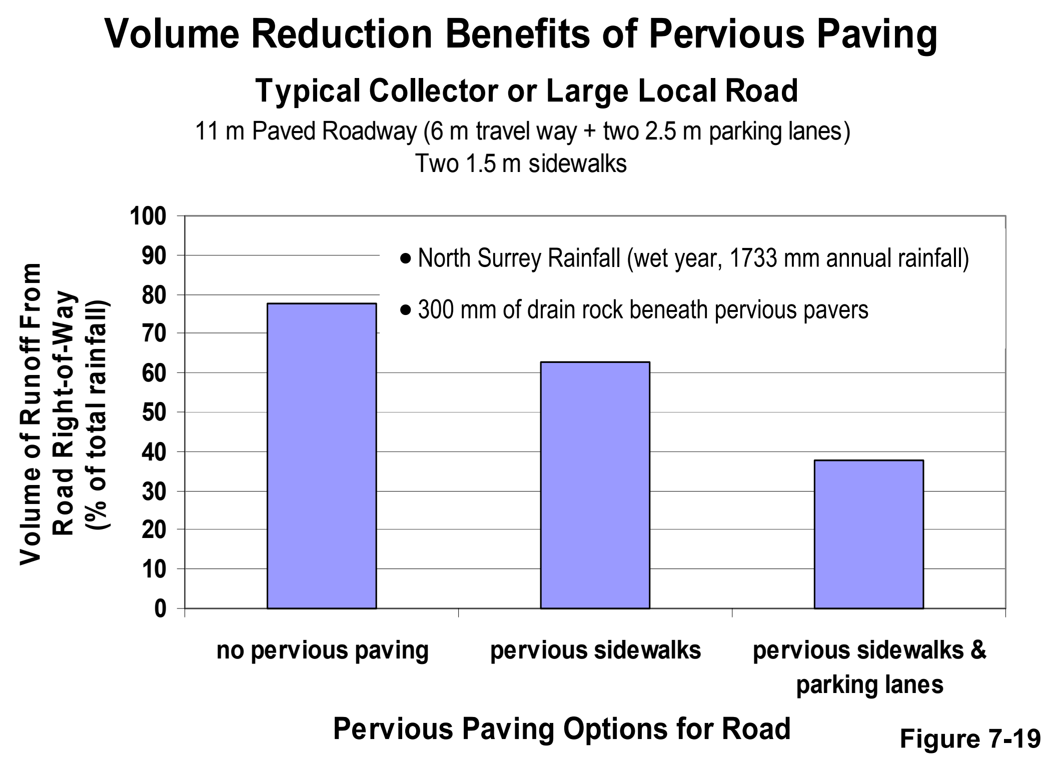


Figure 7-19

Pervious Decks

Runoff from decks or patios can be virtually eliminated by using wood decks with space between the boards (see Figure 7-20) rather than impervious surfaces such as concrete.

Rainfall hitting a spaced wood deck flows to the ground below, and provided there is a reasonable depth of absorbent soil beneath the deck, runoff from the deck is eliminated.

This is an example of a simple, well-known, site design strategy that can effectively reduce impervious coverage and promote infiltration.

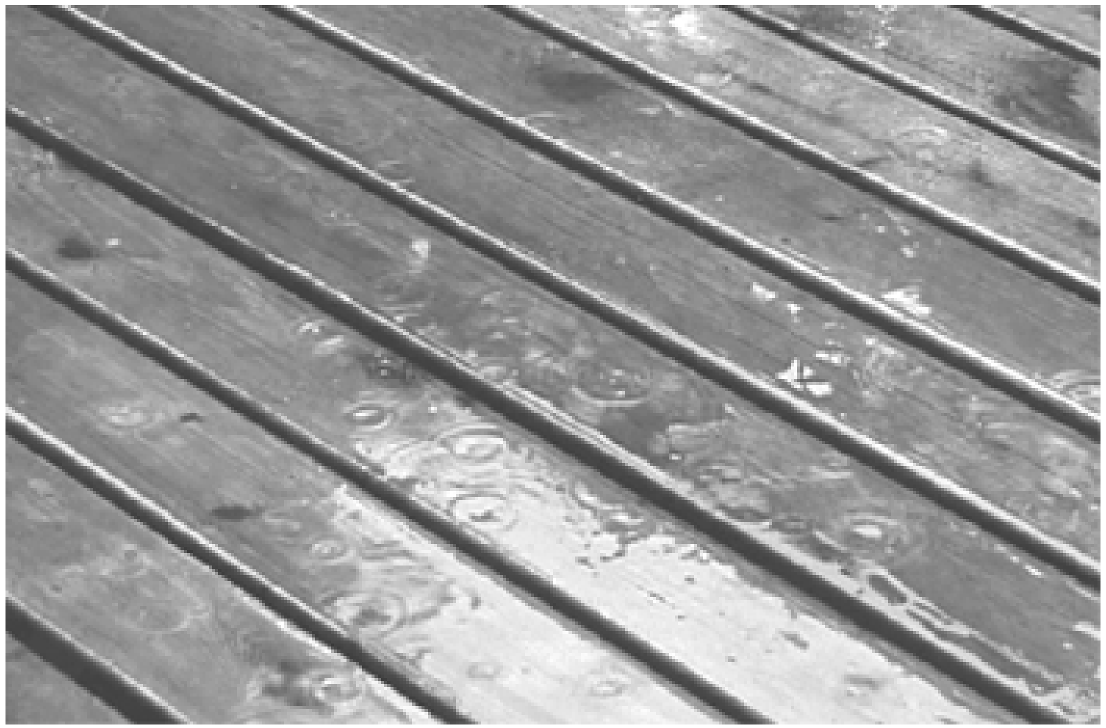


Figure 7-20 Pervious Decks

Applying Combinations of Infiltration Strategies

Figure 7-21 illustrates an example of the installation of selected infiltration techniques on a typical single-family lot, where the performance target is to capture and infiltrate 60 mm of rainfall per day in order to provide both rainfall capture and runoff control in an on-parcel system.

- Roof drain leaders outfall through a debris catcher to an array of infiltration chambers (see Figures 7-7a and 7-7b) in the front lawn. In order to infiltrate the runoff from the 280 m^2 roof, a 7.6 m x 6 m infiltration areas is provided. This could be entirely in the front yard, or could be split over various locations in the yard based on soil characteristics and landscaping objectives.
- The infiltrator chambers have an overflow pipe connected to the street storm drain system that allows rainfall events that exceed the storage capacity to overflow.
- The plan also shows an interceptor perforated drain along the downstream property boundary. This is shown as an illustration only. It could be installed as required on lots with steep slopes or seepage problems to remove surface water and shallow interflow and deliver it to the storm drain system. Ideally, there should be at least 9 m between the infiltration chamber and the perforated drain. This would provide an approximately 30-day delay between the time that water is absorbed as interflow and the time it is removed by the perforated drain. The 30-day delay is based on a moderate 12.5 mm/h infiltration and interflow rate. Delays between infiltration chamber and footing drains would follow a similar pattern, where each foot of interflow distance represents a day or more of delay.
- The bulk of the site is maintained with absorbent soils. Special care is taken to ensure that the top 300 mm of soil are highly absorbent, by avoiding compaction and ensuring high organic matter content.
- Driveway and surface paving is shown as permeable pavers, with a reservoir base course. This ensures that rainfall landing on the driveway is stored underground and allowed to soak into the underlying soils.
- The rear outdoor living area is a spaced wood deck over absorbent ground. This allows rainfall to bypass the deck and infiltrate into the ground below. See Figure 7-20 for details.
- Reducing the building roof area on the site would reduce the amount of infiltration chamber area required.

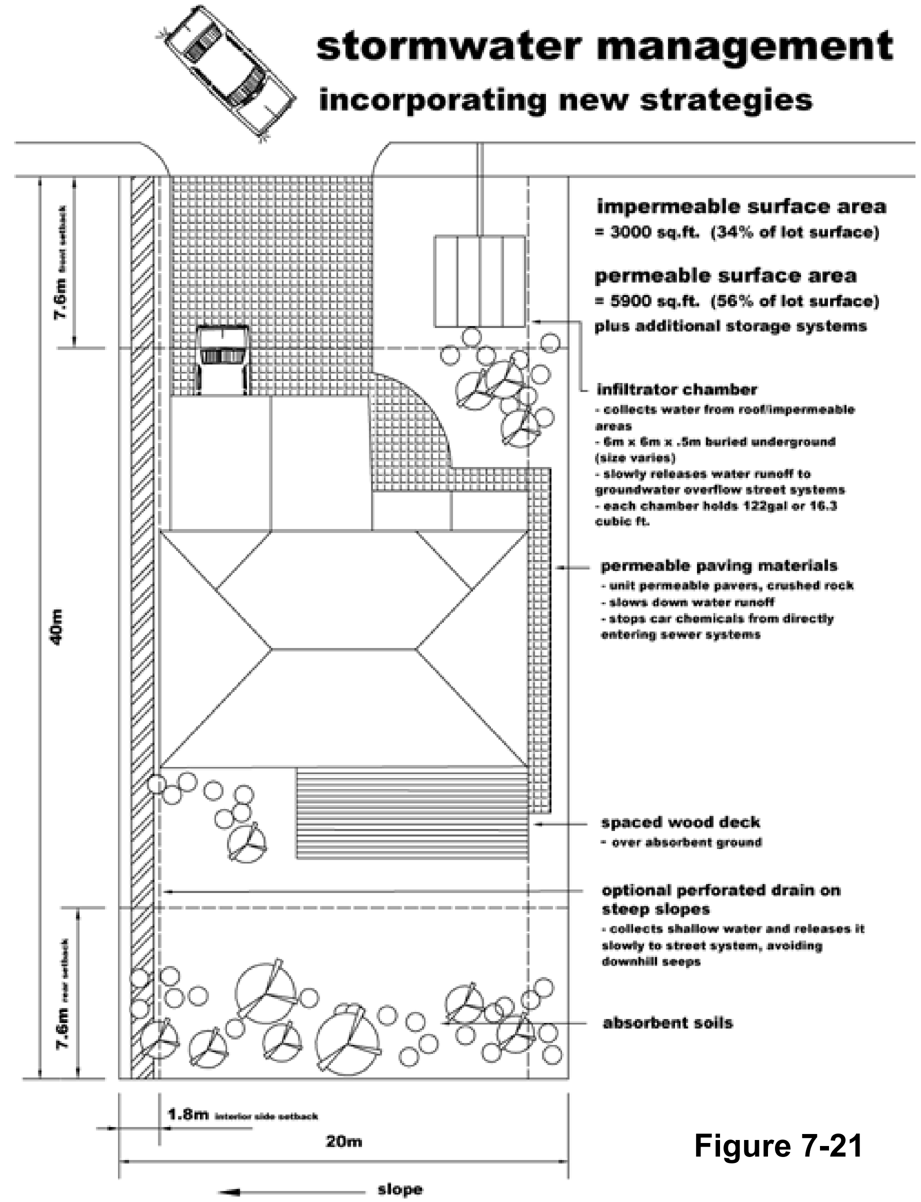


Figure 7-21

Infiltration Strategies for Land Uses with High Levels of Surface Parking

Figure 7-22 shows an example of infiltration strategies for a typical commercial land use with extensive surface parking areas. This Figure shows how a combination of swales with infiltration trenches and bioretention areas could be integrated into parking lot design to infiltrate runoff from rooftops and paved surfaces.

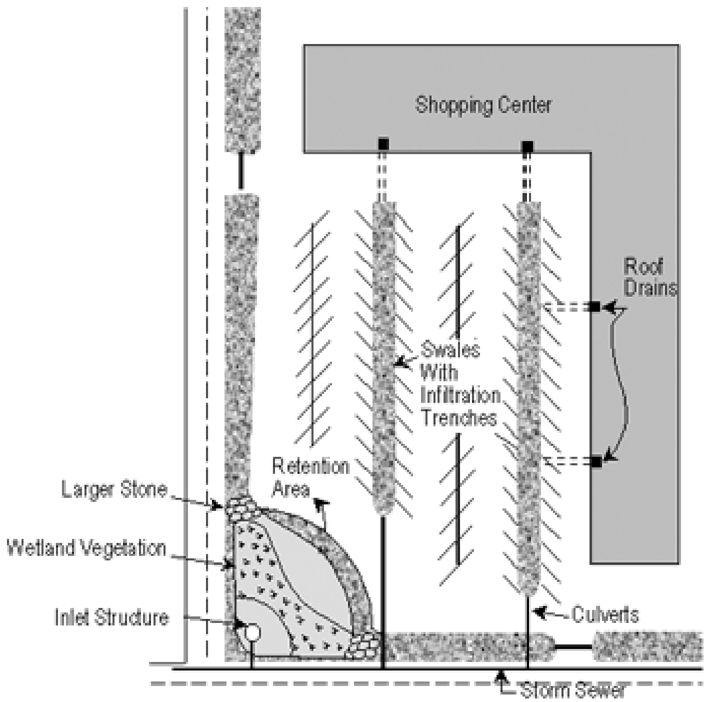


Figure 7-22 Designing Parking Lots that Infiltrate

Cost Implications of Infiltration Facilities

The costs of infiltration facilities are highly variable and depend on site-specific conditions such as soil type, topography, the scale of installation, and infiltration facility design. Typical installation costs for infiltration facilities range from about \$30 - \$170 per m^2.

The operation and maintenance requirements for surface facilities are mainly aesthetic (e.g. landscape maintenance). Annual operation and maintenance costs for surface infiltration facilities are typically in the range of 5-10% of capital costs.

Operation and maintenance requirements for sub-surface facilities are less frequent but can be more costly (e.g. periodic cleaning of soakaway trenches). Annual operation and maintenance costs for sub-surface infiltration facilities are typically in the range of 5-20% of capital costs.

Pervious Paving Costs

The cost of installing of pervious paving is typically in the range of \$20 - \$30 per m^2, depending on the design and site conditions. This is significantly more expensive than conventional paving (approximately \$5 - \$10 per m^2). Also, the operation and maintenance costs associated with vacuum sweeping may be substantial if a community does not already have the necessary equipment.

Design and Construction Tips for Infiltration Facilities

- Site-specific percolation tests should be carried out (ideally under saturated soil conditions) to determine the hydraulic conductivity of soils on a development site, and to identify suitable infiltration areas. Percolation tests should be performed at the depth of proposed infiltration facilities.
- Infiltration facility sites should be protected during construction from compaction and sedimentation, by pre-identifying and fencing, or other means. Inadvertent compaction should be removed by ripping or scarifying the site prior to installation of infiltration facilities.
- Infiltration facilities should be placed over undisturbed or lightly compacted ground (about 80% modified proctor density) to maximize exfiltration of rainfall into the underlying subsoil.
- Adequate sediment and erosion control during construction is essential to prevent clogging of infiltration facilities and underlying soils.
- Pipes leading to infiltration facilities should be fitted with debris catchers and cleanouts to minimize the movement of sediment and debris into the facilities. This is particularly important for sub-surface infiltration facilities.
- Infiltration facilities should be designed with pathways to allow overflow to escape to downstream watercourses via a storm drain system or overland flow.

Tips for Bioretention Facilities

- Low points of bioretention facilities should be planted with flood-tolerant plants.
- Higher areas should be planted with streamside or upland species. Examples of appropriate bioretention plants are shown below:

Frequency of Flooding	Botanical Name	Common Name
Winter standing water	Juncus spp.	Rush
Occasional standing water	Carex spp.	Sedge
Rare flooding	Spiraea douglasii	Hardhack
No flooding	Rosa spp.	Shrub rose

  These plants would work best in coastal climates, but may also be used in other parts of the province. Appropriate plant species will vary across the province depending on biogeoclimatic zone.
- Soils in bioretention areas should have the characteristics of absorbent soils, discussed in Section 7-3.
- Bioretention facilities should be constructed in the dry season whenever possible, or they should be totally isolated from flows during construction, to protect other parts of the drainage catchment form sedimentation.
- In areas where soils are relatively impermeable, bioretention facilities can be designed with a sub-drain to slowly remove water that infiltrates through the absorbent soil layer. This filters out sediments and many pollutants.

Tips for Pervious Pavers

- Pervious paving systems are at risk of being plugged by silt or organic debris that washes onto the surface layer. To avoid this risk, careful attention should be paid to protecting the pervious paving from sedimentation during construction. In addition, most pervious pavement systems are designed with a high factor of safety for permeability e.g. often the permeability at time of construction is 10 times that required for the successful performance of the pavement (i.e. a Factor Of Safety of 10).
- The pervious paving system includes a special base course under the paving designed to hold the stormwater until it has time to soak into the ground below. This 'reservoir' base course is often made of fractured drain rock (railway ballast) that has about 33% void. The depth of the base course is designed with the storage capacity for stormwater as one consideration, with the surface live load and bearing capacity of the underlying soils as other factors. Generally, the deeper the base course, the more stormwater holding capacity and the greater the structural strength. Slope on the pervious pavers should be between 1% and 6%. Calculation of the reservoir capacity should consider any drainage areas flowing to the pavement.
- Pervious paving should not be used on any stormwater quality 'hot spot' where surface contaminants may be concentrated and enter the groundwater (e.g. gas stations, wrecking yard, fleet storage yards, or other sites that store hazardous materials).
- A vertical pipe inlet should be installed so that the reservoir base course overflows to a storm drain when full.

Operation and Maintenance Tips for Infiltration Facilities

- Sediment and debris must be regularly removed from debris catchers and cleanouts.
- Periodic cleaning of infiltration facilities will likely be required to remove accumulated sediment and maintain hydraulic performance.

Tips for Bioretention Facilities

- Provisions for dry season watering of plants in bioretention facilities is essential, especially in the plant establishment period.
- Normal landscape maintenance, with an emphasis on minimum inputs of fertilizer and integrated pest management is appropriate.

Tips for Pervious Pavers

- Where pervious paving is used, regular street sweeping with vacuum and brush machinery is needed to remove surface sediment and organics that may enter the cracks and reduce permeability.
- Low traffic areas (e.g. roadway medians) may experience some weed growth in the cracks (which is a problem for any paved surface). Steam-based weeding systems are available to efficiently manage weed growth without use of herbicides.
- Snow clearing of properly installed pervious pavements can be achieved with standard equipment. Following the manufacturer's design specifications should eliminate any significant freeze-thaw issues.

7.6 Type 3 Source Control - Green Roofs

Replacing impervious rooftops with green roofs can significantly reduce the volume and rate of runoff from building lots. A layer of absorbent soil and vegetation on top of building and parkade rooftops can retain rainfall and allow it to evaporate or transpire. The runoff from a green roof passes through the absorbent soil layer to an underdrain layer (there is no surface runoff), and thereby attenuates peak runoff rates.

Green roofs are classed into two categories: *extensive* green roofs which typically have a shallow soil profile of 20 to 100 mm and support mosses, grasses and sedums; and *intensive* green roofs with soil depths greater than 100 mm able to support substantial vegetation (shrubs, trees, etc.). Intensive green roofs are typically landscaped features that require more maintenance than extensive green roofs.

Green roofs are common in many parts of Europe and are becoming more common in North America. They are often applied for reasons other than stormwater management; engineered green roofs may also provide heating or cooling savings by insulating buildings, as well as aesthetic benefits, air quality benefits, and reductions in the 'urban heat island' effect.

Figure 7-23 shows a lightweight extensive green roof on an airport building. Figure 7-24 shows an example cross-section of an intensive green roof over a parking garage.

Figure 7-23 Lightweight Extensive Green Roof

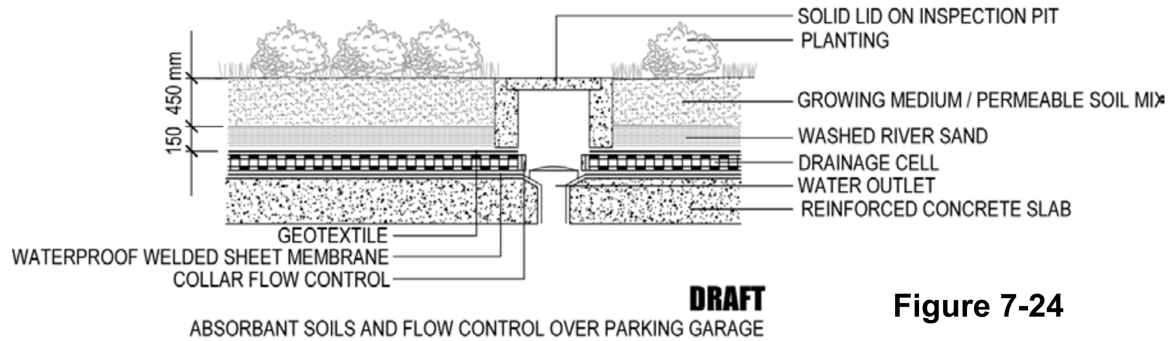


Figure 7-24

The Effectiveness of Green Roofs under Different Rainfall Conditions

Figure 7-25 shows that green roofs provide more significant reduction in runoff volume where (and when) total annual rainfall is lower. As total rainfall decreases, a greater percentage of total rainfall becomes evapotranspiration.

Green roofs would be most effective at reducing runoff volumes in drier parts of the province, and would be more effective in drier years as opposed to wet years.

In terms of reducing runoff volume, extensive green roofs can be almost as effective as intensive green roofs.

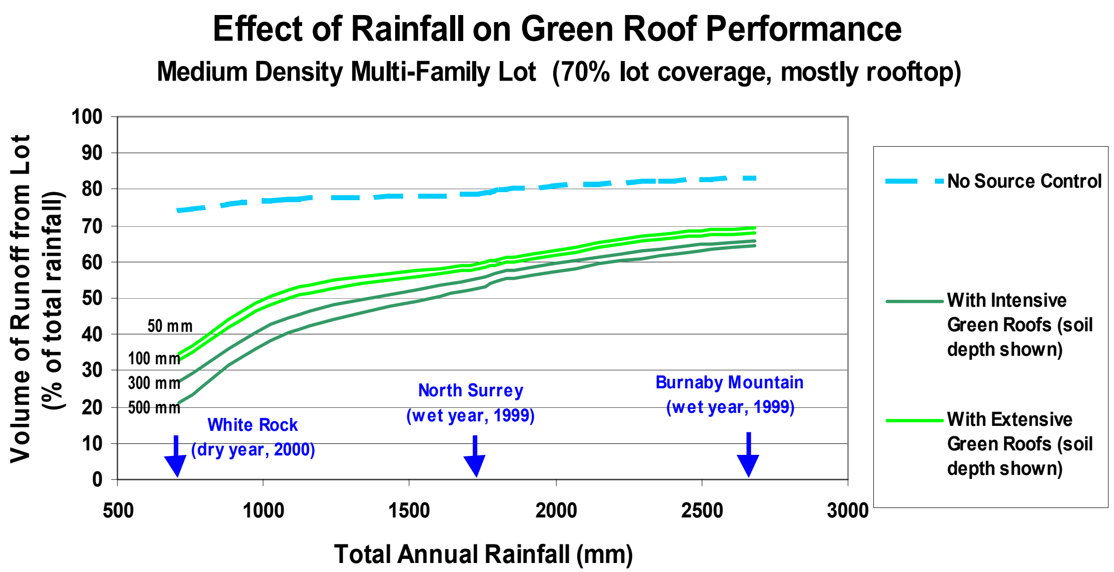


Figure 7-25

The Importance of Green Roof Soil Depth

Increasing the depth of absorbent soil increases the retention capacity of green roofs. This decreases the volume and rate of green roof runoff, as shown in Figures 7-26a and 7-26b.

The volume reduction benefits of increasing green roof soil depth diminish beyond about 70 mm.

In order to maximize the reduction in runoff rates from large, prolonged storms that occur during wet weather periods, intensive green roofs with about 300 mm of soil depth are needed (see Figure 7-26a). Where building structural limitations do not permit this soil depth, green roofs with shallower soil profiles may still be able to achieve significant reductions in runoff rates from long duration wet weather storms that are less extreme and/or in locations with less rainfall.

Significant reduction in runoff rates from short intense storms (i.e. cloudbursts) that occur during dry weather periods can be achieved using extensive green roofs with 100 m of soil depth (see Figure 7-26b).

Figure 7-26b shows the runoff rate from an extremely intense cloudburst (100-year return period) that occurred in White Rock on June 8th, 1999. This event is discussed in more detail in Section 7.8.

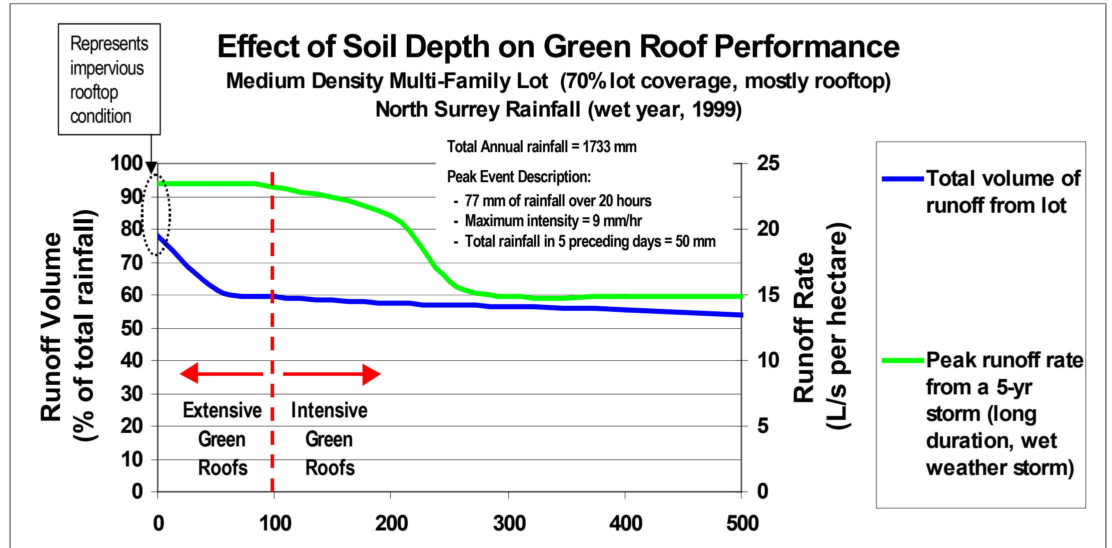


Figure 7-26a

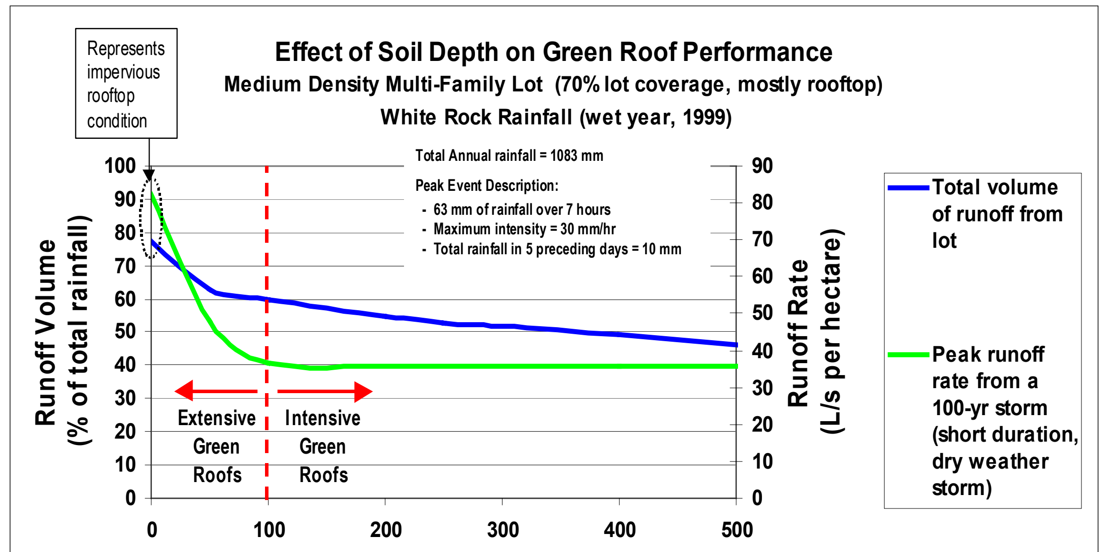


Figure 7-26b

Benefits of Green Roofs for Different Land Uses

Figures 7-27a and 7-27b show that the benefits of green roofs, in terms of reducing runoff volume and rate, is most significant for land uses with high percentages of rooftop coverage, such as high density multi-family or commercial uses (without substantial surface parking). Green roofs have less benefit for single family land uses, and it is likely less feasible to implement green roofs on single family buildings.

The Importance of Parking Type

Note that the type of parking provided for multi-family and commercial land uses has a big impact on the potential benefits of green roofs (green roofs can be applied to parkades but not to surface parking). Figures 7-27a and b show modeling results for multi-family and commercial land uses with limited surface parking (i.e. rooftop coverage is approximately equal to impervious coverage).

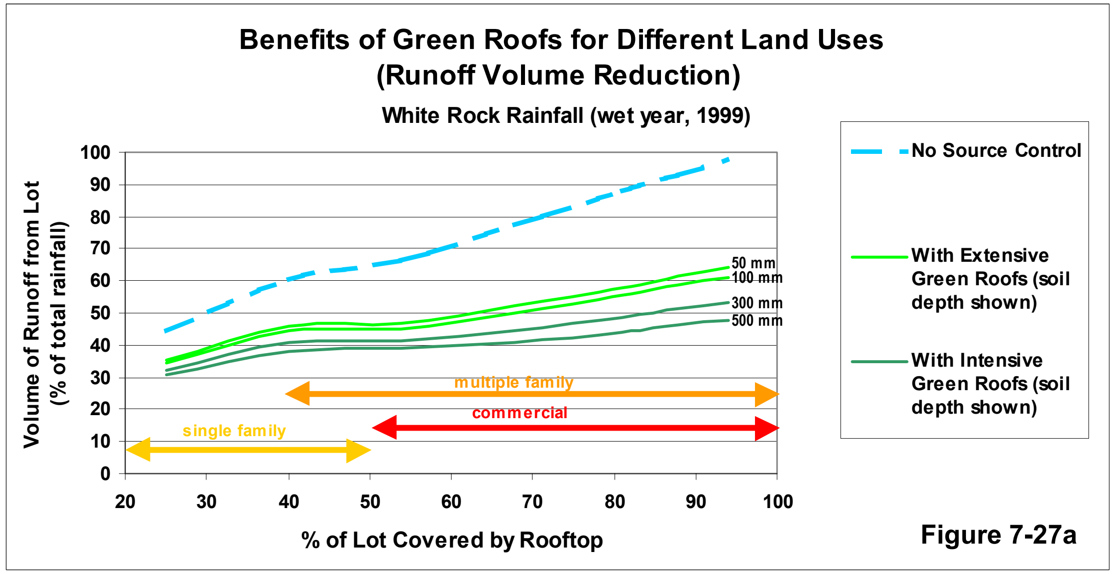


Figure 7-27a

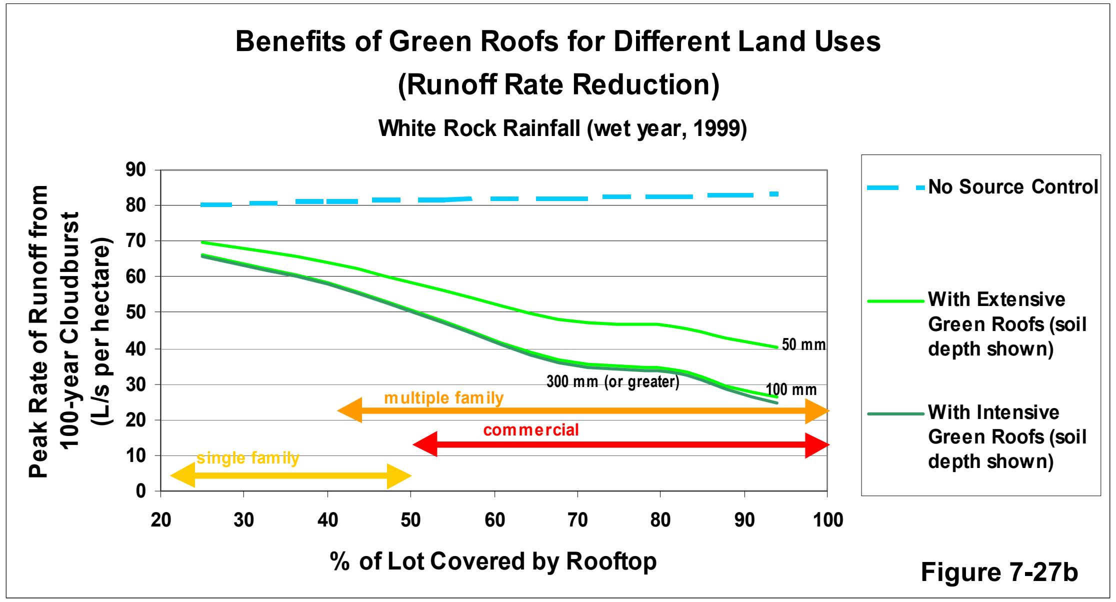


Figure 7-27b

Cost Implications for Green Roofs

The costs of green roofs are highly variable and depend on site-specific conditions, such as the scale of installation, vegetation type and green roof design. Typical installation costs for green roofs infiltration facilities range from about \$60 to \$150 per m^2 (intensive green roofs with 300 mm or more of soil depth are likely to be near the high end of this range). There may also be increased structural costs (although this is not likely a factor for concrete buildings).

Note that the scale of the installation alone can influence the installation cost of green roofs by a factor of 3 or more. This is a direct consequence of the fact that the present market for green roofs in North America is too small to be economically efficient. The cost of installing green roofs in Germany (where a mature green roof industry exists) is typically half the cost of a similar installation in North America.

Annual operation and maintenance costs for green roofs are typically in the range of \$1 to \$2.50 per m^2. Operation and maintenance costs are typically highest in the first year when plants may require establishment watering, weeding, and some replacement.

Design and Construction Tips for Green Roofs

- To reduce structural costs, the design of the absorbent soils over the parking garage lid or roof may use a light weight growing medium. The depth of the soil related to its absorbency may also be fine-tuned for structural load efficiency.
- If light-weight soils are used, they can be subject to wind erosion when they dry out. Appropriate scheduling of soil placement, and temporary protection of the soils until planted or watered should be arranged.
- Roof water should be kept separate from runoff from paved surfaces, which can be polluted with hydrocarbons and heavy metals. Whereas paved surface runoff may require treatment, most green roof runoff will be clean enough to be released directly to storage and receiving waters.
- Proper waterproofing and flashing are essential for green roofs.
- Most green roof systems include a root growth inhibitor to keep roots from invading the waterproof membrane area.
- The most successful green roof systems use drought tolerant plants, and avoid grasses.
- Establishment watering may be required, using either surface standard watering devices, or an automatic irrigation system. Watering requirements will vary based on the green roof system chosen.

Operation and Maintenance Tips for Green Roofs

- Intensive roofs are typically landscaped features that require a higher level of maintenance than extensive green roofs. Through proper plant selection, it may be possible to design extensive green roofs that are essentially self-sustaining and require very little maintenance.
- Irrigation, fertilization and pesticide/herbicide application should be kept to a minimum. Occasional weeding of wind-blown seeded plants may be required.
- Storage in a plastic drainage layer, or equivalent storage volume in drain rock, under the green roof soil can increase the effective rainfall capture and storage volume.
- The drainage outflow from the parking garage lid should be connected to infiltration facilities, in suitable areas of the site off the parking garage, with an overflow to the storm drain system.
- Drain inlets from green roofs will require regular inspection (as is normal practice).
- Normal landscape maintenance techniques should suffice for the absorbent soils on green roofs. Landscaping contractors must be made aware of the need to avoid damaging roof membranes during maintenance activities.

7.7 Type 4 Source Control - Rainwater Re-use

Just as the trees in a forest use a significant portion of rainfall, capturing rainfall for human re-use can play a key role in managing the Water Balance at the site level. The benefits of rainwater re-use go beyond stormwater management (i.e. reducing the volume and rate of runoff from developed areas). Re-use can also reduce the amount of water drawn from reservoirs and reduce the costs of water supply infrastructure.

In general, the most significant reductions in runoff volume can be achieved by capturing and re-using rainwater for indoor greywater type uses, particularly for land uses with high rates of water use. Re-using rainwater for irrigation typically provides less benefit in terms runoff reduction because the demand for irrigation water occurs during the dry weather periods, and most runoff occurs during wet weather periods.

For rainwater re-use on single family residential land uses, rooftop runoff is typically stored in rain barrels (see Figure 7-28a). For re-use on multiple family, commercial or institutional land uses, rooftop runoff is typically stored in cisterns or detention vaults (e.g. see Figure 7-28b).

Rainwater re-use systems can be combined with infiltration facilities as shown schematically in Figure 7-28b. In catchments where maintaining stream base flows is a key objective, first priority may be given to groundwater recharge, with only surplus water applied to in-building re-use.

Figure 7-28a Rainwater Re-use using Rain Barrels

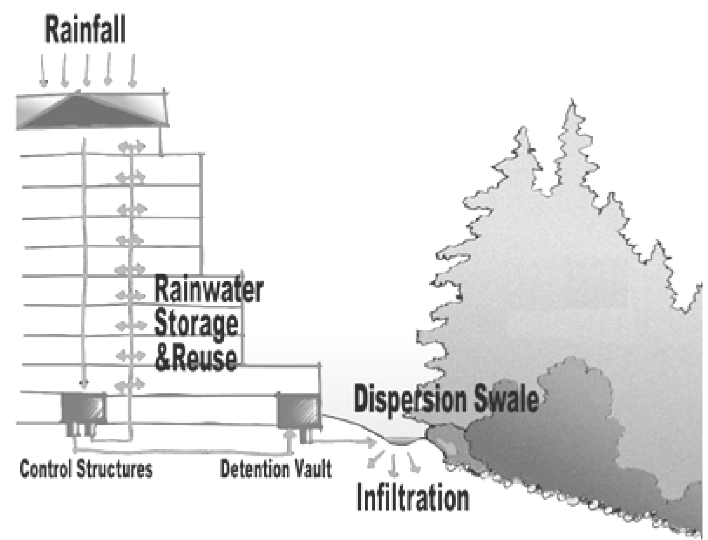


Figure 7-28b Rainwater Re-use using Cisterns

Benefits of Rainwater Re-use for Different Land Uses

Significant reductions in runoff volume can be achieved on high-density residential land uses by capturing and re-using rooftop runoff for toilets and washing machines, as shown in Figure 7-29a. As population density increases, residential water use rates increase, and therefore, the level of reduction in runoff volume that can be achieved through rainwater re-use increases.

The level of volume reduction that can be achieved by re-using rainwater for greywater uses (toilets and washing machines) on commercial land uses varies significantly depending on the type of commercial land use, as shown in Figure 7-29b. Commercial land use types with high water use rates, such as restaurants and bars, can achieve significant runoff reduction, even where density is low (e.g. local commercial).

Note that rainwater re-use for greywater uses is most beneficial on high-coverage land uses where opportunities for infiltration are most limited.

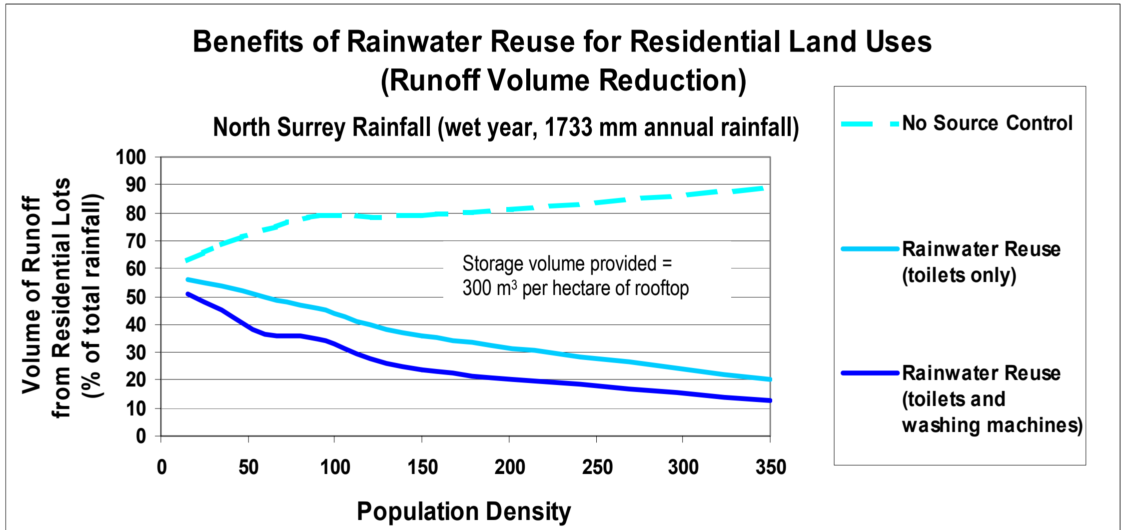


Figure 7-29a

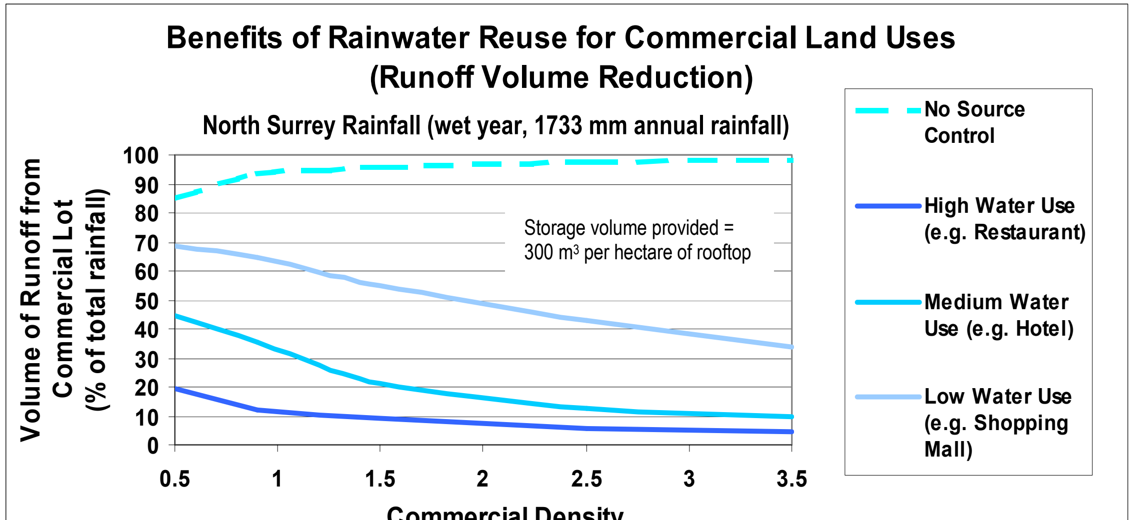


Figure 7-29b

The Impact of Surface Parking

The potential benefits of rainwater re-use are significantly less for land uses that have significant amounts of surface parking, as shown in Figures 7-30. This reflects the assumption that runoff from paved surfaces is less suitable for indoor re-use, primarily due to water quality concerns (although it may be possible with appropriate treatment).

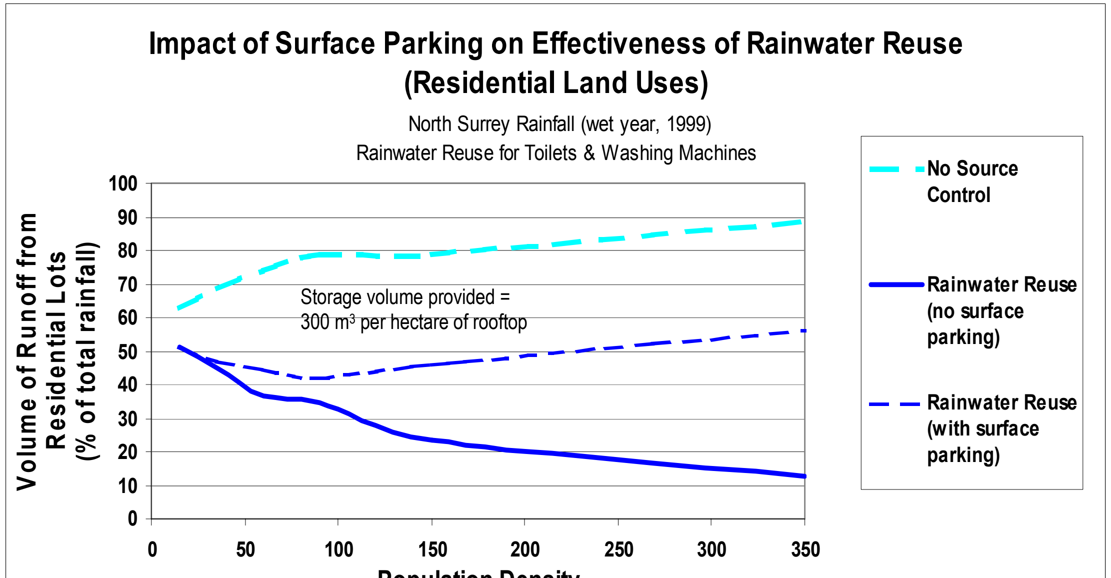


Figure 7-30

The Effectiveness of Rainwater Re-use under Different Rainfall Conditions

Greater reductions in runoff volume can be achieved through rainwater re-use where (and when) total annual rainfall is lower, as shown in Figure 7-31. As total rainfall decreases, water use rates (a function of land use type) become a greater percentage of total rainfall.

In certain situations it may be possible to re-use virtually all rooftop runoff. However, it is important that rainwater re-use systems be designed to ensure that adequate baseflow is maintained in downstream watercourses.

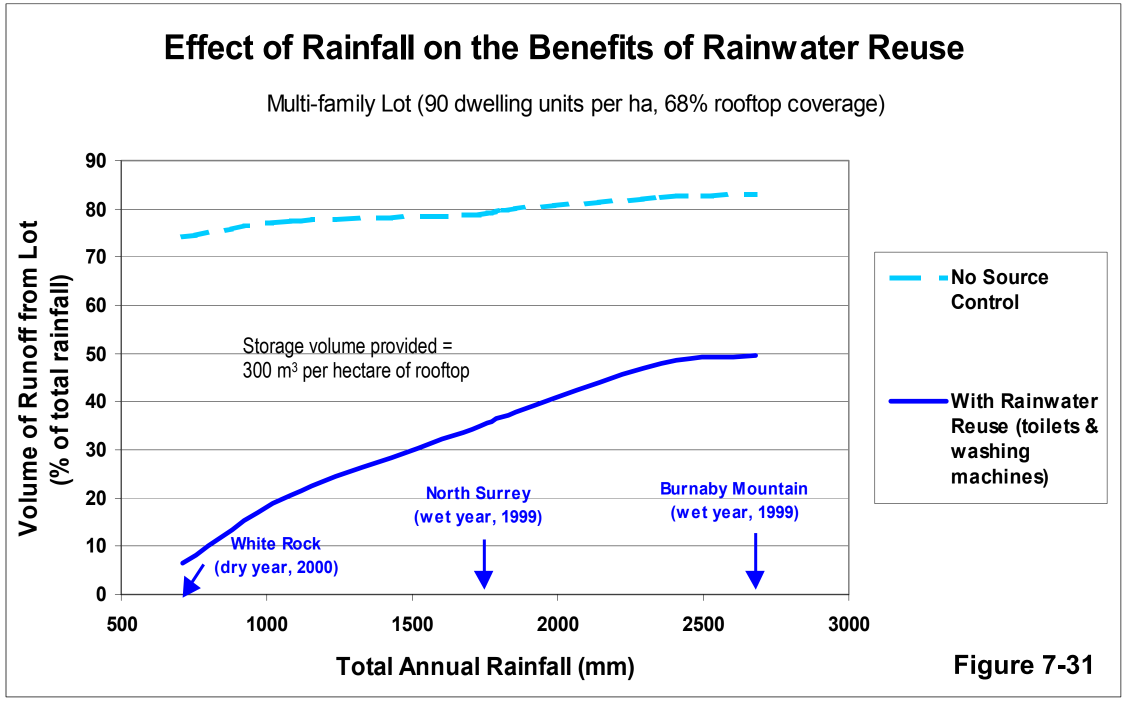


Figure 7-31

Selecting an Appropriate Storage Volume

Increasing storage volume (i.e. size of rain barrels or cisterns) can improve the hydrologic benefits of rainwater re-use, as shown in Figure 7-32. The volume reduction benefits of providing additional storage capacity diminish beyond a relatively low threshold (about 100 m^3 per hectare of rooftop). Beyond this threshold, runoff volume reduction is primarily a function of land use characteristics (e.g. population density, commercial density, land use type and type of parking).

Figure 7-32 also shows that very large storage volumes are needed to achieve any significant reduction in peak runoff rates from extreme rainfall events (e.g. a 5-year winter storm).

Note that this figure is based on Water Balance Model simulations for a very wet year in the GVRD (1733 mm annual rainfall). In locations and/or years with less rainfall, it is likely that the same benefits could be achieved using with less storage volume (and vice versa).

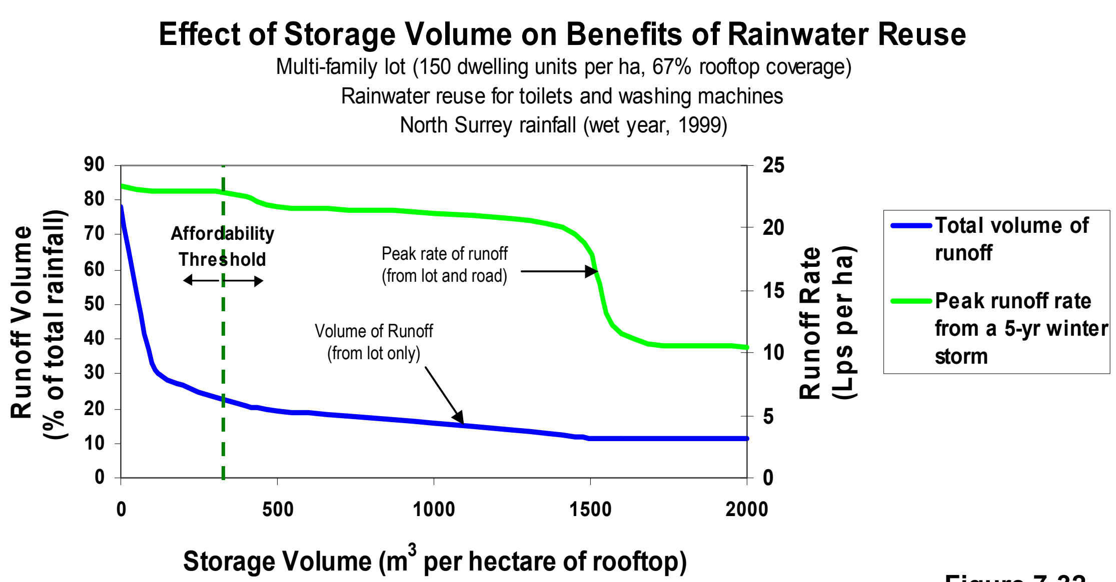


Figure 7-32

Cost Implications of Rainwater Re-use

The design and costs of rainwater re-use systems must be considered in the context of site-specific characteristics, including:

- nature of the development (e.g. water use characteristics, design of individual buildings)
- site-specific rainfall patterns
- characteristics of both stormwater and water supply infrastructure (existing or planned)

Costs implications must be considered at the scale of individual building (e.g. cisterns, additional pipe), as well as at the larger site (or regional) scale (e.g. water use savings, reduction in size of water supply and/or stormwater infrastructure). It is not possible to provide generalized costs estimates for rainwater re-use.

Design and Construction Tips for Rainwater Re-use

- Rainwater re-use systems may be designed to slowly release small amounts of water in order to maintain stream baseflows.
- Rainwater re-use systems in major buildings would require mechanical engineering design.
- There are traditional and evolving new systems for use in single family or small buildings. Some store rainwater right at the eaves, and more traditional systems include rain barrels or plastic vaults with either gravity or pump feed.
- Refer to publications on the subject for details of cistern pre-treatment and dewatering systems. Access for vacuum hose cleaning from a truck is advisable.
- Storage cistern designs are subject to waterproofing and structural engineering.

Operation and Maintenance Tips for Rainwater Re-use

- To reduce contamination of water stored in cisterns, the source of water should generally only be roofs, or other clean sources.
- Occasional cleaning of cisterns may be necessary. This is usually performed by vacuum hose.
- Regular inspection of cisterns is required to ensure that control structures continue to function properly.

7.8 Applying Source Controls to Mitigate Extreme Cloudbursts

One of the anticipated effects of climate change is an increase in the frequency of cloudbursts – high intensity short duration storms - which could cause significant drainage problems.

An extremely intense cloudburst (100 year short duration storm) occurred in White Rock on June 8th, 1999 and caused extensive flood damage. The simulated runoff hydrographs (from a typical multi-family neighbourhood) shown in Figure 7-33 demonstrate how effective the following source control scenarios would be at reducing the runoff from this event:

- **Scenario 1: No Source Control -** All impervious area is directly connected to a storm sewer system and pervious areas are covered by disturbed soil.
- **Scenario 2: Absorbent Landscaping** - Disturbed soil is replaced with 300 mm of absorbent landscaping; peak runoff rate would be reduced by about 27%.
- **Scenario 3: Absorbent Landscaping plus On-Lot Infiltration Facilities** – Same as Scenario 2 except that all lots have bioretention facilities (150 mm of surface ponding on top of 1 m of absorbent soil) covering 10% of lot area; peak runoff rate would be reduced by about 70%.
- **Scenario 4: Absorbent Landscaping plus Intensive Green Roofs -** Same as Scenario 2 except that all residential buildings and parkades have green roofs with 300 mm of soil depth; peak runoff rate would be reduced by about 80%. Note that the same level of runoff rate reduction could be achieved using green roofs with extensive green roofs that have 100 mm of soil depth (see Section 7.6).
- **Scenario 5: Absorbent Landscaping plus Intensive Green Roofs plus On-Street Infiltration Facilities** – Same as Scenario 4 except that all roads have one 3 m wide infiltration swale/trench system (as described in Section 7.5) within road right-of-ways; peak runoff rate would be reduced by about 92%.

This case study shows that source controls can be very effective at reducing runoff rate from cloudbursts, and thus partially mitigating some of the anticipated effects of climate change.

Another anticipated effect of climate change is an increase in the amount of fall/winter rainfall, which will increase total runoff volume. The watershed case studies presented in Chapter 8 show that source controls can also be effective at mitigating this effect of climate change.

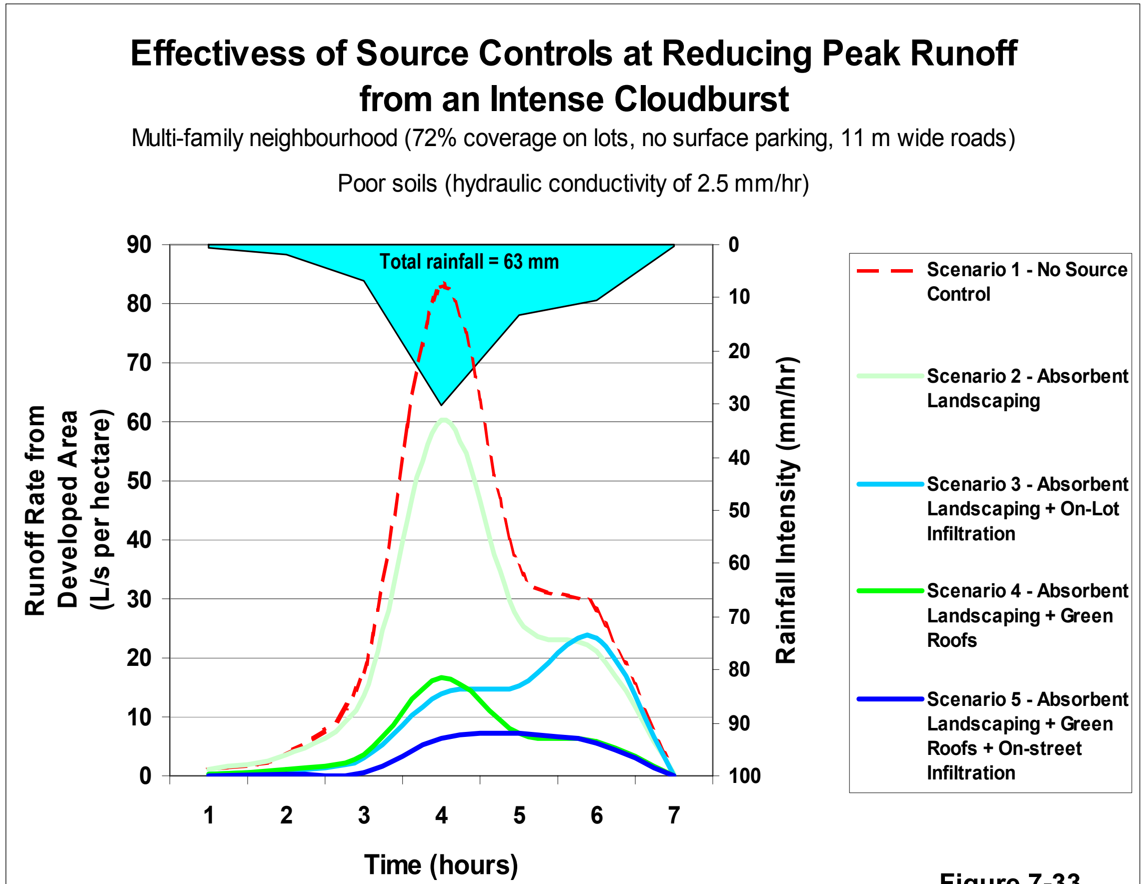


Figure 7-33

7.9 Communicating Performance Targets to Developers

To achieve performance targets, appropriate stormwater management practices must be integrated with site design. For this to happen, performance targets must be clearly communicated to developers in a format that they can apply to the design of stormwater systems at the site level.

Case Study Example: Design Guidelines for Developers

Infiltration has been identified as the most applicable source control option in the City of Chilliwack.

Chilliwack's *Design Guidelines for Stormwater Systems* provide step-by-step procedures for land developers to follow in order to design infiltration and detention systems that meet the City's design criteria for rainfall capture and runoff control. This example shows how to communicate performance targets and design criteria to developers. These Guidelines also specify performance monitoring requirements.

The Design Guidelines consist of the following forms:

- **Form 1 - Development Site Summary Characteristics**
- **Form 2 – Criteria for Absorbent Landscaping**
- **Form 3 – Design of Infiltration Facilities**
- **Form 4 – Design of Detention Facilities**
- **Form 5 – Performance Monitoring Requirements**

These forms are reproduced on the following pages.

City of Chilliwack – Design Guidelines for Stormwater Systems

Procedure for Sizing Infiltration and Detention Facilities

Form 1 – Development Site Summary Characteristics

Total development site area:

- A_{total} = _______ ha

Minimum hydraulic conductivity of on-site soils (from on-site percolation testing):

- **H** = _______ mm/hr

Total impervious area on development parcels (excluding green roofs):

- $IA_{on\text{-}lot}$ = _______ ha

Total impervious area on roads (excluding pervious paving):

- IA_{road} = _______ ha

Total impervious area on development site

- $IA_{total} = IA_{on\text{-}lot} + IA_{road}$ = _______ha

Total pervious area on development site

- $PA_{total} = A_{total} – IA_{total}$ = _______ha

Site and Key Plan

Form 2 - Criteria for Absorbent Landscaping

The design guidelines presented in Forms 3 and 4 are based on *impervious areas only*.

On-site pervious areas must be 'self-mitigating' (i.e. meet rainfall capture and runoff control targets). In order to achieve this:

- ❑ **Minimum depth of absorbent soil* for on-site pervious area = 300 mm**

  * must meet *BC Landscape Standard* for medium or better landscape. The range of acceptable soil textures is shown below:

Lightest Soil:	Heaviest Soil:	Typical Design Soil:
Sand 90%	Sand 55%	Sand 75%
Silt/Clay 5%	Silt/Clay 25%	Silt/Clay 15%
Organic Matter 5%	Organic Matter 20%	Organic Matter 10%

Form 3 – Design of Infiltration Facilities

Rainfall capture criteria: capture and infiltrate 300 m^3 of rainfall per day per impervious hectare

Infiltration facilities are to be provided as follows:

- On individual development parcels to capture runoff from rooftops and parking areas (e.g. by means of on-lot soakaways)
- Within road right-of ways to capture runoff from paved roadway (e.g. by means of roadside infiltration trenches)

Sizing Infiltration Facilities (applies for both development parcels(1) and roads)

Step 1) Select Design Depth, **D**

D = _____ m

D = distance from bottom of infiltration facility to the maximum water level (the point where overflow occurs)

Step 2) Select Facility Type and Determine Effective Depth, **D_{eff}**

D_{eff} = [D x VS] = _____m

VS = void space storage, the ratio of the volume of water retained per unit volume of the infiltration facility. Typical values for different types of infiltration facilities are shown in Table B on the following page.

Step 3) Determine Minimum Footprint Area, **A** *(i.e. bottom area) needed to meet rainfall capture target*

A_{min} = [(____ m^2, *from Table A*) *x* (_____ m^2 of IA served)] / 1000

A = the total area (in plan view) covered by the infiltration facility

(1) A typical facility size may be developed for multiple lots that have similar soil characteristics and similar amounts of IA.

Conveyance of Overflow from Infiltration Facilities

Overflow from infiltration facilities (on-lot and on-road) should be conveyed into runoff control facilities (refer to Form 3) via a stormwater drainage system, most likely within the road ROW. Road drainage may consist of:

a) a perforated pipe at the top of an infiltration trench
b) a catch basin connected to storm sewer pipe
c) a surface swale

Providing Runoff Control Storage in Infiltration Facilities (Optional)

Increasing the dimensions of infiltration facilities (whether they are on on-lot or on-road above the minimum requirement (i.e. $A > A_{min}$) reduces the storage volume that must be provided in off-lot runoff control facilities (refer to Form 4).

The amount of runoff control volume provided by on-lot and on-road facilities can be calculated as follows:

- **$V_{on\text{-}site}$ = [**Facility depth **(D)** x Footprint Area **(A_{actual})] – [D** x **A_{min}] =** ____ m^3

The total runoff control volume provided by all on-lot and on-road facilities **(Σ $V_{on\text{-}site}$)** can then be subtracted from community detention requirements (refer to Form 4).

Table A - Required Footprint Area (in m²) for Infiltration Facilities (per 1000 m² of impervious area served by the facility)

Effective Depth of Infiltration Facility[1]	Hydraulic Conductivity of On-Site Soils[2] (mm per hour)				
	5	10	25	50	> 100
0.25 m	175	125	75	50	30
0.5 m	140	90	55	40	25
1.0 m	120	70	40	30	20
1.5 m	110	65	35	25	15
2.0 m	100	60	30	20	15

[1] Depths for rainfall capture facilities must be selected based on site-specific characteristics and constraints. The feasible depth may be governed by physical constraints (e.g. depth to the water table or to bedrock). The effective depth is equal to total depth multiplied by void space, and will depend on facility type (see Table A).

[2] Based on percolation tests from the development site (ideally carried out under saturated conditions, following periods of extended rainfall). Sizing of rainfall capture facilities should normally be based on the *minimum* percolation test results from a development site. Tests should be performed at the locations and depths of proposed infiltration facilities.

Table B - Typical Void Space Storage Values (VS)

Infiltration Facility Type[3]	Storage Medium	Typical Void Space (VS)
Retention ponds	Open	1.0
Bioretention facilities	Absorbent soil	0.2
Soakaways (infiltration trenches/pits)	Gravel or drain rock	0.33
Infiltration Chambers	Sub-surface chambers & surrounding gravel	0.55

[3] Infiltration facilities may be a combination of types. In this case, effective depth of the facility is the sum of total depth multiplied by VS, for each layer. For example, a bioretention facility with 0.3 m of ponding depth on top of a 1.5 m absorbent soil layer would have effective depth, D_{eff} = [1.5 m x 0.2] + [0.3 m x 1] = 0.6 m.

Form 4 – Design of Detention Facilities

Runoff Control Criteria: Detain an additional 300 m^3 of rainfall per impervious hectare and release at 1 Lps per hectare (total site area)

Designing Community Detention Facilities

The storage volume that must be provided in community detention storage facilities (e.g. wet or dry detention ponds) is:

- ❑ $V_{off\text{-}site} = [IA_{total} \times 300\ m^3/ha] - [\Sigma\ V_{on\text{-}site}] =$ _____ m^3

The rate of release from detention storage is:

- ❑ $R = A_{total} \times 1$ L/s per ha = _____ L/s

Form 5 – Performance Monitoring Requirements

Target: to provide an accurate picture of how rainfall moves through the stormwater system to enable future evaluation of system performance and optimization of design criteria

) Monitoring within Development Sites

The City will select certain development sites as demonstration projects and develop a comprehensive monitoring plan for these sites. The costs of installation and continued operation of monitoring equipment will be funded through Development Cost Charges.

The purpose of monitoring within development sites is to evaluate and refine the City's design criteria and customize criteria for different zones within Chilliwack. In order to properly evaluate the performance of a stormwater system, the Water Balance of the development site served by that system must be defined. Therefore, it is important to monitor a representative sample from each component of the stormwater system, including:

- **On-Lot Rainfall Capture Facility monitoring** – Monitor water levels and overflow from at least one on-lot rainfall capture facility.
  - for surface facilities - install a compound weir, water level sensor and data logger at the overflow point
  - for sub-surface facilities – install a piezometer (to measure water level) and data logger
- **Road Infiltration/Drainage monitoring** – Monitor the road drainage flow from at least one section of road. This may include more than one drainage path (e.g. perforated pipe plus catch basins connected to a storm sewer).
  - install a compound weir, water level sensor, and data logger in a manhole at the downstream end of the road
- **Runoff Control Facility monitoring** – Monitor water levels and outflow from detention facilities (e.g. community detention ponds)
  - install a compound weir, water level sensor and data logger in the outlet control manhole

B) Monitoring at the Catchment Level

The City will install streamflow and TSS monitoring stations downstream of catchments where land development is occurring to verify that development practices are adequately protecting downstream hydrology and water quality. The costs of installation and continued operation of monitoring equipment will be funded through Development Cost Charges.

Refer to Figure 5-8, in Chapter 5 for illustration of a comprehensive monitoring program.