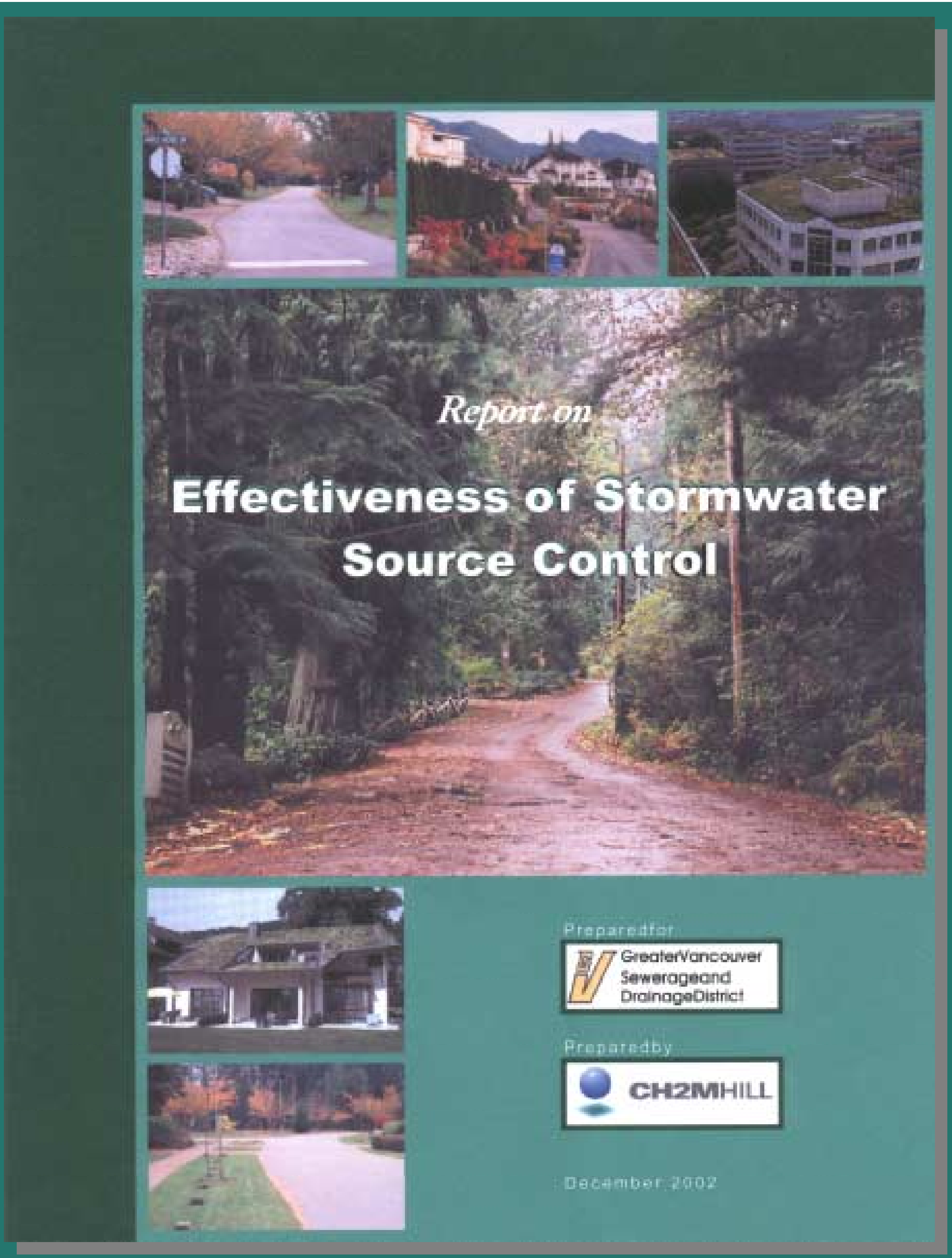

Report on

Effectiveness of Stormwater Source Control

Prepared for

Greater Vancouver
Sewerage and
Drainage District

Prepared by

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December 2002

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APPENDIX A STILL CREEK CASE STUDY

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Section 1 – Context and Overview

1.1 The Source of Stormwater Related Problems

Land development alters the natural water balance. When natural vegetation and soils are replaced with roads and buildings, less rainfall infiltrates into the ground, less gets taken up by vegetation, and *more becomes surface runoff*.

Traditional ditch and pipe systems have been designed to remove runoff from impervious surfaces as quickly as possible, and deliver it to receiving waters. Stormwater runoff arrives at the receiving waters much faster and in greater volume than under natural conditions.

This causes channel erosion, flooding, loss of aquatic habitat, and water quality degradation. If these impacts are not avoided, there can be litigation, as well as financial and political implications.

1.2 The Purpose of Source Control

The purpose of *stormwater source control* is to capture rainfall at the source (on building lots or within road right-of-ways) and return it to natural hydrologic pathways - infiltration and evapotranspiration - or reuse it at the source. Source control creates *hydraulic disconnects* between impervious surfaces and watercourses (or stormdrains), thus reducing the volume and rate of surface runoff.

Source control is at the heart of a significant change in approach to stormwater management:

- **from a reactive approach** that only 'deals with the consequences' of land use change, often at great public expense.
- **to a proactive approach** that also 'eliminates the root cause of problems' by reducing the volume and rate of runoff at the source.

Figure 1-1 illustrates the proactive approach. The focus of stormwater source control is on runoff volume reduction (rainfall capture), but also has significant runoff rate control benefits (runoff control and flood risk management). This report demonstrates that source controls can be very effective at reducing runoff volumes and at reducing peak runoff rates from relatively large storms (e.g. 5-yr storms) or from very intense short duration storms (e.g. 100-yr cloudburst). However, the ability of source controls to reduce peak runoff rates from very large, long duration storms (e.g. a 100-yr winter storm) is limited. Even with source controls, stormwater systems must be designed to safely convey these events.

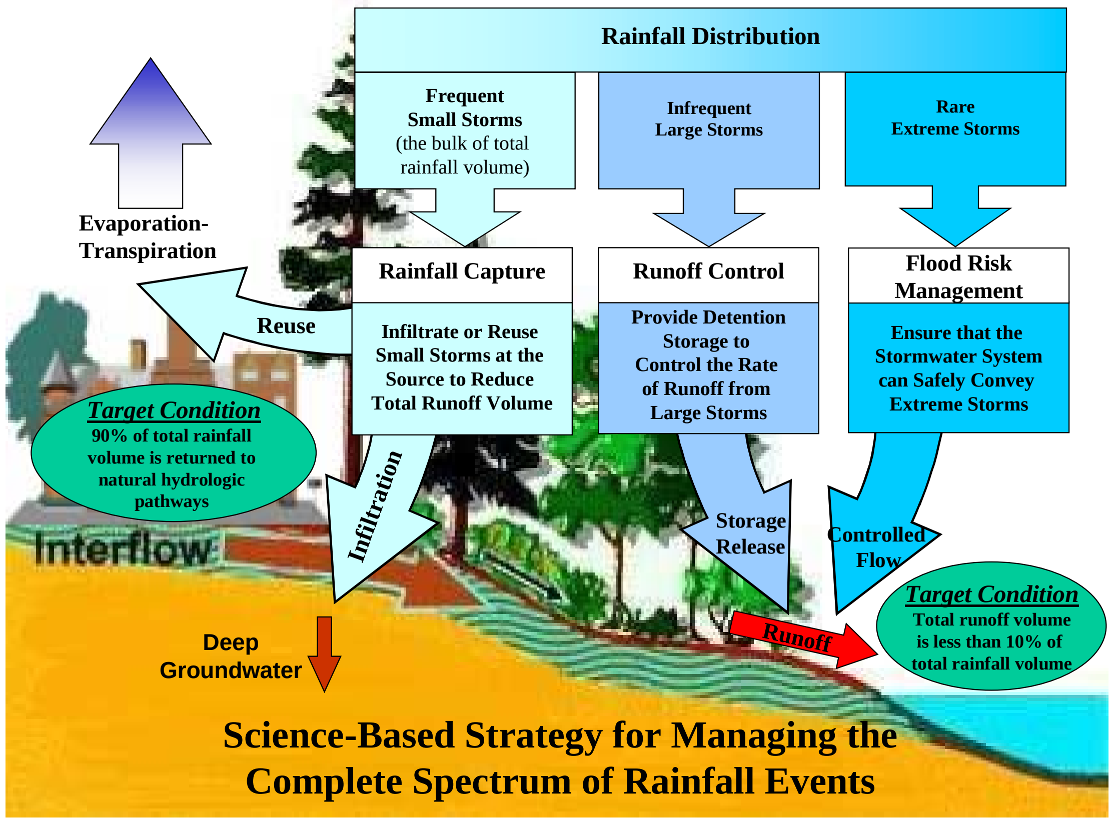


Figure 1-1

Target Condition for Water Balance Management

Recent research shows that that stormwater related impacts typically start to occur once the impervious percentage of a watershed reaches about 10%. Therefore, an appropriate Performance Target for a healthy watershed is to **limit total runoff volume to 10% (or less) of total rainfall volume**, which means that **90% of rainfall must be returned to natural hydrologic pathways** (i.e. infiltration and evapo-transpiration) or reused at the source.

1.3 The Need for Source Controls in the GVRD

The Greater Vancouver Region is projected to experience significant population growth over the next 50 years (possible doubling). This will lead to densification of existing land uses and some development of existing natural areas, which will increase the volume and rate of stormwater runoff discharged into watercourses in the GVRD. The increased runoff is likely to result in:

- ☐ the need for upgrades and/or repairs to drainage infrastructure in many parts of the GVRD.
- ☐ further degradation of aquatic ecosystems in urban watersheds.
- ☐ further water quality deterioration (also a result of population increase).
- ☐ increased flooding risk to life and property.

The effects of climate change are likely to exacerbate these impacts. The amount of fall/winter rainfall in the GVRD is anticipated to increase over the next 50 years due to climate change, which will further increase runoff. Climate change is also expected to increase the frequency of high-intensity rainfall events (cloudbursts), thus increasing the potential for flash flooding.

The impacts of increased runoff and more frequent cloudbursts can be avoided by applying stormwater source controls on future development *and* re-development projects in the GVRD. The application of source controls on re-development projects can also support restoration of aquatic ecosystems and decrease flooding risk over time, thus turning a potential problem (the combination of densification and climate change) into an opportunity (watershed restoration).

This report provides guidance for local government staff and developers regarding where and how to implement various source control options.

1.4 Integrating Source Controls into Stormwater Management Plans

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 critical stream reaches**
  - where there are significant resources to be protected and/or restored.
  - where there are drainage problems, such as high flooding risk.
- ☐ **Characterize development pressures on land areas that drain into these critical reaches.**
  - are there plans for new development on 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

Note that the 10% runoff volume target (see Figure 1-1) is 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.

It is also important to realize that maintaining or restoring the ecological health of a watershed will also reduce the source of flooding risk and improve water quality. *Protecting aquatic resources, protecting property, and protecting water quality are complementary objectives.*

1.5 Performance of Stormwater Source Controls

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

- ☐ **Impervious Area Controls**
- ☐ **Absorbent Landscaping**
- ☐ **Infiltration Facilities (on lots and along roads)**
- ☐ **Green Roofs**
- ☐ **Rainwater Reuse**

The focus of the report is on defining the hydrologic performance of each source control category for a range of land use types, soil conditions, rainfall conditions, and source control designs.

For each source control category, the report also provides design guidance and discusses cost implications, operation and maintenance requirements, and water quality benefits.

This information in this report will enable local government staff to:

- ☐ determine what can realistically be achieved through the application of source controls.
- ☐ determine which source control options are worth pursuing.
- ☐ estimate the likely return on investment.

The most appropriate source control options and design features for any given development or re-development site must be evaluated based on site specific conditions, such as soil type, land use type, rainfall, and groundwater characteristics.

1.6 The Importance of a Long Term Vision

It may take many years to achieve the potential benefits of stormwater source control. Therefore, the opportunities for source control application must be considered in the context of a long-term vision (e.g. for watershed restoration) that is shared by all stakeholders. The following components of this report provide a long term perspective on the opportunities for source control:

- ☐ **A 50-year Timeline** – The opportunity to restore degraded watersheds by applying source controls will arise as re-development occurs over time. A 50-year time line is considered when evaluating watershed retrofit case studies. This time line corresponds to a typical re-development cycle.

- ☐ **Watershed Case Studies** – Watershed retrofit scenarios are modeled for three case study watersheds in the GVRD; MacKay Creek (North Vancouver), McKinney Creek (Maple Ridge), and Quibble Creek (Surrey). These case studies demonstrate the potential for restoring watershed health over 50-year timeline, as existing land uses re-develop and various combinations of source controls are applied.

- ☐ **Climate Scenarios** – The watershed retrofit scenarios also consider the long term effects of climate change. 50-year climate change scenarios are applied to the case studies to quantify the anticipated hydrologic impacts of climate change, including the effect on source control performance.

1.7 Modeling Source Control Performance

The commonly used hydrologic modelling 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)** was developed to simulate the hydrologic performance of stormwater source controls. 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** (hourly) and **evapo-transpiration data** (daily) over a long period of record (at least a year). Historical rainfall data is modified to create climate change scenarios.
- ☐ **Site design parameters** for each land use type being modelled (e.g. size of roads, 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 certain types of source controls)
    - source control design parameters (e.g. infiltration area, green roof depth, cistern storage volume)
- ☐ **Soils information**, including:
    - surface soil parameters (e.g. maximum water content, vegetation rooting depth)
    - sub-surface soil parameters (e.g. saturated hydraulic conductivity)

The sensitivity of source control performance to any of these model inputs can be tested by comparing modeled scenarios.

1.8 Hydrologic Performance Indicators

The hydrologic effectiveness of stormwater source controls is evaluated relative to the following performance indicators:

- ☐ **Total runoff volume,** which is the primary indicator of impact on aquatic habitat. As the proportion of impervious land area increases, *every rainfall event* produces more surface runoff, which corresponds to greater streamflow velocities. The result is an increase in the frequency of streamflow events that cause stream channel erosion.
- ☐ **Number of times the natural mean annual flood (MAF) is exceeded,** which is another indicator of impact on aquatic habitat. The cross-section of stream channels tend to reach equilibrium with the MAF. When the MAF increases, the stream channel erodes to expand its cross-section.
- ☐ **Peak runoff rate from extreme rainfall events** (e.g. a 5-yr or 100-yr storm), which is an indicator of flooding risk impact on drainage infrastructure. As the peak runoff rates increases it is more likely that drainage infrastructure may not be able to convey peak flows without causing property damage or posing a threat to public safety.

Without source control, land use densification, new development, and climate change will increase all of these indicators. The hydrologic effectiveness of stormwater source controls is measured based on their ability to reduce the magnitude of these indicators. This provides an indication of the potential benefits of source controls for stream health management (the first two indicators), and drainage infrastructure management (the third indicator). However, benefits will depend on watershed specific conditions (e.g. value of aquatic resources, condition of drainage infrastructure).

1.9 The Cost of Source Control

This report 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.

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 be able to reduce the cost of storm sewer pipe needed for a new development project, or avoid the need for costly drainage infrastructure upgrades in watersheds where densification is occurring.

1.10 The Role of the Expert Panel

There is a lack of scientifically defensible data on the long-term effectiveness and benefits of stormwater source controls. The following quotes from the Water Environment Research Foundation (WERF) and the US Environmental Protection Agency (USEPA) highlight this information gap:

- ❑ *"Best management practices (BMP) and sustainable urban drainage systems (SUDS) are becoming more popular as local governments and utilities attempt to find methods to combat the adverse impacts of stormwater. But there has been little systematic research to date on the costs, long-term effectiveness, and ecological impacts of BMP/SUDS. This project will assess the design, performance, and life-cycle costs (capital as well as operation and maintenance) of selected BMP/SUDS."*

  --- Funding announcement and Request for Proposals from the Water Environment Research Foundation (WERF), July 2001

- ❑ *"The US Congress appropriates close to $200 million annually for NPS projects. Very little of this money has been spent on monitoring, so EPA has inadequate information about the effectiveness of the projects that have been funded. Scientifically based information on the impacts of BMPs to receiving waters (benefits) generally is not available….the agency has not spent much funding on researching infiltration or bioretention practices such as Low Impact Development and there is a paucity of effectiveness and cost information on these practices."*

  --- Robert Goo, NPS Control Branch, USEPA Headquarters (Washington, DC), April 23rd 2001, in an email communication with Patrick Condon

The key to bridging the source control information gap was in tapping the expertise and knowledge of those individuals from around the world who are pioneering source-control applications and research. The relevant experience of the seven *Expert Panel* members is summarized in the adjacent table.

The input provided by the Expert Panel was key in the development of the Water Balance Model and in the preparation of this report on the effectiveness of stormwater source controls.

Expert Panel Members	Relevant Experience
William Derry (CH2M HILL, Seattle) *Best Management Practices*	He is a Founding Director of the *Center for Urban Water Resources Management* at the University of Washington (Seattle). He provides input in identifying research needs, and has early access to research results. He is a member of an ASCE National Expert Panel on BMPs.
Charles Miller (CH2M HILL/Roofscapes, Philadelphia) *Green Roof Technology*	His passion – and life mission - is Green Roofs. He is on a leave-of-absence from CH2M to concentrate on growing his own company: ***Roofscapes***. This is the only company in North America dedicated to the engineering of roof landscape and BMPs for hydrologic applications. He has strong business connections with the European 'green roof' industry.
David Reid (Lanarc, Nanaimo BC) *Landscape Architecture*	His expertise covers environmental planning and landscape architecture. The latter has been key to developing standards for on-site applications, notably for the Burnaby Mountain Sustainable Community. He is co-author of *Stormwater Planning: A Guidebook for British Columbia*.
Daniel Medina (CH2M HILL/George Mason University, Washington DC) *Low Impact Development*	He has specific experience related to Low Impact Development initiatives in the Chesapeake Bay region. This experience includes performance monitoring of LID stormwater control options. He was Project Manager for several initiatives to promote LID as the primary approach to development in Prince George's County, Maryland. These efforts include the County's LID Integrated Practices Manual, the Bioretention Manual, and computer rendering of LID control measures.
Patrick Condon (University of British Columbia) *Urban Site Design*	His staff has scoured North America to track down any and all information related to the performance of Green Infrastructure. He has produced a series of Technical Bulletins.
John Argue (University of South Australia) *Infiltration Technology*	He describes himself as a 'nuts-and-bolts' engineer. His research focus has been on Infiltration Technology since 1984. He has written a Design Manual based on his Demonstration Project experience. He is the pre-eminent authority on infiltration in the English-speaking world.
Peter Coombes (University of Newcastle, Australia) *Stormwater Re-Use Technology*	His applied research is built around Water Balance Modelling and source control Demonstration Projects. His focus is "stormwater re-use" (both indoor and outdoor).

1.11 The Importance of Demonstration Projects

In coming years, monitoring programs from development projects that apply source controls (e.g. the Burnaby Mountain and East Clayton developments) will begin yielding performance data that will enable better evaluation of source-control effectiveness. This performance data is the key to *learning from experience* and *constantly improving* source control practices.

As stated by one of the Expert Panel members:

> *"What is lacking is knowledge on how to implement source control technologies to the best advantage of the community"*
>
> --- Peter Coombes University of Newcastle, Australia

The purpose of this report is to bridge the source control information gap until performance data is available, and to provide a starting point for more widespread application of stormwater source controls in the GVRD.

1.12 Structure and Scope of Report

This report comprises eight sections:

- Section 1 develops a framework;
- Sections 2 through 6 correspond to each of the five categories of source controls;
- Section 7 presents the three watershed case studies; and
- Section 8 explains how to move from planning to action.

Sections 1 through 6 are the building blocks that provide the fundamental understanding of source control performance for a range of rainfall conditions, soil types, and land uses. Section 7 then answers this core question: ***Are watershed restoration targets achievable over a 50-year timeline, and does it make sense to implement changes in standard practice?*** (Drilling down for more details is outside the scope of this project). Section 8 explains the systematic steps for incrementally securing developer acceptance of the need to implement source controls.

1.13 Caveats on the Information in this Report

Purpose of the Information

This report provides quantitative information on the hydrologic performance of stormwater source controls (i.e. their ability to reduce the volume and rate of runoff). The purpose of this information is to help identify opportunities to manage stream health and/or stormwater infrastructure by applying various categories of stormwater source controls, and to provide *a starting point* for integrating stormwater source control into:

a) long range land use and infrastructure planning decisions.

b) the design of stormwater systems at the site level.

Limitation of Scenario Modelling

The Water Balance Model (Refer to section 1.7) was used to generate a series of 'what if' 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 modelling 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 report are examples, and do not reflect the complete range of available source control options. There are many combinations of stormwater source controls not evaluated in this report (e.g. integrated stormwater infiltration and reuse systems) that could provide substantial benefit. The examples are intended to provide a starting point for source control application, and should not limit innovation in applying other combinations and permutations of source controls.

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 define:

- ☐ the operation and maintenance (O & M) practices that are required to maintain source control performance over the long term.
- ☐ the costs of these O & M practices

In order 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 records of ongoing O & M practices.

Operation and Maintenance Considerations

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, reuse facilities or green roofs). Maintenance responsibility for these facilities will most likely shift to individual landowners or strata corporations, which places a greater reliance on the conscientiousness of individuals.

Education of local government staff, developers and the general public regarding the need for source controls and the O & M requirements for ensuring long-term performance is essential to the successful widespread 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 stormwater source control.

The Water Quality Benefits of Source Control

While this report mentions the water quality benefits of each source control category, it does not provide a quantitative evaluation of water quality benefits. Further research is needed to provide a quantitative reference on the effectiveness of source controls for improving water quality (groundwater and surface water).

An evaluation of water quality effectiveness, 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. increase in the volume and rate of runoff). This understanding led to selection of appropriate hydrologic performance indicators (see Section 1.8), and development of the Water Balance Model.

Section 2 - Impervious Controls

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.

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 in the catchments of critical stream reaches can support stormwater management goals. However, stormwater is just one of many factors that need to be considered when making land use decisions.

2.1 The Importance of Site Design Practices

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. In Portland and Eugene, new standards for local streets do not exceed 8 m (many local roads in the GVRD have 11 m paved roadways). 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. Building layout also has important implications for source control (in terms of providing space for infiltration facilities, as discussed in Section 4).
- ☐ **Reduce Parking Standards** - Reducing parking standards reduces the amount of space devoted to parking (driveways, parking lots, parkades). Residential parking standards are often around 2 on-site parking spaces per dwelling unit. However, in compact and/or high density communities where dwelling units are within walking distance to transit and services, parking standards are being reduced to 1.3 or even as low as 1 space per dwelling unit. There are other factors that reduce the need for parking, including, 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 (underground or structures). There is also greater opportunity to mitigate the runoff from parkades using green roofs or rainwater reuse, as discussed in Sections 5 and 6. 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 a 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.

2.2 Source Controls - A Key Element of Site Design

Implementing urban 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% 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).

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 facilties, and
- there is more space available to locate infiltration facilities.

This can significantly improve the effectiveness of infiltration facilities, as discussed in Section 4.

Section 3 - Absorbent Landscaping

3.1 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, and high populations of earthworms and microbes stir and mix the organic matter 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.

3.2 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. The surface absorbent soil layer should have high organic content (about 10 to 25%). The surface vegetation should be either herbaceous vegetation with a thickly matted rooting zone (can be 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 type of hydrologic characteristics required. Often this can be achievable by adding organic matter to existing top soils on a residential site.

3.3 Absorbent Soil Depth

Figure 3-1 shows that runoff from pervious areas can be virtually eliminated by providing a *300 mm layer of landscaped absorbent soil*, even where the hydraulic conductivity of the underlying soil is low. This graph 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.

Since trees typically have very deep rooting zones (often in the range of 2 metres), there is virtually no surface runoff from forested areas. Preserving forested areas through implementation of an urban forestry strategy is an effective way to ensure absorbent landscaping.

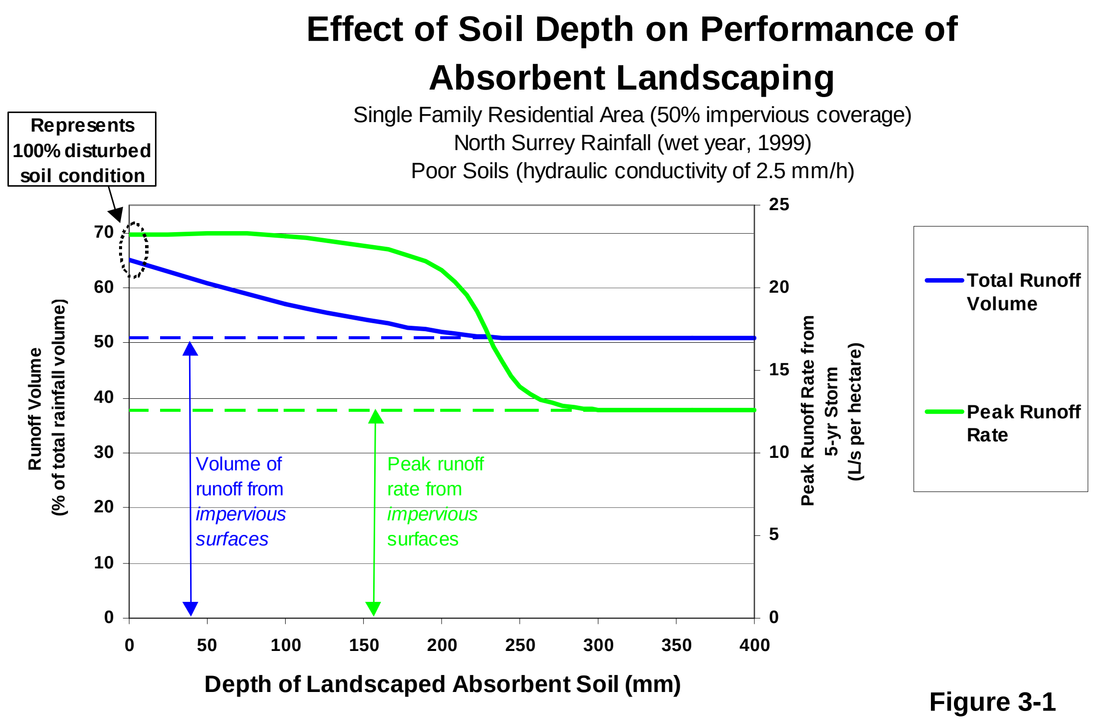


Figure 3-1

3.4 Benefits for Different Land Uses

Figure 3-2 and Figure 3-3 show the level of reduction in runoff volume and runoff rate that could be achieved by using absorbent landscaping on different land use types.

The benefits of absorbent landscaping are more significant for land uses with lower levels of site coverage and higher proportion of pervious area (e.g. single family residential), especially in terms of reducing peak runoff rates. Implementation of absorbent landscaping standards may be more difficult for single family land uses because there is greater reliance on the stewardship ethic of individual landowners.

Figure 3-3 shows that absorbent landscaping is particularly beneficial in terms of reducing peak runoff rates. During large rainfall events (e.g. 5-yr storm) disturbed soil can generate nearly as much runoff as impervious surfaces, whereas an absorbent soil layer (300 mm deep) 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.

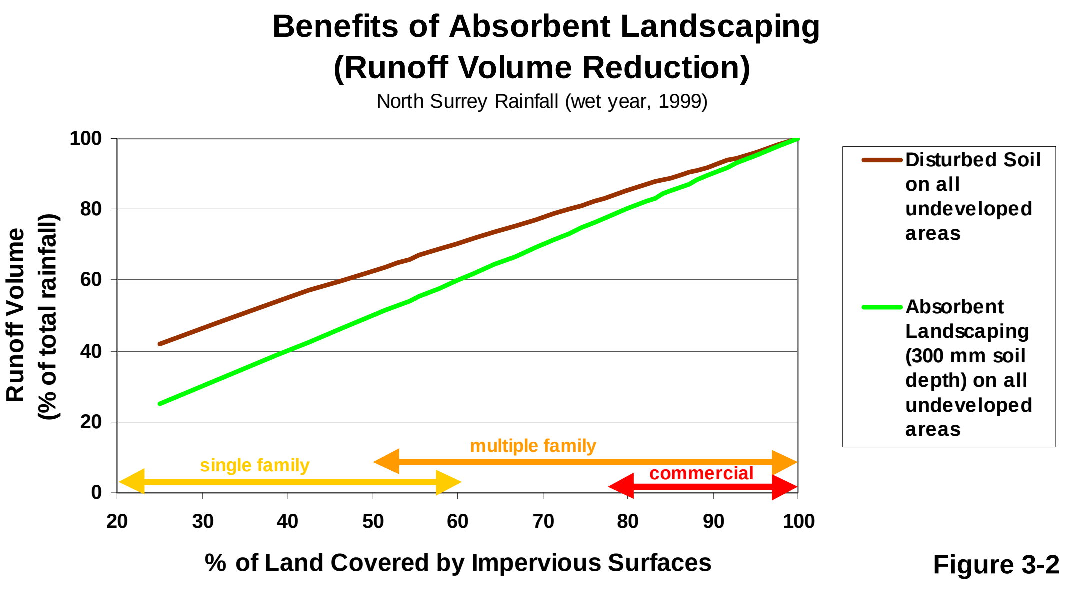


Figure 3-2

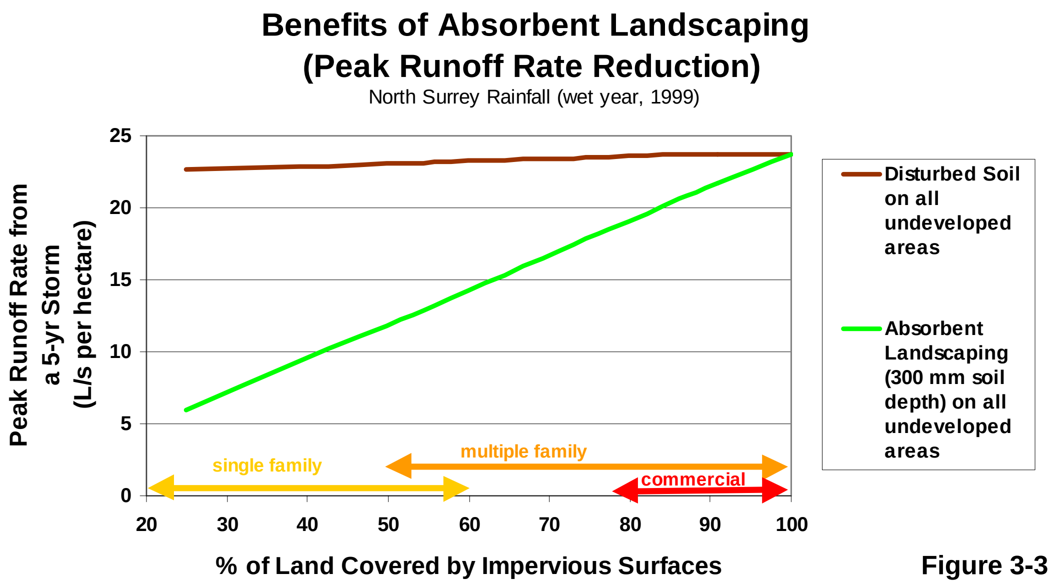


Figure 3-3

3.5 The Effect of Rainfall

Figure 3-4 shows that the benefits of absorbent landscaping are more significant where rainfall is higher (e.g. North Vancouver). This is because increased rainfall leads to more runoff from disturbed soil, but does not lead to more runoff from absorbent landscaping.

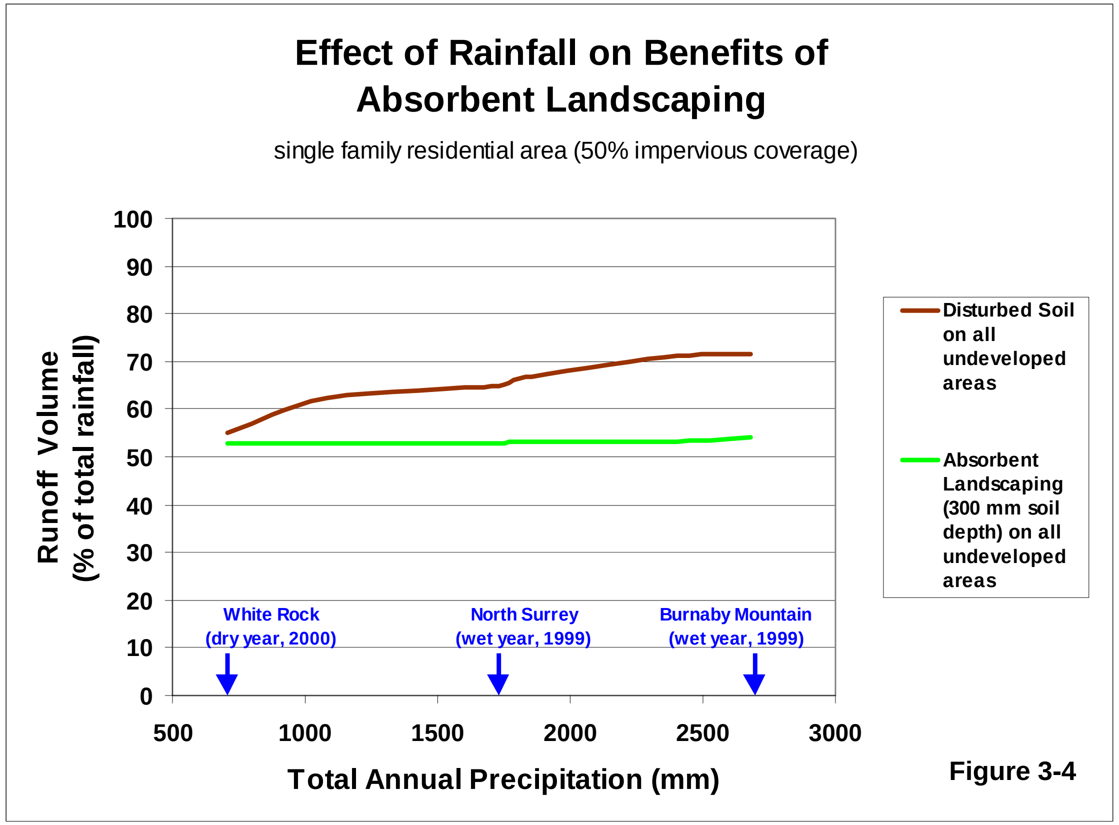


Figure 3-4

3.6 Cost Implications

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, the soil depth would be about 450mm, with shrub or groundcover and trees.

3.7 Absorbent Landscaping Maintenance Tips

- ❑ In shrub beds, regular application of bark mulch, natural leaf drop, or other organic inputs will keep burrowing insect populations high, and increase soil permeability.
- ❑ In lawn areas, use of a proper sandy topsoil will avoid compaction problems. Aerating techniques can assist air and water exchange in local 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.
- ❑ Provisions for dry season watering of plant materials is essential, especially in the plant establishment period.
- ❑ Maintenance requirements (and costs) are typically highest in the first year when plants may require establishment watering, weeding, and some replacement.

3.8 Soil Rehabilitation

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

- ❑ Mixing in organic content (e.g. compost), which is the most effective soil rehabilitation method.
- ❑ 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.

Section 4 – Infiltration Facilities

4.1 Disconnection of 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 the runoff from impervious surfaces on development parcels (rooftops, driveways, parking lots) and roads (paved roadway and sidewalks).

Figure 4-1a and 4-1b show that the runoff volume and rate reduction benefits that can be achieved by disconnecting impervious surfaces varies significantly depending on the type of surface this runoff is dispersed over.

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-yr 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 volumes and peak runoff rates can be achieved by dispersing runoff over a forested area. The deep 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 functions 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. The storage capacity needed to provide this runoff retention can be provided in a layer of absorbent soil or gravel, on the ground surface (ponding), or in sub-surface infiltration chambers. Types of infiltration facilities are compared on the following page.

Figures 4-1a and 4-1b show that infiltration facilities can achieve greater reductions in runoff volume and rate where soils have better hydraulic conductivity. The effect of soil type on infiltration facility performance is evaluated further in Section 4.5

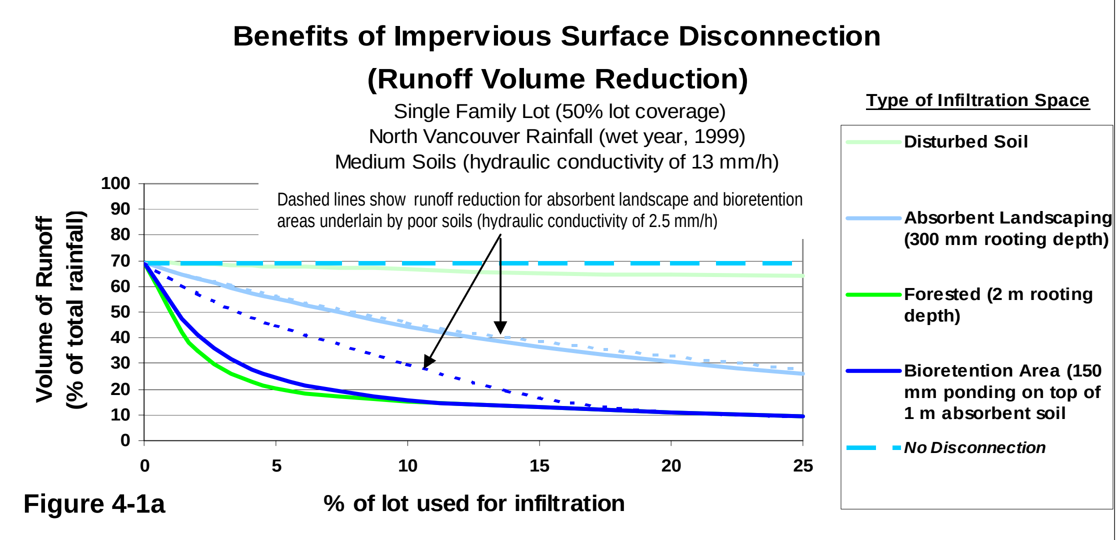


Figure 4-1a

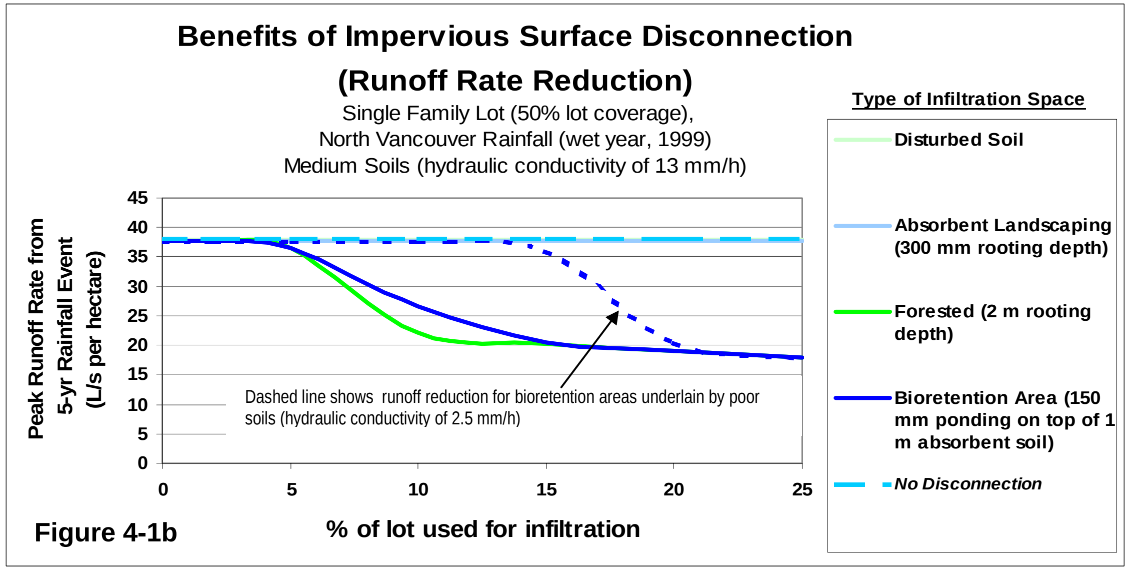


Figure 4-1b

4.2 Types of Infiltration Facilities

Figure 4-2 compares the hydrologic effectiveness of the following types of infiltration facilities:

- **Surface Facilities (Bioretention Facilities)** – Runoff is stored in a layer of absorbent soil and/or on the ground surface (also called Rain Gardens). Surface vegetation is essential, as with absorbent landscaping. Surface facilities can be aesthetically landscaped and integrated into the design of open spaces.
- **Sub-surface Facilities (Soakaways) –** Runoff is stored in a sub-surface layer of gravel or drain rock and/or in infiltration chambers (i.e. 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 under a driveway).

Figure 4-2 shows that a soakaway would be slightly more effective than a bioretention facility of the same depth (with no surface ponding). This is because gravel stores more runoff per unit volume than absorbent soil. Placing an infiltration chamber in a soakaway increases its storage volume, and improves its effectiveness. Similarly, surface ponding increases the storage capacity and improves the effectiveness of bioretention facilities, particularly for facilities with low absorbent soil depth.

Infiltration facilities can be a combination of the two types described above. For example, infiltration swales along roads, which consist of an absorbent soil layer (surface swale) on top of a gravel filled trench (i.e. soakaway). The effectiveness of infiltration swales is shown in section 4.5.

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

4.3 Infiltration Facility Depth

The depth of an infiltration facility refers to the distance from the bottom of the facility (i.e. infiltration face) to the overflow level. Increasing depth increases the retention storage capacity, thus decreasing the amount of overflow (i.e. runoff), as shown in Figure 4-2. The benefits of additional storage 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 in Section 4.5).

It is also important to note that shallow infiltration facilities generally provide the best opportunity for recharging the soil interflow zone.

Constraints on Infiltration Facility Depth

Appropriate depths for infiltration facilities must be selected based on site-specific characteristics and constraints. 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 (or bedrock). ***Infiltration facilities are not appropriate in areas where the water table is at or near the ground surface*** (e.g. high water table areas such as Richmond). Appropriate depths for surface facilities may also be governed by safety or aesthetic considerations.

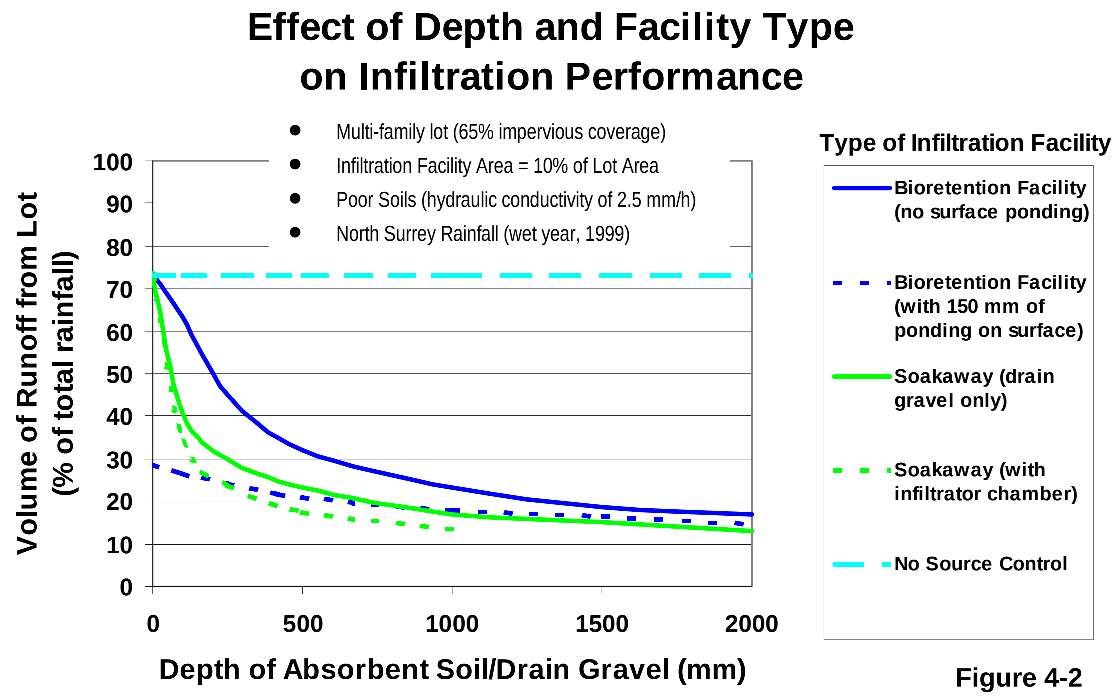


Figure 4-2

4.4 The Effect of Rainfall

Figure 4-3a shows that the performance of infiltration facilities decreases as rainfall increases. The same infiltration facility design would be more effective in a drier part of the GVRD (e.g. White Rock) than it would be in a wetter area (e.g. North Vancouver). This is because more rainfall causes more runoff to be concentrated into infiltration facilities, which leads to more overflow.

Note that the volume of runoff without infiltration (i.e. the starting point of the curves on Figure 4-3a) is greater for higher rainfall locations. This is better illustrated in Figure 4-3b.

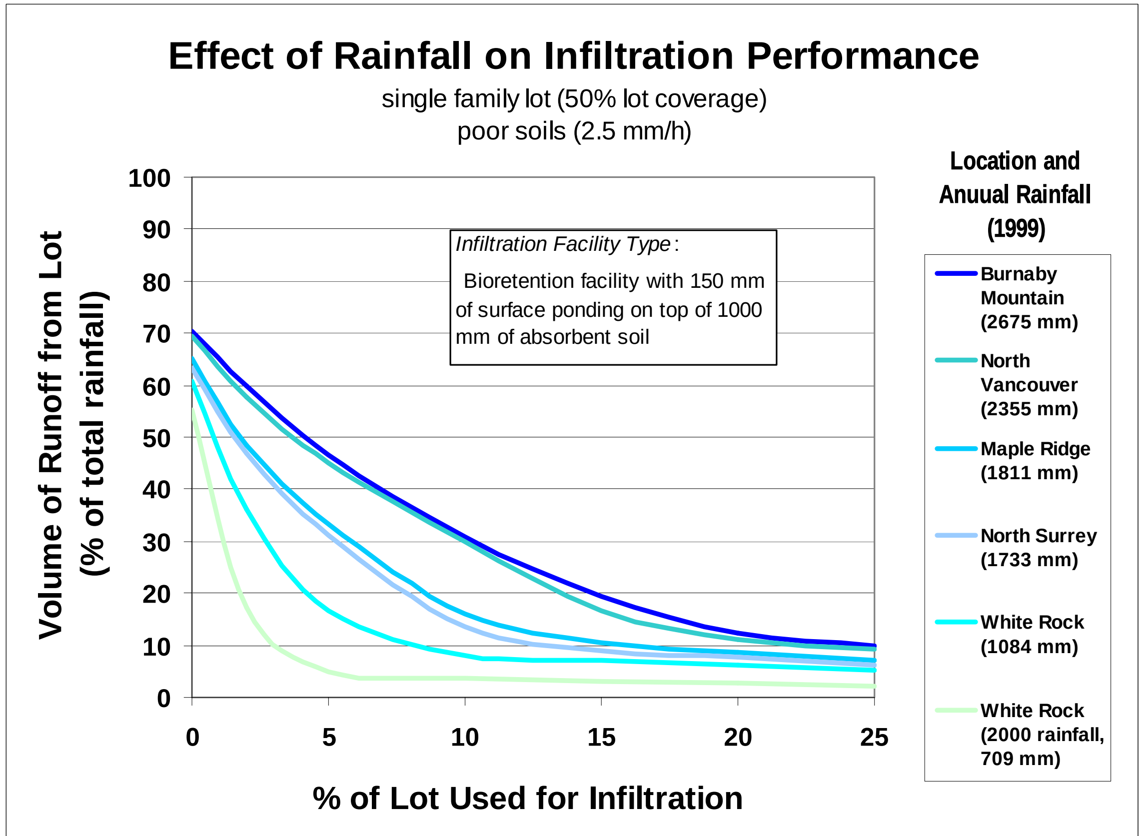


Figure 4-3a

Figure 4-3b shows that rainfall has less effect on infiltration facility performance where the hydraulic conductivity of sub-surface soils is better. This graph also illustrates that soil type has a greater impact on performance than rainfall. The impact of soil type on infiltration facility performance is discussed further in the following section (Section 4.5).

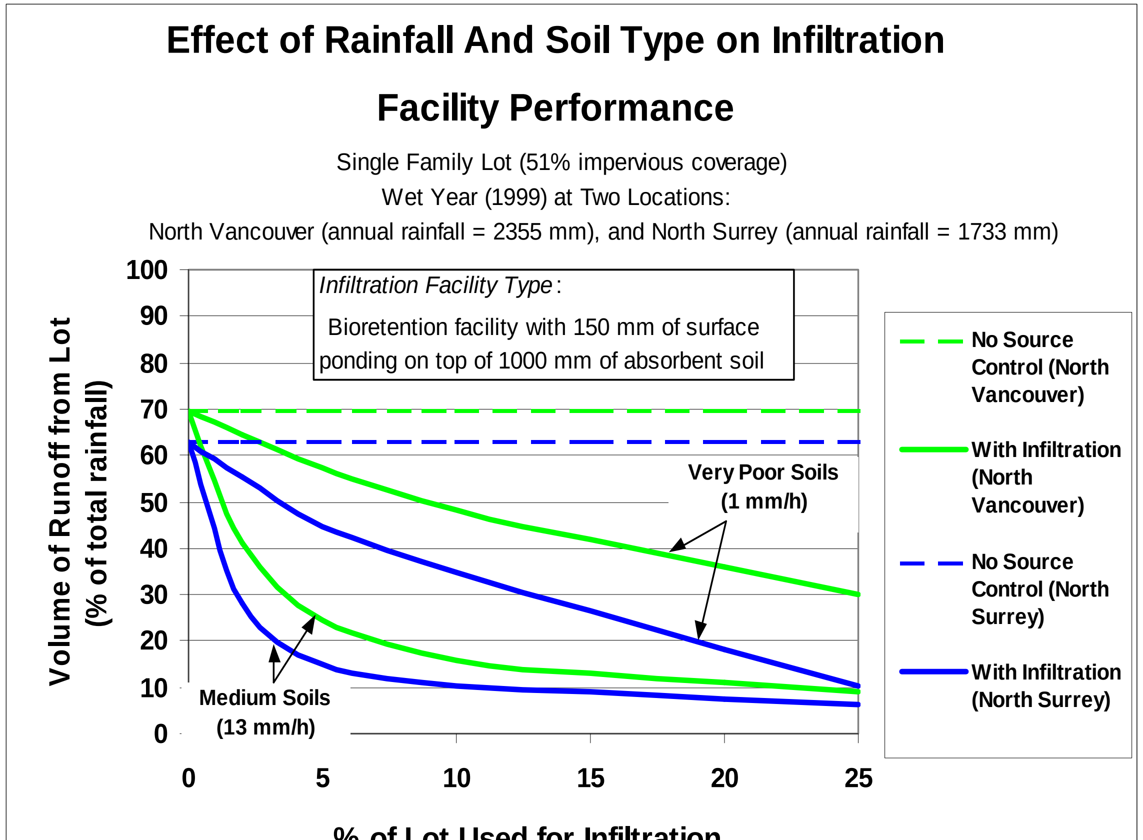


Figure 4-3b

4.5 Performance Curves for Infiltration Facilities

The *Infiltration Performance Curves* (Figures 4-5a through 4-5w) presented on the following pages show how the hydrologic effectiveness of infiltration facilities (i.e. amount of reduction in runoff volume and rate) varies depending on the following key 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 that water can exfiltrate from infiltration facilities depends on the hydraulic conductivity of surrounding soils. Infiltration facilities are most effective where the hydraulic conductivity of soils is high (e.g. sandy soils). Since much of the GVRD is reportedly covered with sandy soils, there appears to be an opportunity for widespread application of infiltration facilities in this region.
- ❑ **Amount of Area Provided for Infiltration –** Footprint area is the most important design parameter of 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 that this runoff can exfiltrate.

  The benefits of providing additional area diminish beyond a certain level. This level depends on land use and soil type, as shown by the Infiltration Performance Curves.

Sets of Infiltration Performance Curves that reflect a range of soil conditions (hydraulic conductivity ranging from of 1 mm per hr to 50 mm per hour) are provided for:

- ❑ 8 land use types, with total lot coverage ranging from 30% (e.g. low-density single family) to 98% (e.g. town centre commercial).
- ❑ 4 road types, with paved roadway widths ranging from 8.5 m (e.g. local roads) to 16 m (e.g. divided arterials). All roads are also assumed to have two 1.5 m sidewalks.

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

Performance Thresholds

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

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

These thresholds are shown on each infiltration performance curve. Note that affordability threshold will likely govern for lower coverage land uses (e.g. single family residential) and feasibility threshold will likely govern for higher coverage land uses (e.g. commercial uses).

Feasibility Thresholds

As lot coverage increases there is less space available to locate infiltration facilities. The *feasibility thresholds* shown on the Infiltration Performance Curves reflect an estimate of the maximum amount of space that could be used for infiltration. These thresholds will actually be highly site specific because they depend on the layout of impervious and pervious spaces within the lot (or road), and on soil type.

It is typically not possible to use all undeveloped lot space for infiltration facilities. 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 and the clearance distance should be about 5 m for heavy clay soils.

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

Affordability Thresholds

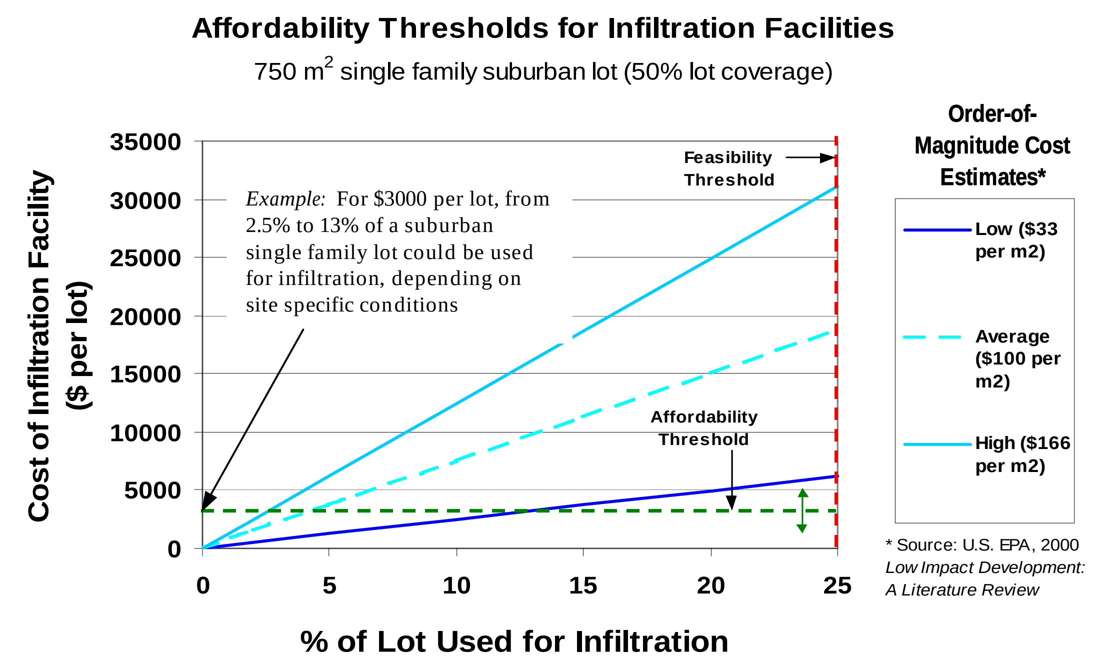
Increasing the size of infiltration facilities improves their effectiveness (as shown in Figures 4-5a through 4-5v), but also increases their cost. Local governments must establish *affordability thresholds* based on the community’s willingness to pay and on the potential benefits of the infiltration facilities (e.g. stream protection, avoided drainage costs). ***Note that the affordability thresholds shown on the Infiltration Performance Curves are for illustration purposes only, and reflect judgement as to what seems appropriate.***

Establishing Affordability Thresholds

Figure 4-4a and 4-4b show 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?

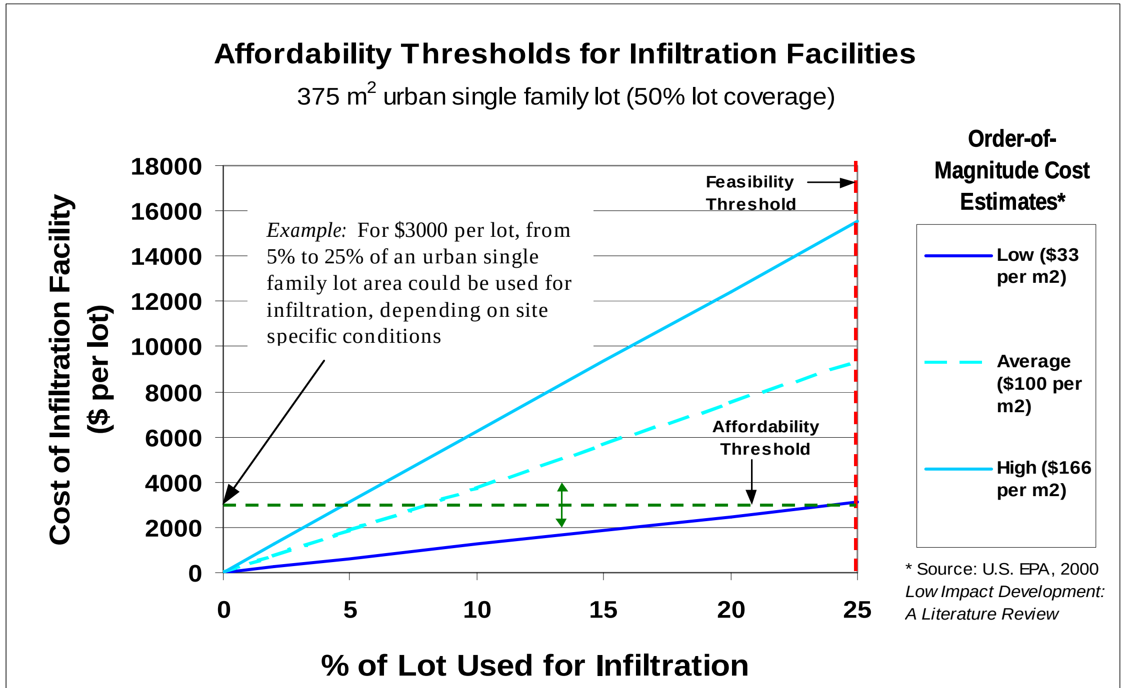
The costs of infiltration facilities can be highly variable depending on site specific conditions, such as amount and type of material that needs to excavated. The benefits of infiltration facilities are also highly dependent on site-specific conditions, and therefore, site specific cost-benefit analyses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



Example: For $3000 per lot, from 2.5% to 13% of a suburban single family lot could be used for infiltration, depending on site specific conditions

* Source: U.S. EPA, 2000 *Low Impact Development: A Literature Review*

Figure 4-4a



Example: For $3000 per lot, from 5% to 25% of an urban single family lot area could be used for infiltration, depending on site specific conditions

* Source: U.S. EPA, 2000 *Low Impact Development: A Literature Review*

Figure 4-4b

Underlying Assumptions for the Infiltration Performance Curves

In order to show the effect of **soil type, land use type,** and **infiltration area** on the performance of infiltration facilities, the *Infiltration Performance Curves* (Figures 4-5a through 4-5w) are based on the following assumptions regarding other factors that affect performance:

Design of Infiltration Facilities

The Infiltration Performance Curves show the modeled performance of the following infiltration facility designs:

- *For infiltration along roads*, two-layer swale and infiltration trench systems:
    - Top Layer (surface swale) = 300 mm of absorbent soil (as described in Section 3).
    - Bottom Layer (infiltration trench) = a gravel filled trench with perforated overflow pipe 300 mm above the trench bottom.
- *For on-lot infiltration*, bioretention facilities (or rain gardens) with 150 mm of ponding depth on top of 1000 mm of absorbent soil (characteristics of absorbent soil described in section 3).

Rainfall Conditions

The Infiltration Performance Curves show the results of Water Balance Model simulations for a very wet year in North Surrey (1999). This is also representative of an average rainfall year in North Vancouver.

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. In locations and / or years with less rainfall, infiltration facilities are likely to perform better than the Curves indicate (and vice versa).

Depth to Water Table

The Infiltration Performance Curves assume that the groundwater table is a reasonable depth below the bottom of infiltration facilities (at least 0.5 m), which means that the water table is assumed to be at least 1.5 m below the ground surface. This is likely to be the case for most upland areas in the GVRD, particularly in developed areas where buildings have foundation drains (the drains govern water table level)..

Runoff from Undeveloped Areas

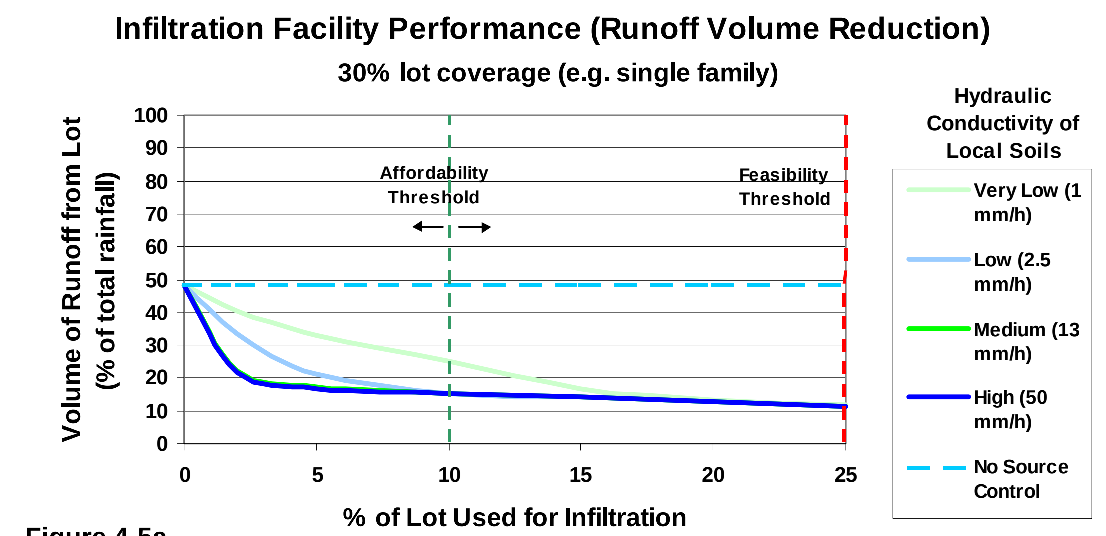
All pervious surfaces are assumed to be disturbed soil (i.e. no absorbent landscaping). Runoff from disturbed soil on building lots is *not* captured by bioretention facilities, but runoff from disturbed soil within road right-of ways *is* captured by infiltration swales.

Note that lower coverage land uses have more runoff from disturbed soil, which is reflected in the Performance Curves for on-lot infiltration facilities (they show runoff from entire lot).

Runoff Reduction Indicators (Rate and Volume)

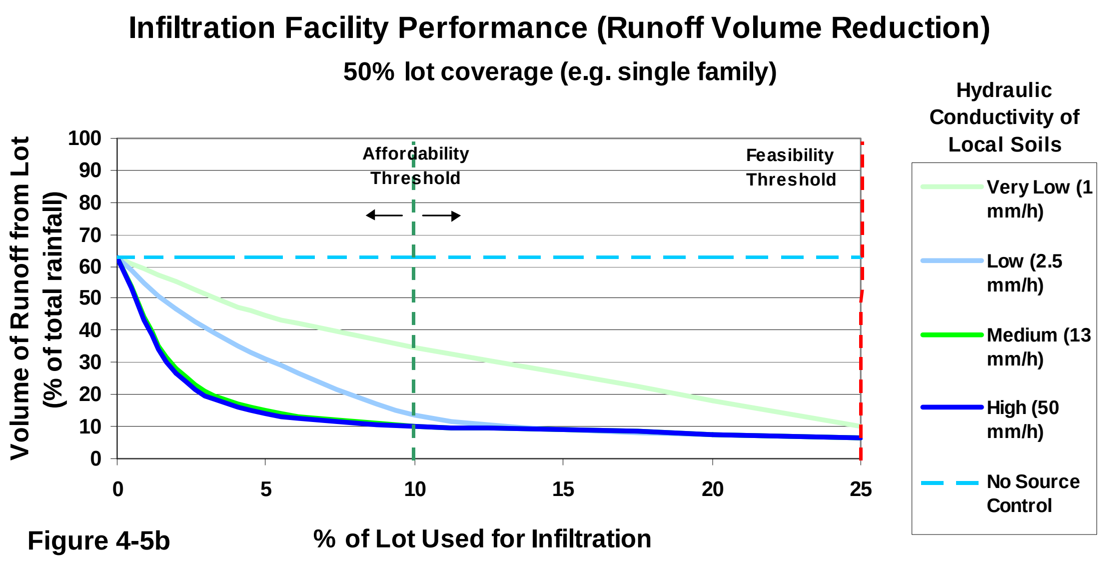
All Runoff Rate Reduction Curves show the rate of runoff from an entire development area (i.e. building lots *and* road right-of ways).

The Runoff Volume Reduction Curves for on-lot infiltration facilities show the volume of runoff from the lots only. The Volume Reduction Curves for infiltration facilities along roads show the volume of runoff from the road right-of ways only.



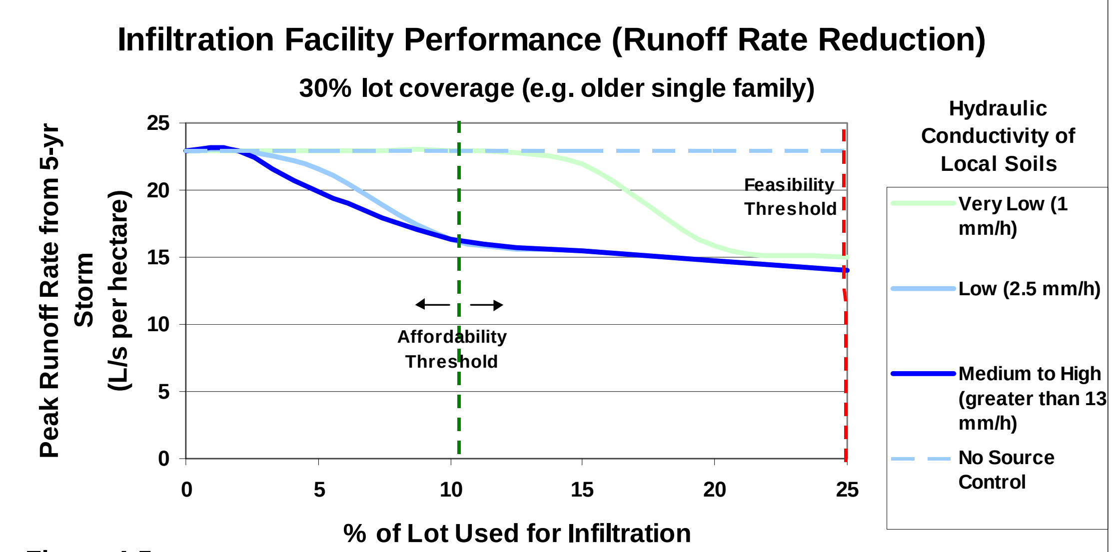
Infiltration Facility Performance (Runoff Volume Reduction)

Figure 4-5a



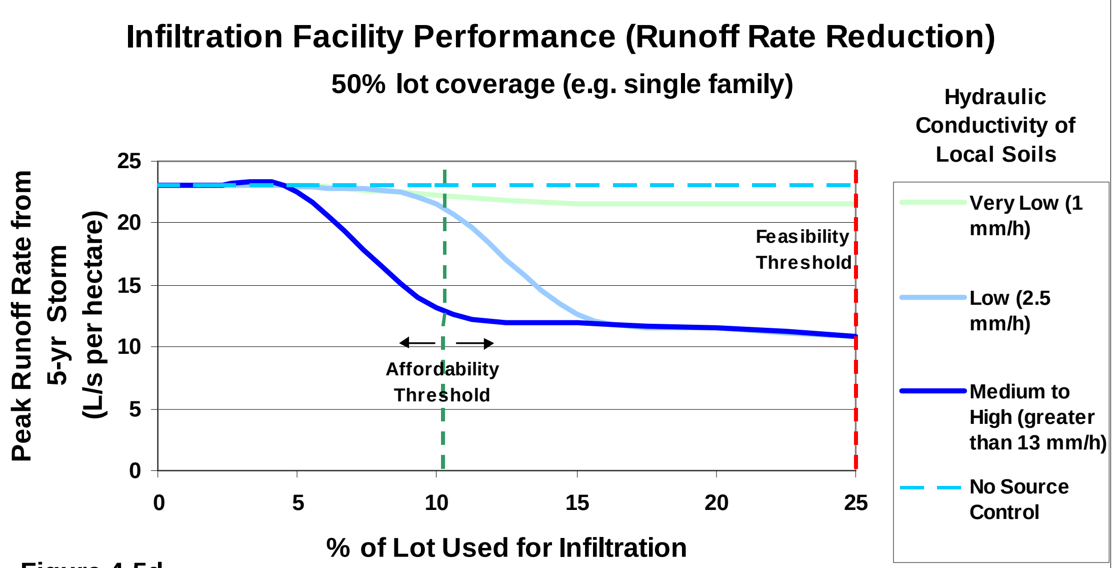
Infiltration Facility Performance (Runoff Volume Reduction)

Figure 4-5b



Infiltration Facility Performance (Runoff Rate Reduction)

Figure 4-5c



Infiltration Facility Performance (Runoff Rate Reduction)

Figure 4-5d

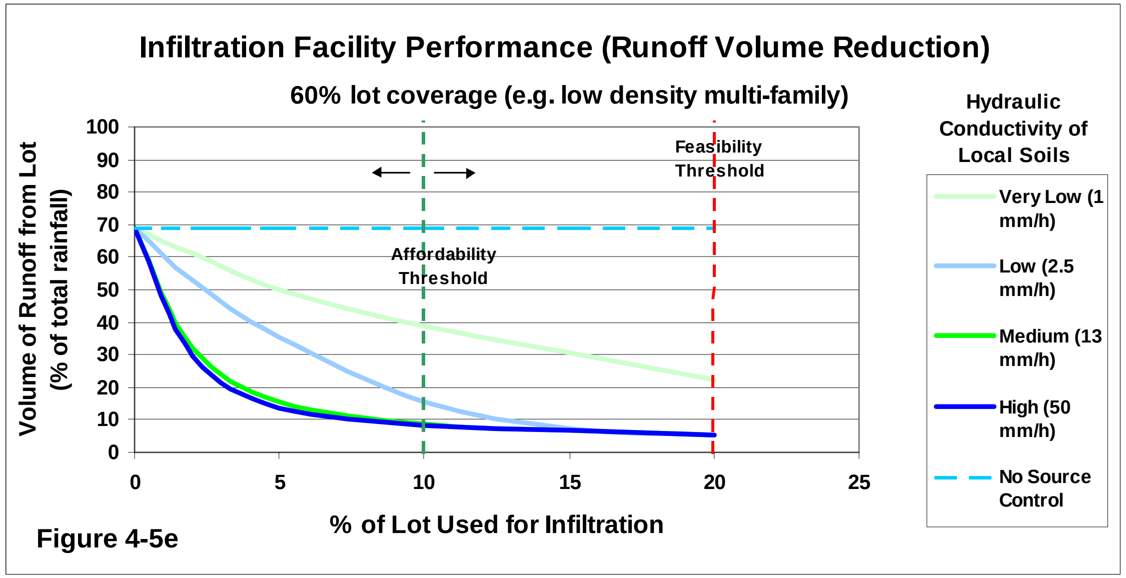


Figure 4-5e

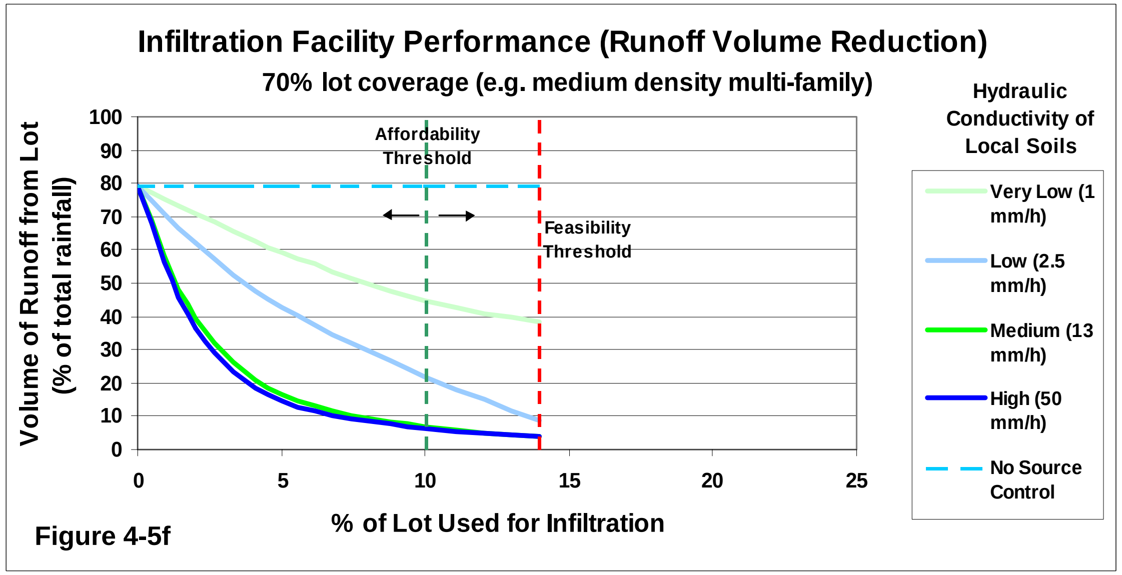


Figure 4-5f

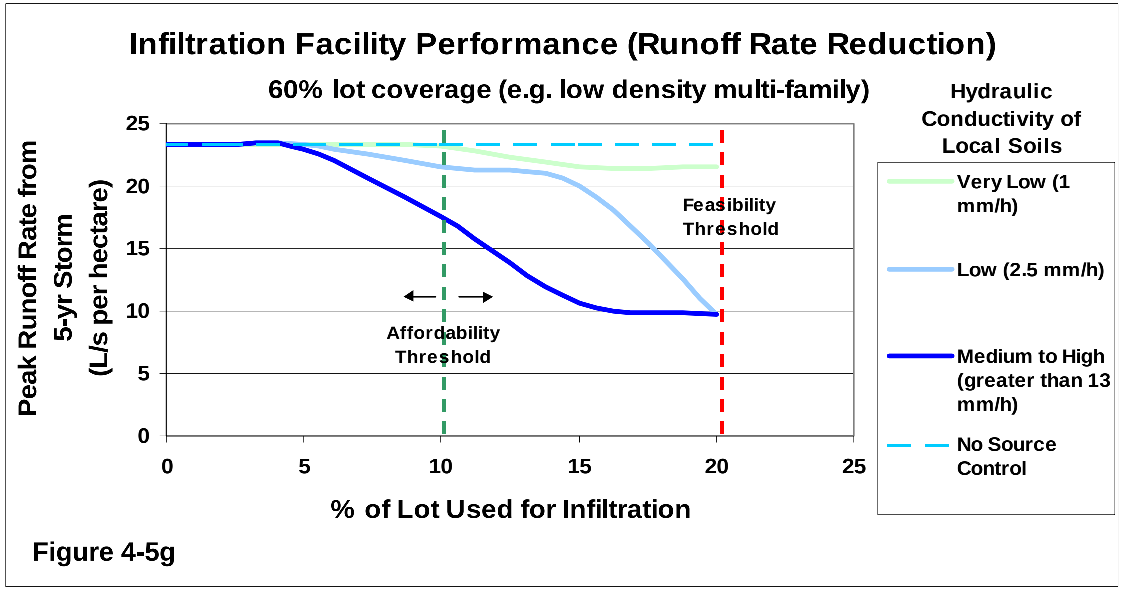


Figure 4-5g

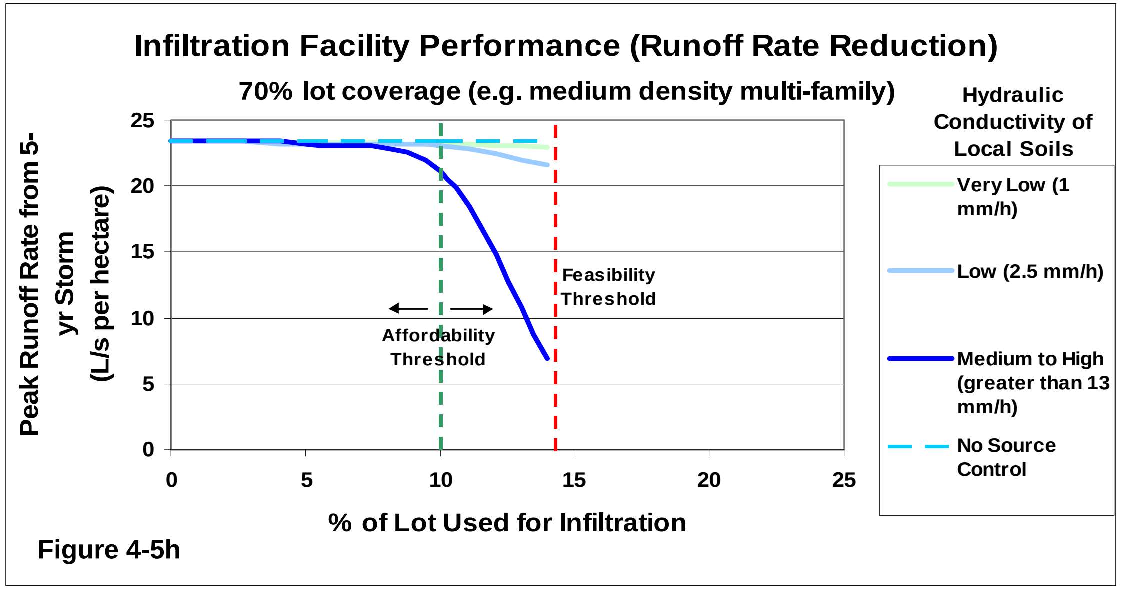


Figure 4-5h

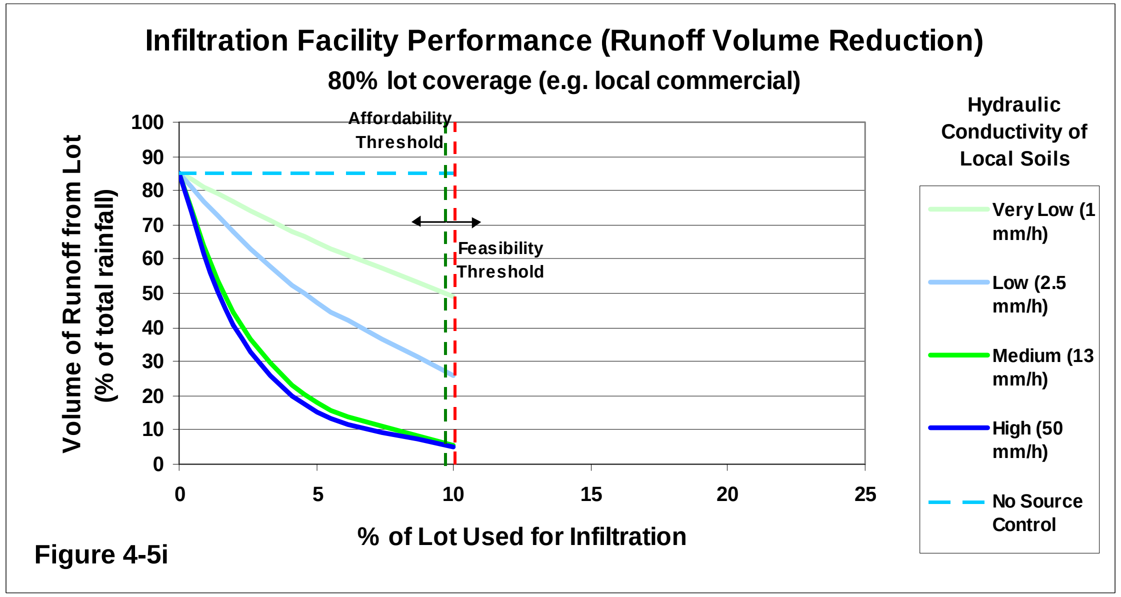


Figure 4-5i

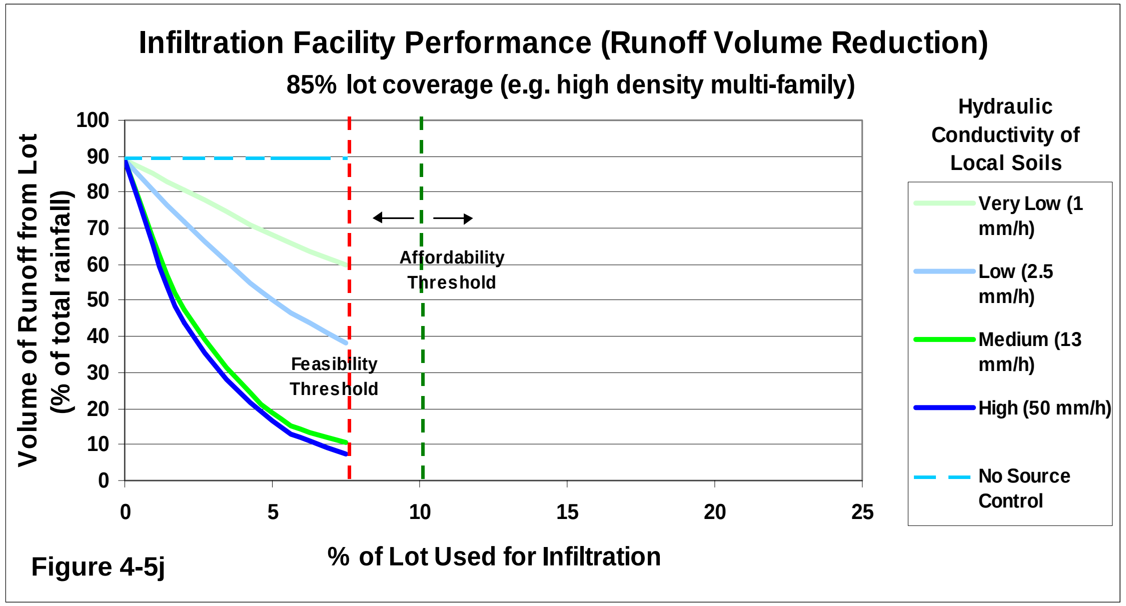


Figure 4-5j

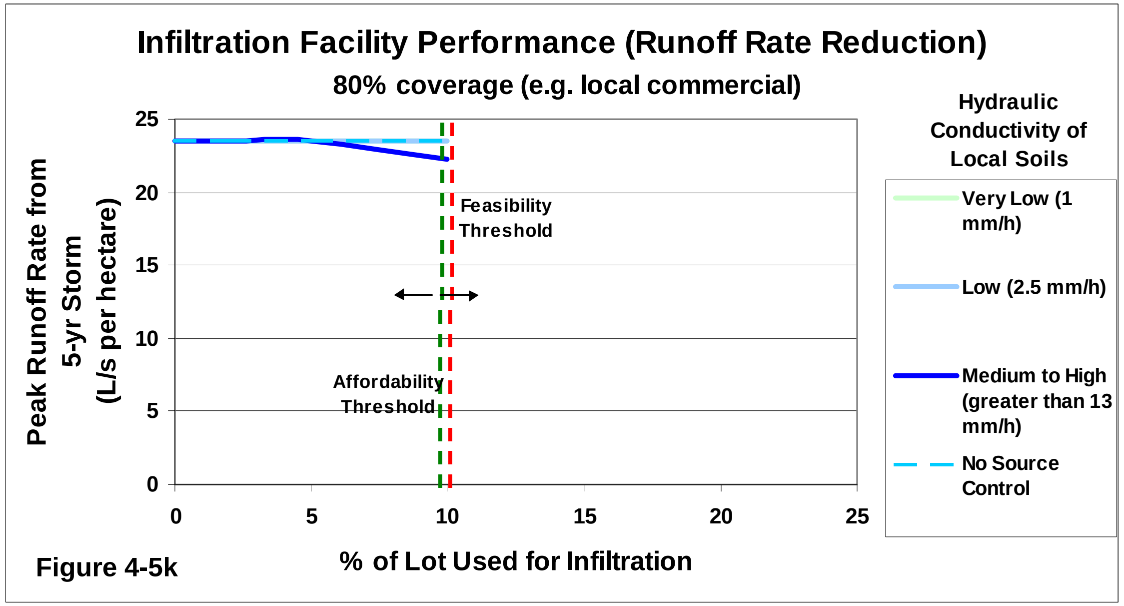


Figure 4-5k

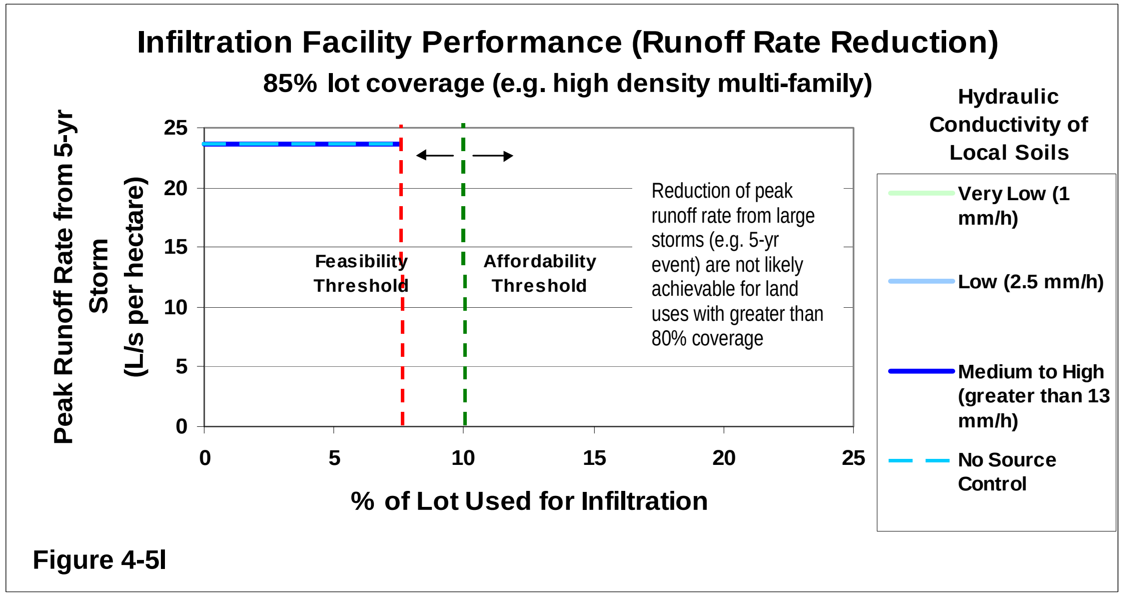


Figure 4-5l

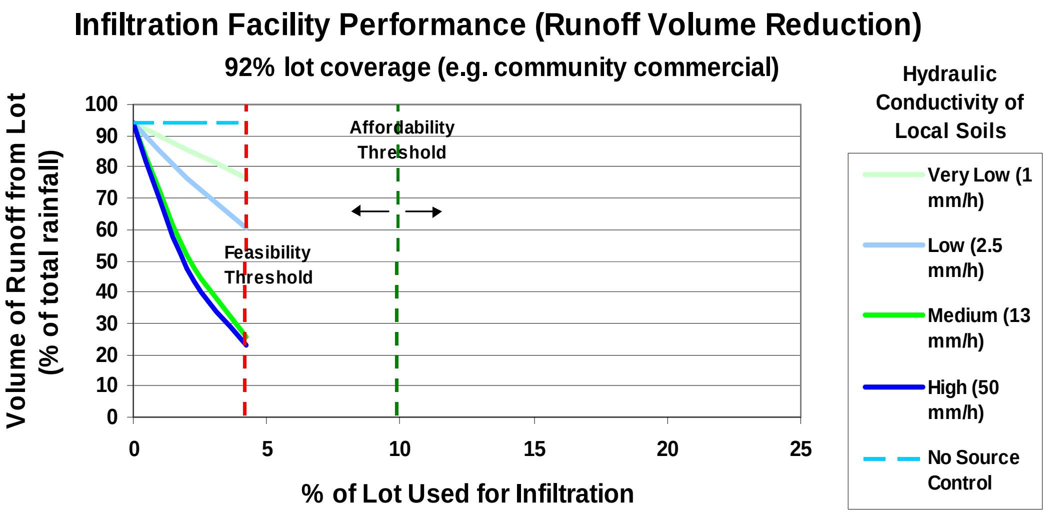


Figure 4-5m

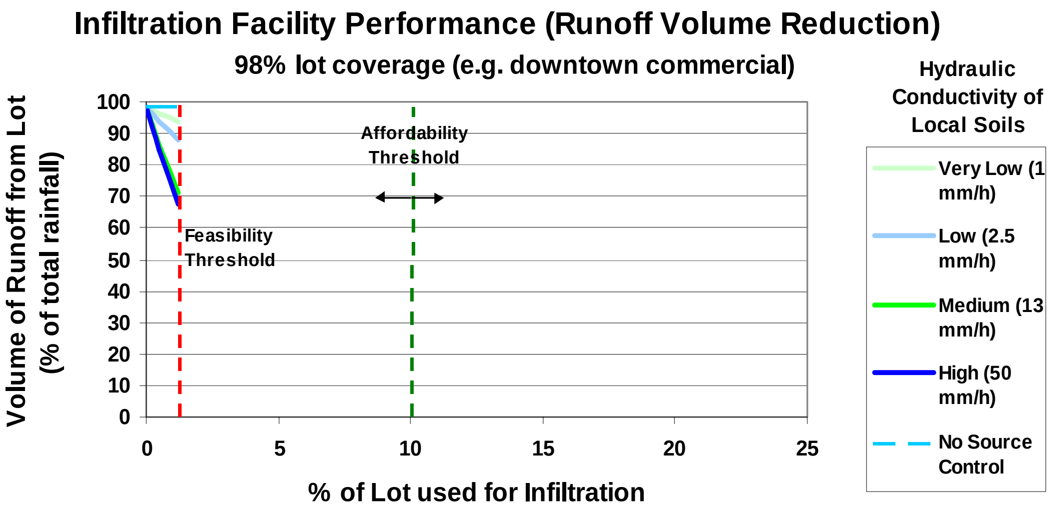


Figure 4-5n

Achievable Level of Runoff Volume Reduction for Different Land Use Types

Figure 4-5o provides a summary of the level of runoff volume reduction that could be achieved using infiltration facilities 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 threshold or affordability threshold, as shown on the preceding Infiltration Performance Curves). All of the assumptions applied to the preceding Infiltration Performance Curves (see pg. 17) also apply to Figure 4-5o.

Where soils have medium or better hydraulic conductivity (greater than 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 4-5o 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 percent, on single family and medium density multi-family land uses.

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

Soil Types	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/)

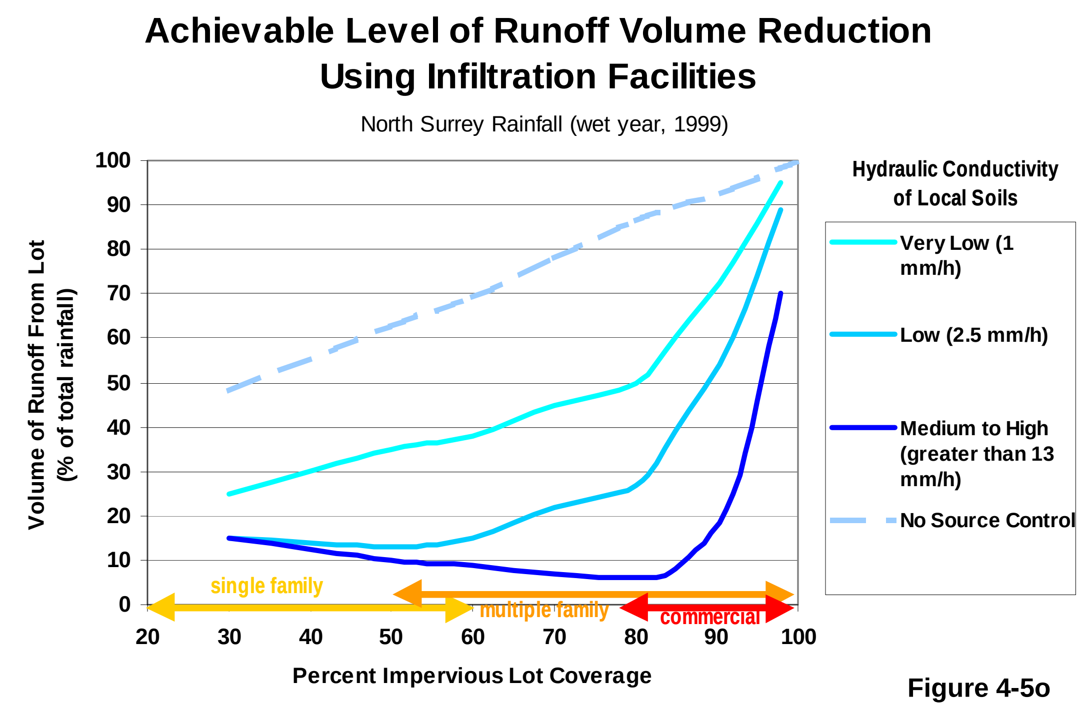


Figure 4-5o

Performance of Infiltration Facilities on Roads

The Performance Curves on the following pages show the performance of infiltration facilities on roads. In general, on-road facilities are more effective than on-lot facilities because there is typically less *concentration of runoff* (i.e. the ratio of impervious area to infiltration area is lower).. In good soil conditions road runoff can be virtually eliminated.

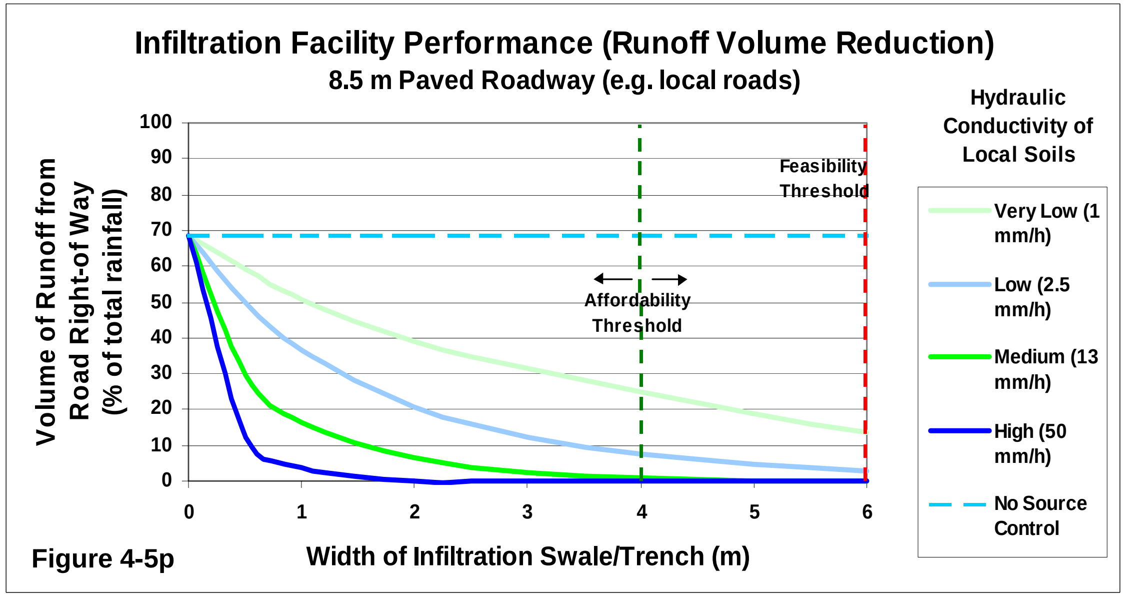


Figure 4-5p

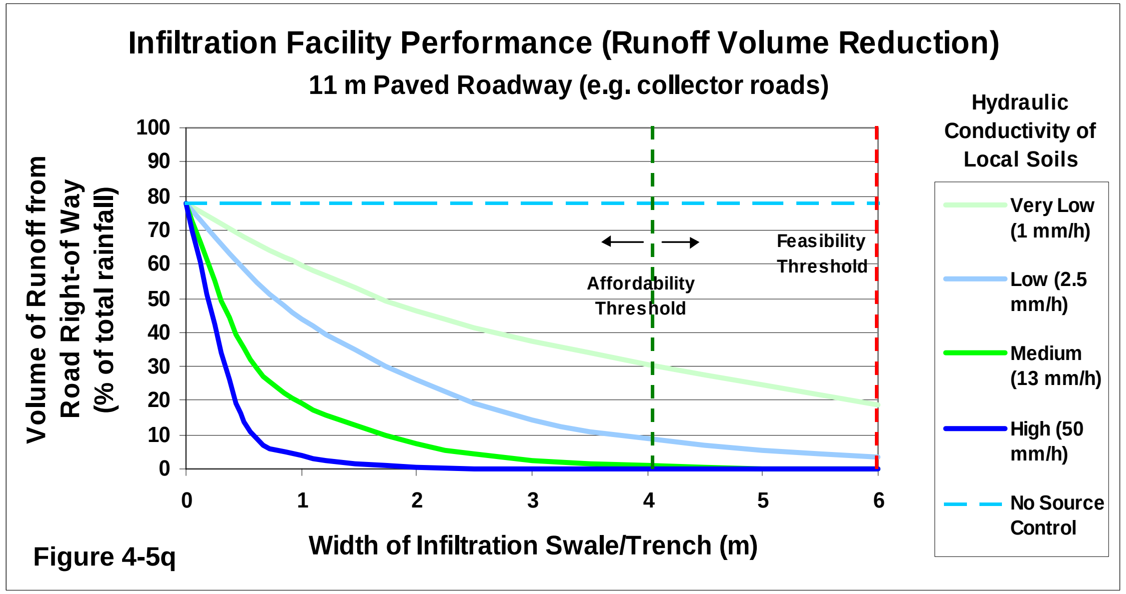


Figure 4-5q

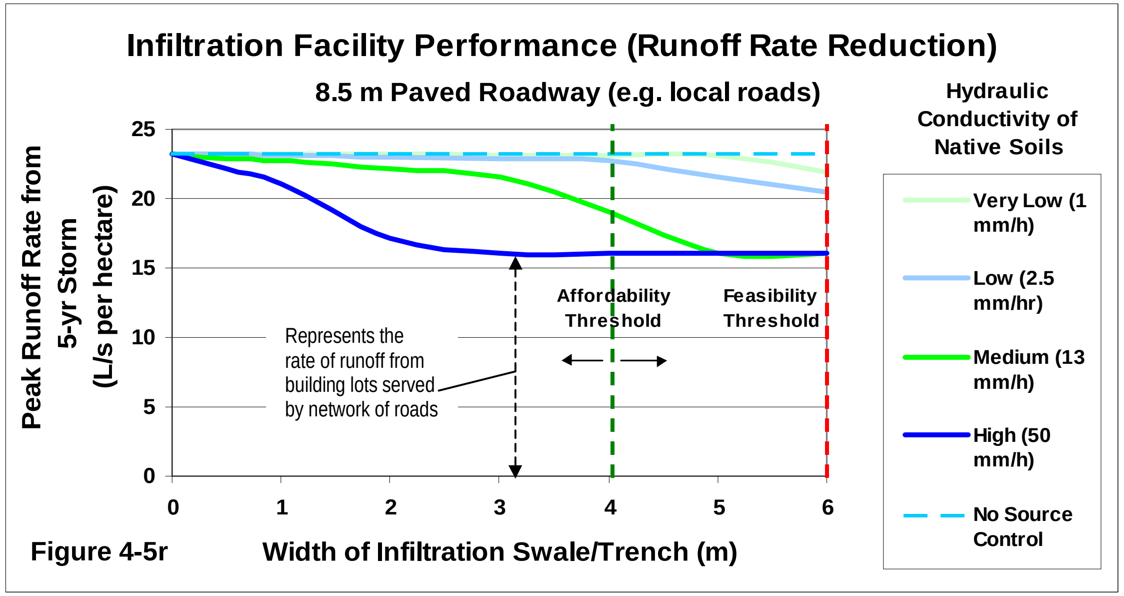


Figure 4-5r

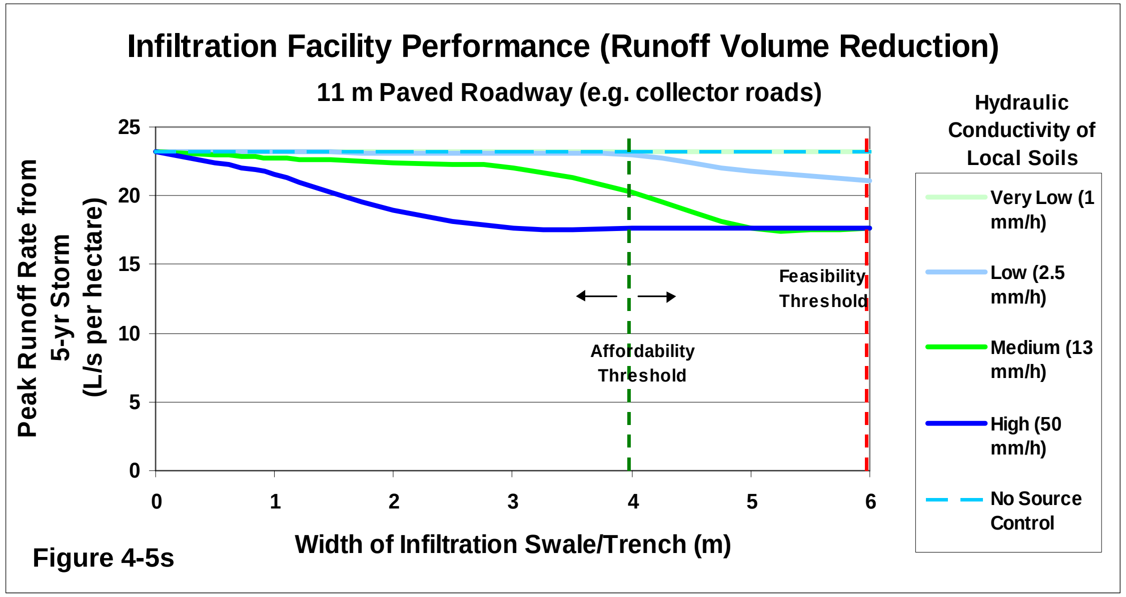


Figure 4-5s

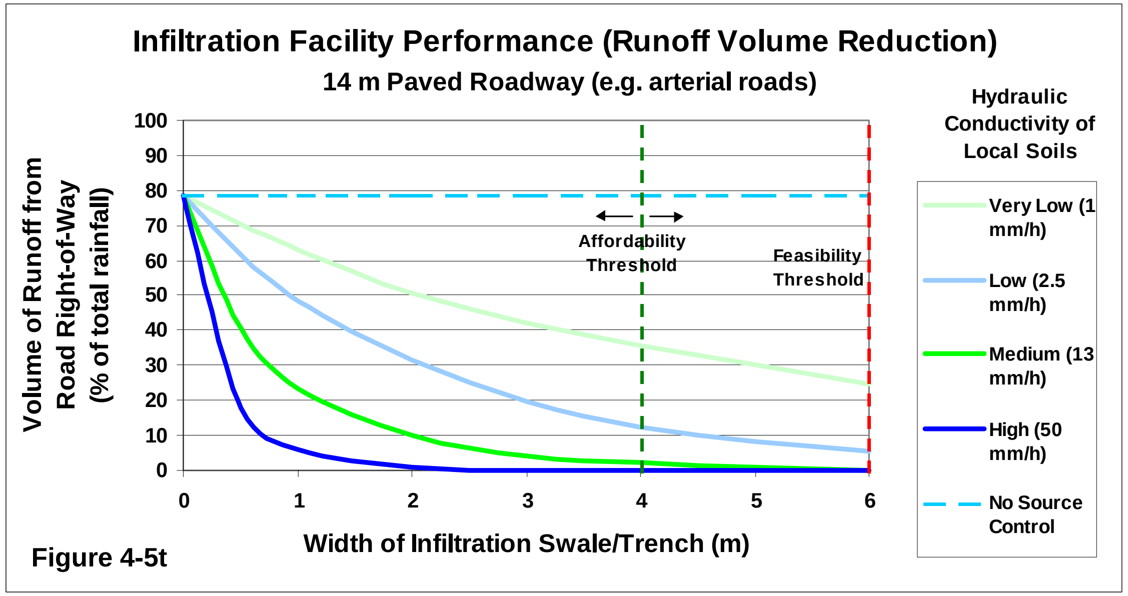


Figure 4-5t

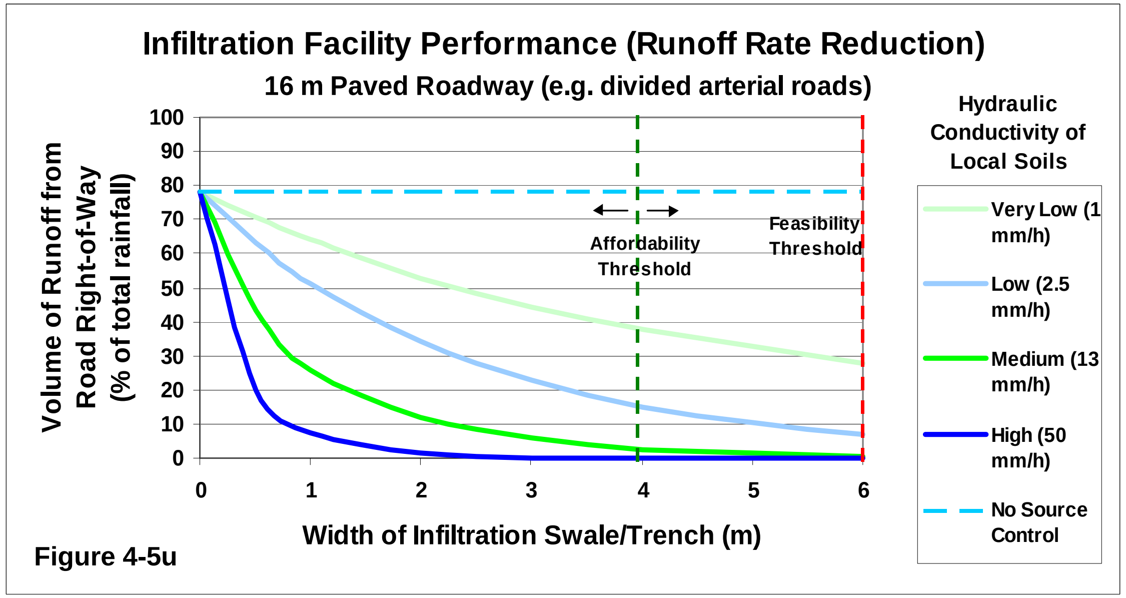


Figure 4-5u

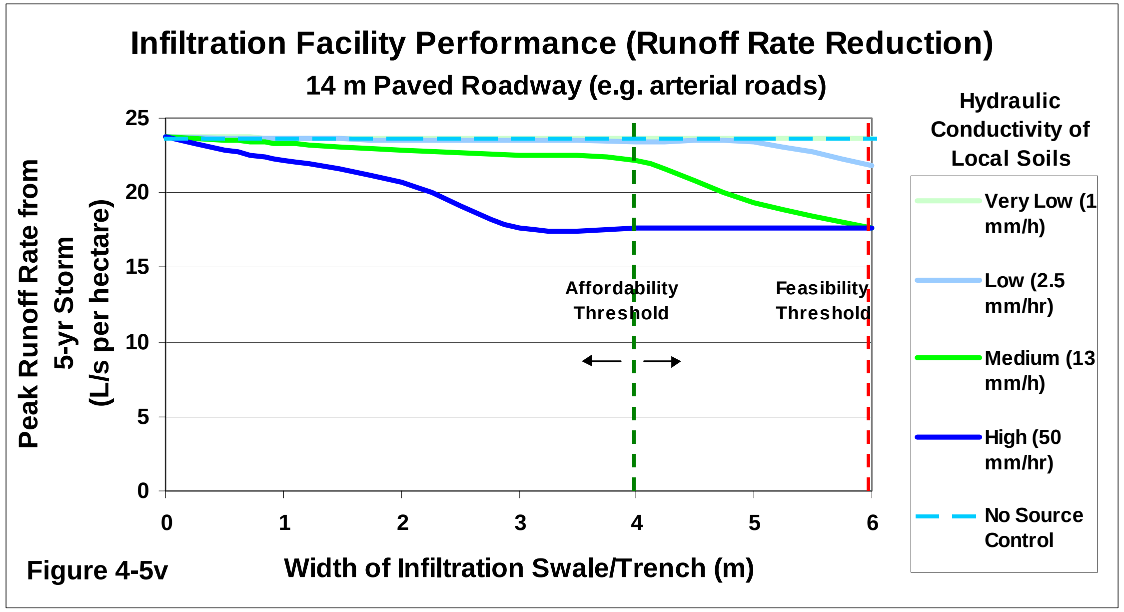


Figure 4-5v

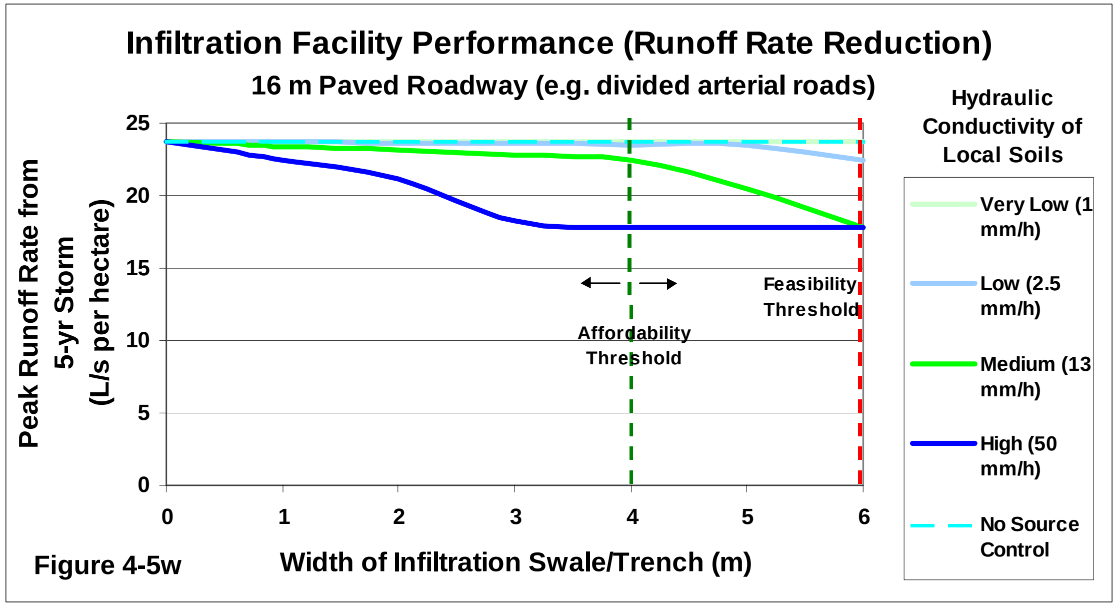


Figure 4-5w

4.6 Benefits of Pervious Paving

The runoff from paved surfaces can be virtually eliminated by replacing impervious pavement with pervious paving installed on top of 300 mm of reservoir base course (drain rock). Pervious paving can be applied on areas with light (or no) vehicle traffic (e.g. driveways, shoulders of roadways, sidewalks, overflow parking areas). Figure 4-6 provides an example of how pervious paving options for roadway can reduce runoff volume.

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

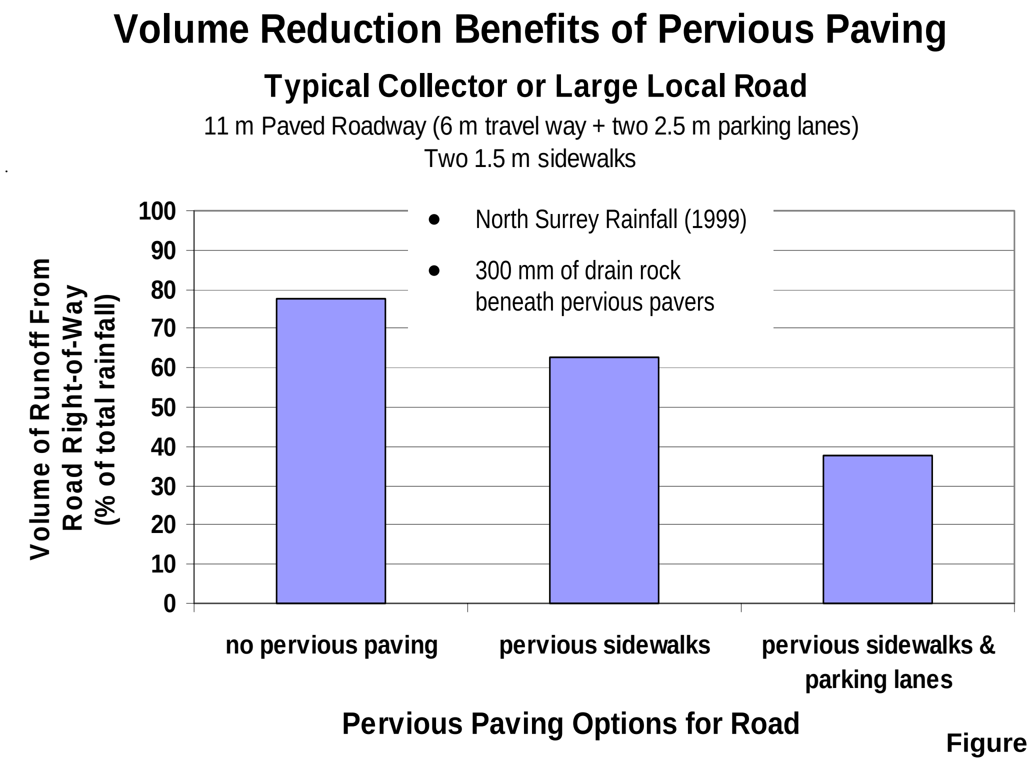


Figure 4-6

4.7 Water Quality Benefits of Infiltration Facilities

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

4.8 Cost Implications

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) and surface infiltration facilities annual operation and maintenance O & M costs are typically in the range of 5-10% of capital costs.

The operation and maintenance requirements for sub-surface facilities are less frequent but can be more costly (e.g. cleaning out a soakaway trench periodically). O & M costs are typically in the range of 5-20% of capital 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, which is significantly more than conventional paving (approximately \$5 - \$10 per m^2). Also the costs associated with vacuum sweeping may be substantial if a community does not already have the necessary equipment (see Section 4.10).

4.9 Design and Construction Tips

- The performance of infiltration facilities is highly dependant on soil conditions, which can be highly variable within a region or even within a development site. Site-specific percolation tests should be carried out (ideally under saturated soil conditions) to determine the hydraulic conductivity of soils on a development site. Percolation tests must be performed at the depth of the proposed infiltration facilities.
- The low points of bioretention facilities should be planted with plants that tolerate flooding – higher areas should be planted with streamside or upland species. Soils should have the characteristics of absorbent soils, discussed in Section 3.
- Due to their water catchment features, it is important to construct bioretention facilities in the dry season whenever possible, or to totally isolate them from flows during construction.
- Infiltration facility sites should be protected during construction from either compaction or sedimentation, by pre-identification and fencing or other means. Inadvertent compaction should be removed by ripping or scarifying the site prior to installation of infiltration facilities.
- Adequate sediment and erosion control during construction is essential to prevent clogging of infiltration facilities and their underlying soils.

4.10 Operation and Maintenance Tips

- 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.
- 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.
- 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. Pervious paving systems are typically designed with very high safety factors (around 10) to allow for some decline in system performance over time due to some surface plugging.
- Low traffic areas (e.g. roadway medians) may have some weed growth in the cracks (can be a problem for any pavements). Steam-based weeding systems are available to efficiently manage this issue without use of herbicides.

Section 5 – 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 on top of building and parkade rooftops retains rainfall and allows it evaporate or transpire from the rooftop vegetation (mostly sedums and mosses). The runoff from a green roof passes through the absorbent soil layer to an underdrain layer (there is no surface runoff), and therefore, peak runoff rates are attenuated.

Green roofs have been applied for decades throughout the GVRD—primarily as landscape features of high density residential, institutional and commercial developments. Examples of landscaping applications include the City of Vancouver Archives, the Vancouver Public Library, numerous multifamily buildings, the Greater Vancouver Regional District Headquarters, and North Vancouver City Hall.

However, the engineering of green roofs to provide multiple benefits beyond those of landscaping is new to the region. Greenroofs are classed into two categories: <u>extensive</u> green roofs which have typically a shallow soil profile of 20 to 100 mm and support mosses, grasses and sedums; and <u>intensive</u> green roofs with soil depths greater than 100 mm able to support substantial vegetation (shrubs, trees, *et cetera*).

Extensive green roofs are common in many parts of Europe and are now being introduced to North America. They are often applied for reasons other than stormwater management; engineered green roofs may also insulate buildings, provide aesthetic benefits, absorb greenhouse gases, and reduce the ‘urban heat island’ effect.

5.1 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 5-1a and 5-1b. The runoff volume reduction benefits of increasing absorbent soil depth diminish beyond about 100 mm, especially for higher rainfall locations (compare Figure 5-1a and 5-1b).

In order to achieve the maximum reduction in runoff rate from large prolonged winter storms, about 300 mm of soil depth is needed (see Figure 5-1a). However, significant reduction in runoff rates from short intense storms (i.e. cloudbursts) that occur during dry weather periods can be achieved with 100 m of soil depth (see Figure 5-1b). Figure 5-1b shows the runoff rate from an extremely intense cloudburst (peak rainfall intensity of 30 mm/hr) that occured in White Rock on June 8th, 1999. This event is discussed in more detail in Section 7.9.

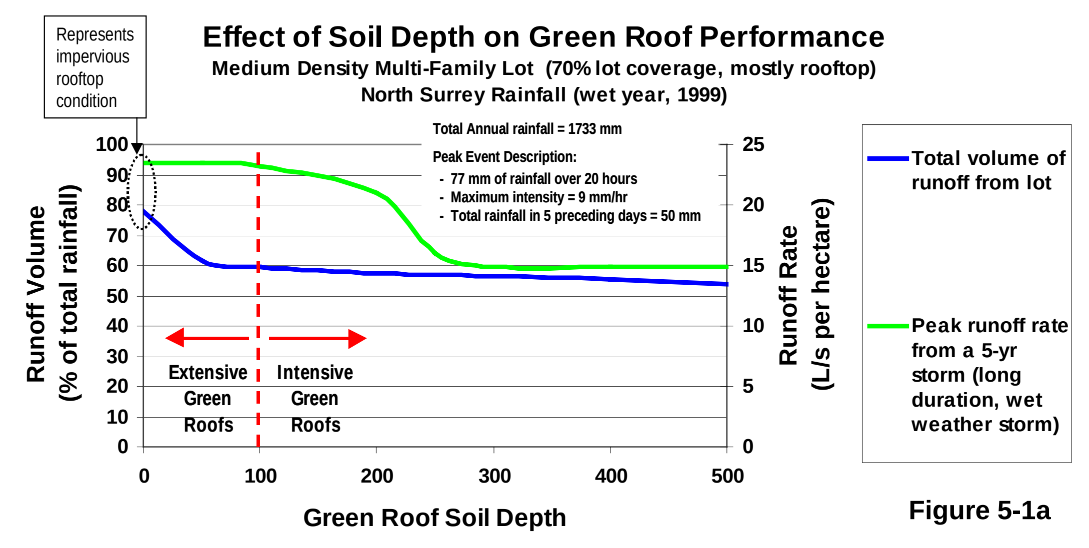


Figure 5-1a

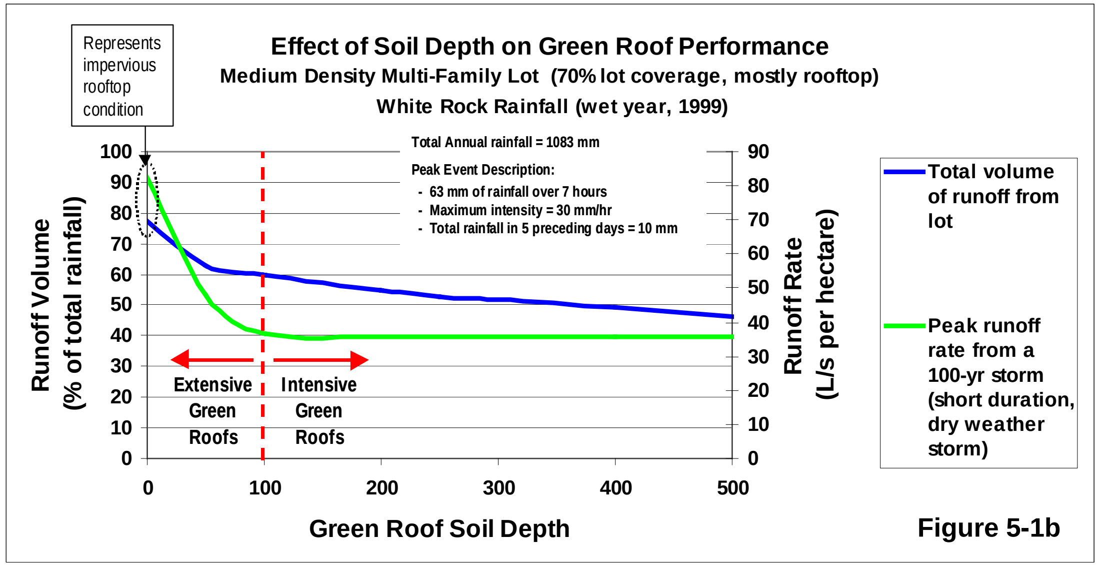


Figure 5-1b

5.2 The Effect of Rainfall

Green roofs provide more significant reduction in runoff volume where (and when) rainfall is lower, as shown in Figure 5-2. As rainfall decreases, potential evapo-transpiration becomes a greater percentage of total rainfall. Green roofs would be most effective in drier parts of the GVRD (e.g. White Rock or Delta), and would be more effective in drier years as opposed to extremely wet years.

Comparing Figures 5-3a and 5-3b with Figures 5-4a and 5-4b shows an example of how green roof effectiveness improves in locations with less rainfall (i.e. White Rock as compared to North Surrey), particularly for extensive green roofs.

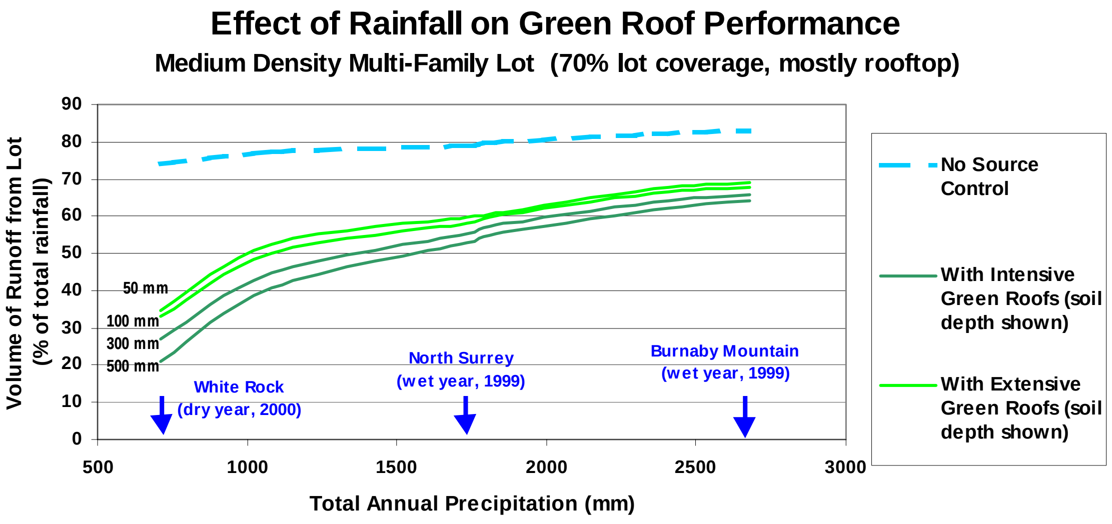


Figure 5-2

5.3 Applicability to Different Land Uses

The reduction in volume and rate of runoff that can be achieved using green roofs is most significant for land uses with high levels of rooftop coverage, such as high density multi-family or commercial uses (without substantial surface parking), as shown in Figures 5-3a, 5-3b, 5-4a, and 5-4b.

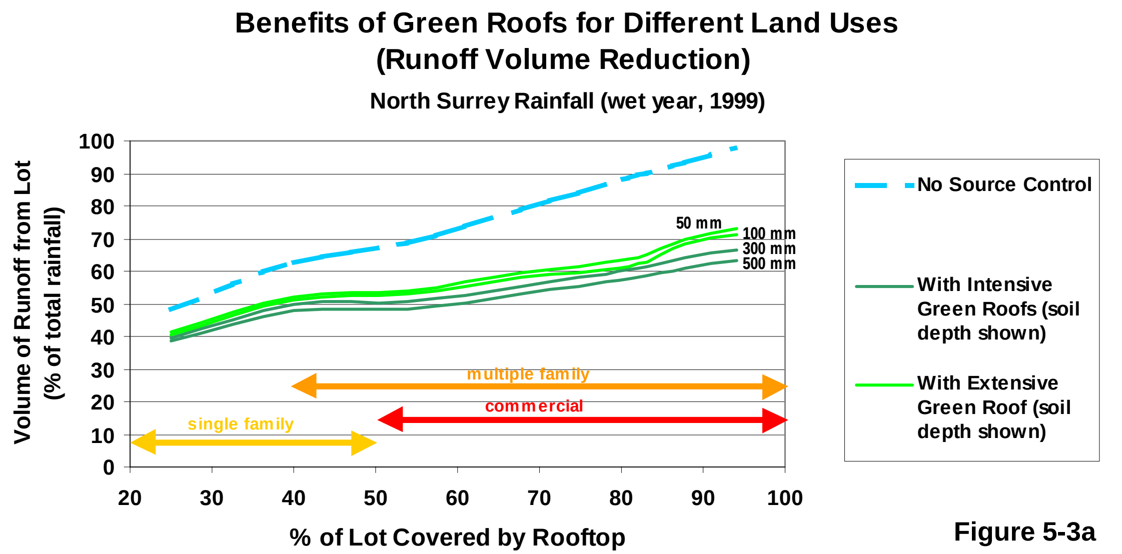


Figure 5-3a

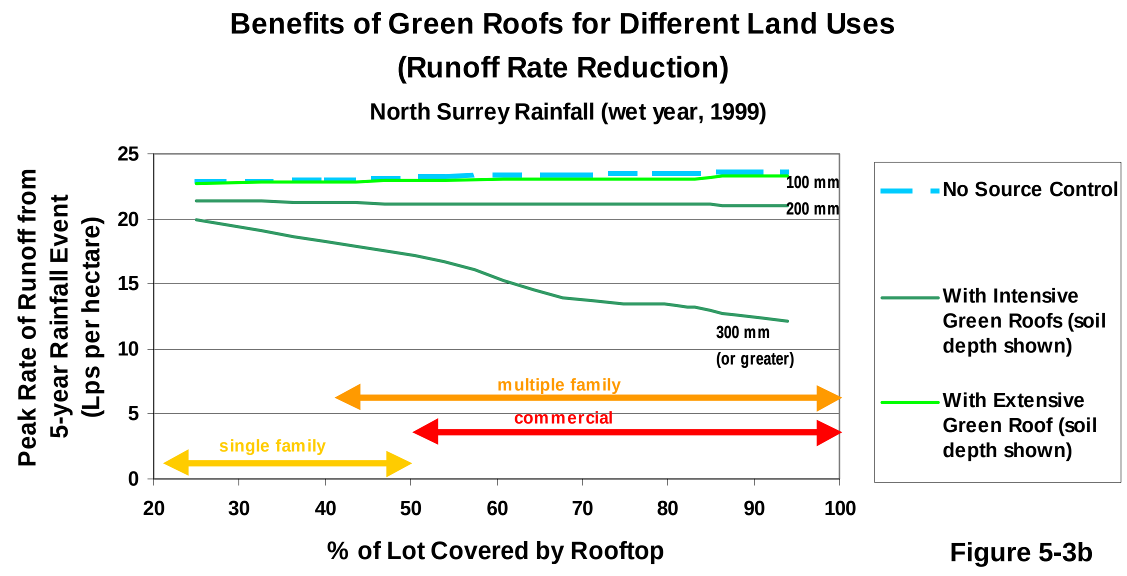


Figure 5-3b

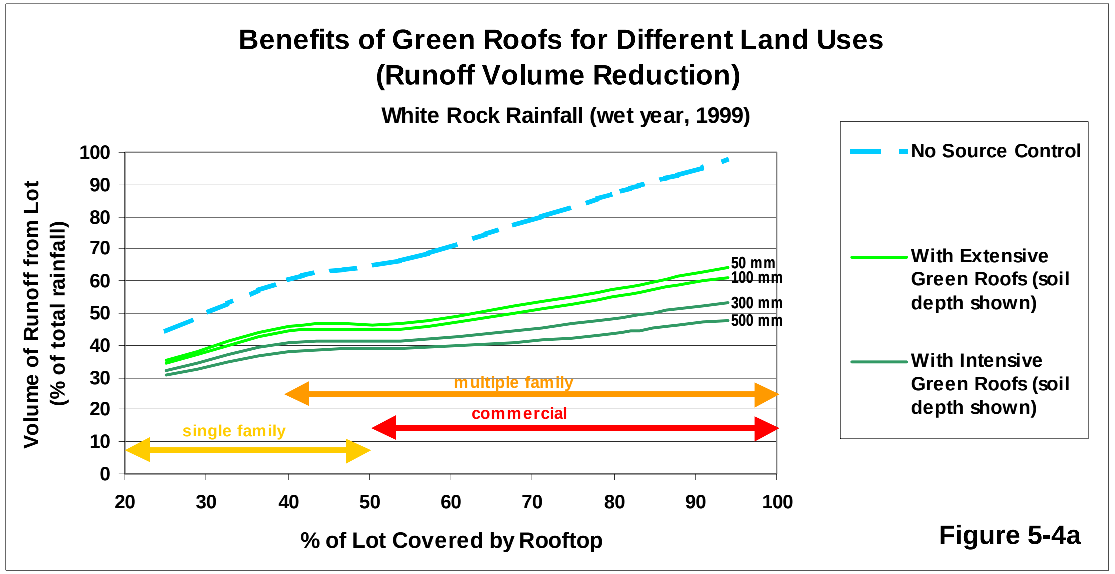


Figure 5-4a

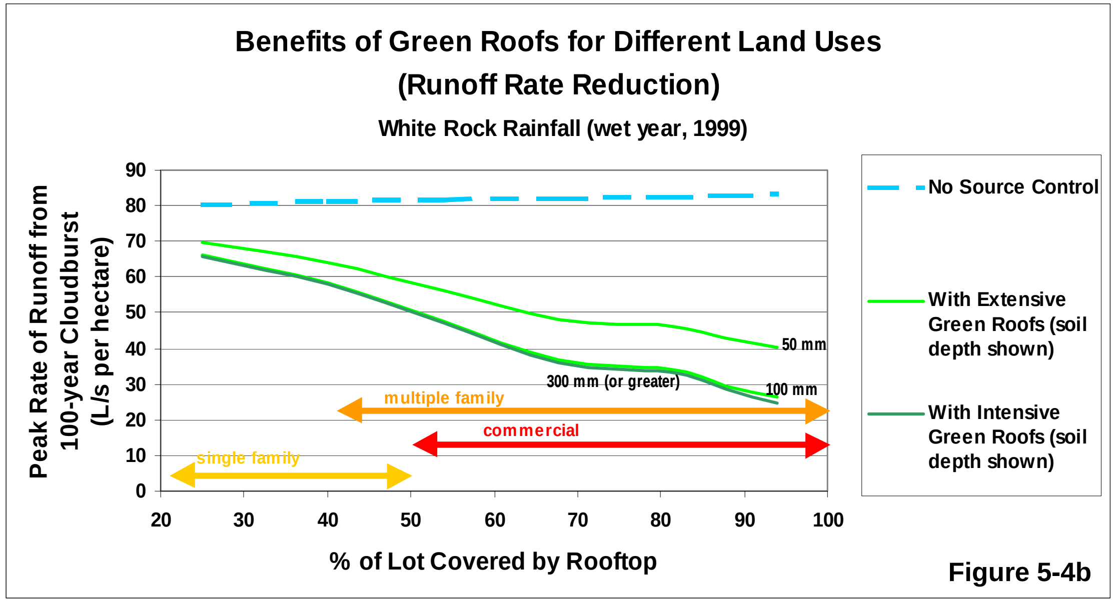


Figure 5-4b

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 5-3a, 5-3b, 5-4a, and 5-4b show the modelling results for multi-family and commercial land uses with limited surface parking (i.e. rooftop coverage is approximately equal to impervious coverage).

5.4 Cost Implications

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 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)..

The City of White Rock recently installed a green roof demonstration project (100 mm soil depth), and found the installation costs to be about $90 per m^2 greater than a conventional impervious roof.

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.

Operation and Maintenance

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

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.

Section 6 – Rainwater Reuse

Just as the trees in a forest use a significant portion of rainfall, capturing rainfall for human reuse can play a key role in managing water balance at the site level. The benefits of rainwater reuse go beyond stormwater management (i.e. reducing runoff from developed areas), which is the focus of this report. Reuse can also reduce the amount of water drawn from reservoirs and reduce the costs of water supply infrastructure.

Reusing stormwater for irrigation provides limited runoff reduction benefit because the demand for irrigation water occurs during the dry weather periods, and most runoff occurs during wet weather periods. Significant reductions in runoff volume can be achieved by capturing and reusing rainwater for indoor greywater uses, particularly for high density land uses. Note that rainwater reuse is most beneficial on land uses where the opportunities for infiltration are most limited.

6.1 Applicability to Different Land Uses

Significant reductions in runoff volume can be achieved on high density residential land uses by capturing and reusing rooftop runoff for toilets and washing machines, as shown in Figure 6-1a. Since residential water use rates increase as population density increases, the reduction in runoff volume can be achieved through rainwater reuse increases as population density increases.

The level of volume reduction that can be achieved by reusing rainwater for greywater type uses (toilets and washing machines) on commercial land uses varies significantly depending on the type and density of commerical land use, as shown in Figure 6-1b. This figure reflects the fact that water use rates for different commercial land use types are highly variable. 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).

Figures 6-1a and 6-1b assume that multi-family and commercial land uses have limited surface parking (i.e. rooftop coverage is approximately equal to impervious coverage). The impact of surface parking is shown on the following page.

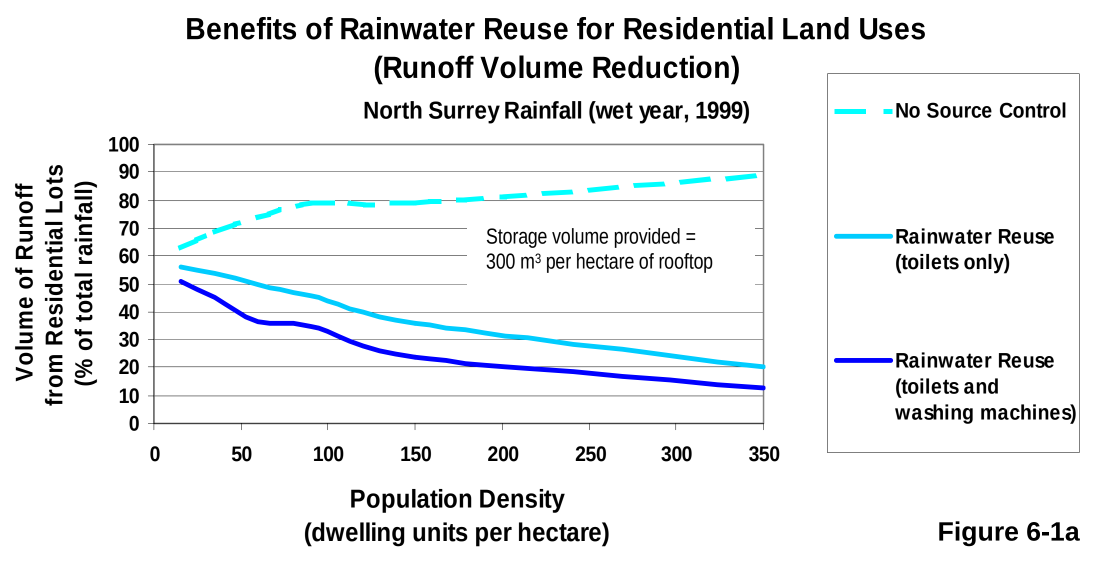


Figure 6-1a

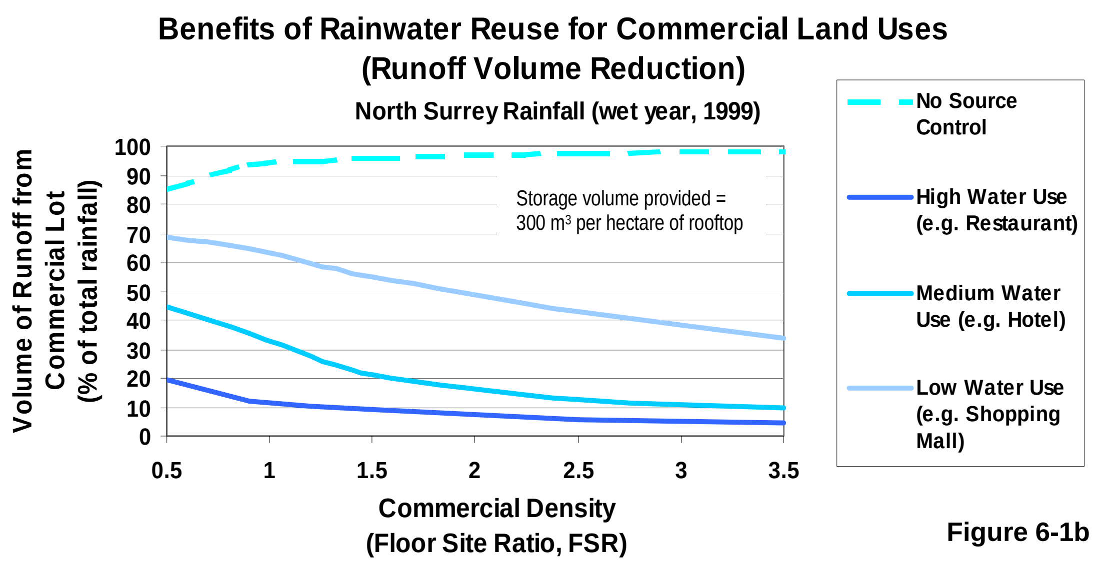


Figure 6-1b

6.2 The Impact of Surface Parking

The potential benefits of rainwater reuse are significantly less for residential and commercial land uses that have extensive amounts of surface parking, as shown in Figures 6-2a and 6-2b. This reflects the assumption that runoff from paved surfaces is not reused for indoor uses, primarily due to water quality concerns (although it may be possible with appropriate treatment).

6.3 The Effect of Storage Volume

Increasing storage volume (i.e. size of rain barrels or cisterns) can improve the hydrologic benefits of rainwater reuse, as shown in Figure 6-3. The volume reduction benefits of providing additional storage capacity diminish beyond a relatively low threshold (about 100 m³ per ha of rooftop). Beyond this threshold, runoff volume reduction is primarily a function of land use characteristics (e.g. population density, commercial density and land use type, type of parking). Very large storage volumes are needed to achieve any significant reduction in peak runoff rates from extreme rainfall events (e.g. a 5-yr winter storm), as shown in Figure 6-3.

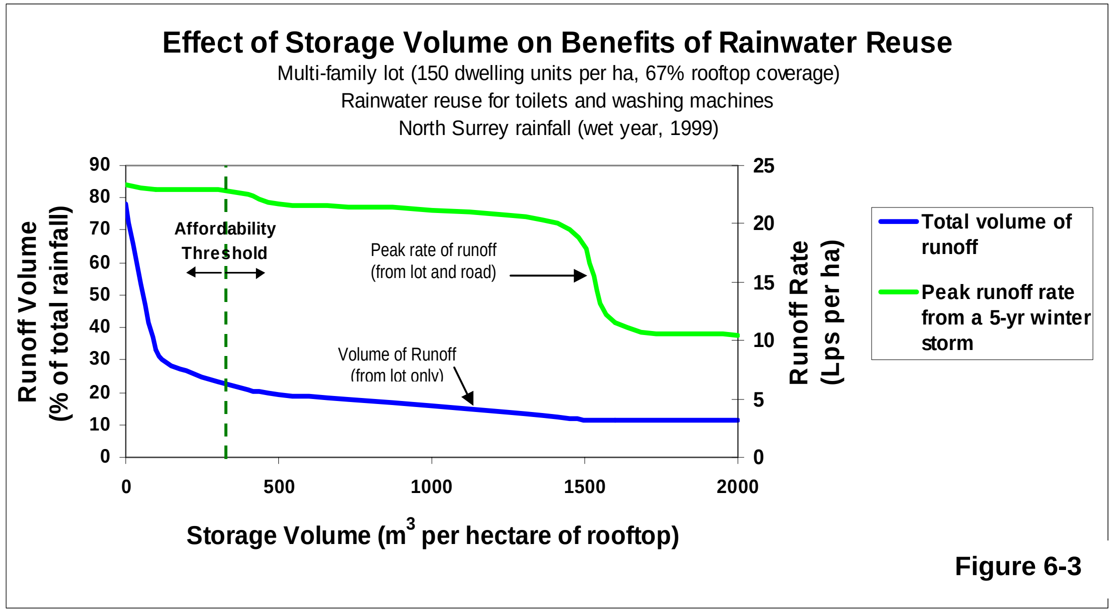


Figure 6-3

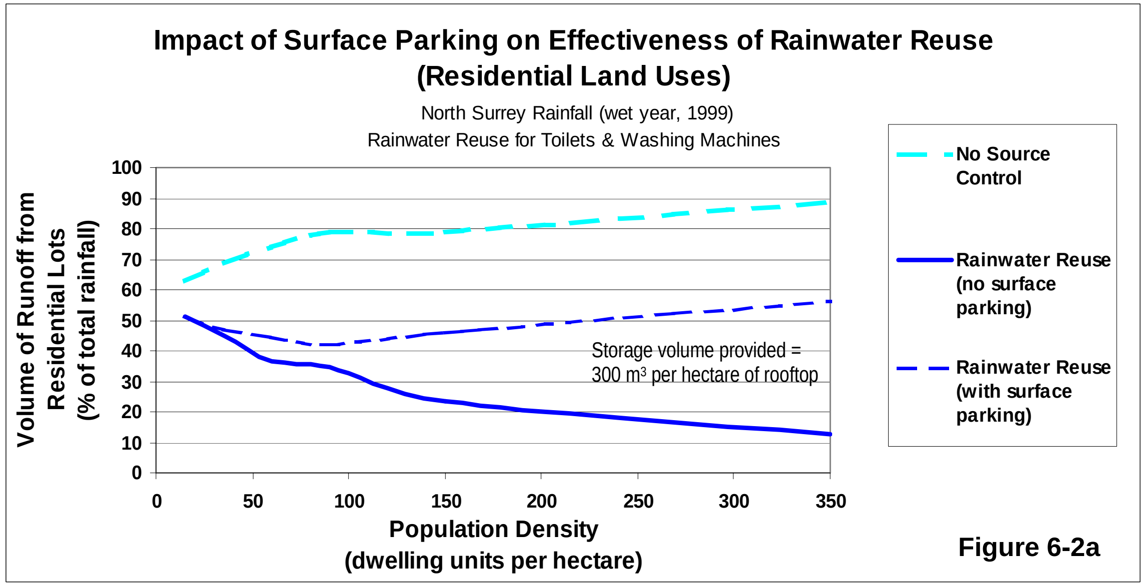


Figure 6-2a

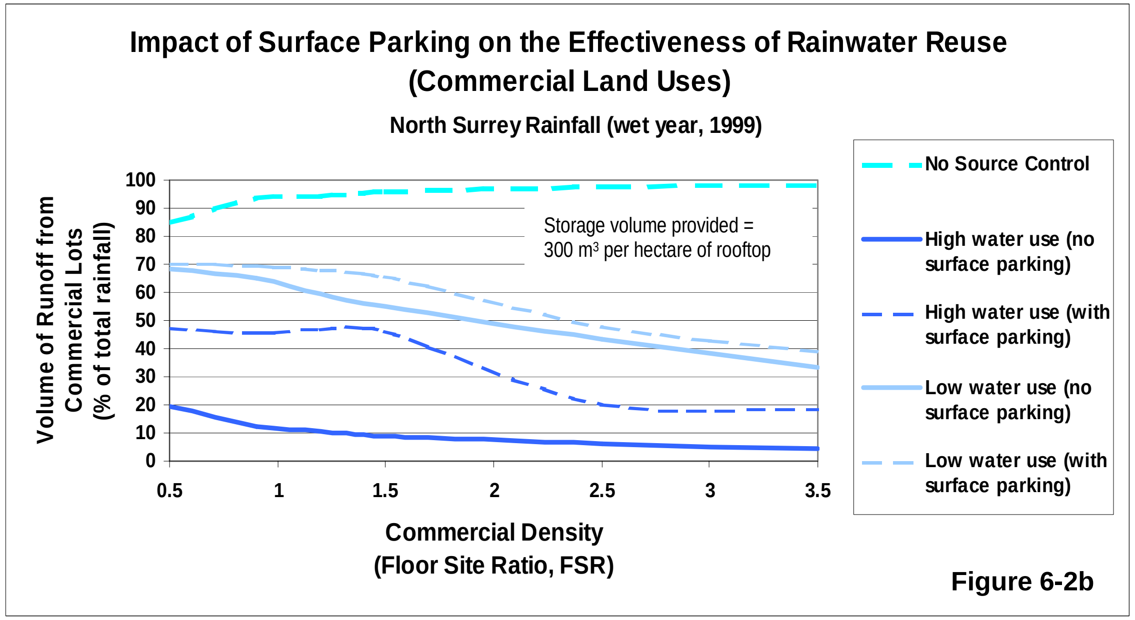


Figure 6-2b

6.4 The Effect of Rainfall

Greater reductions in runoff volume can be achieved through rainwater reuse where (and when) rainfall is lower, as shown in Figure 6-4. As rainfall decreases, water use rates (a function of land use type) become a greater percentage of total rainfall.

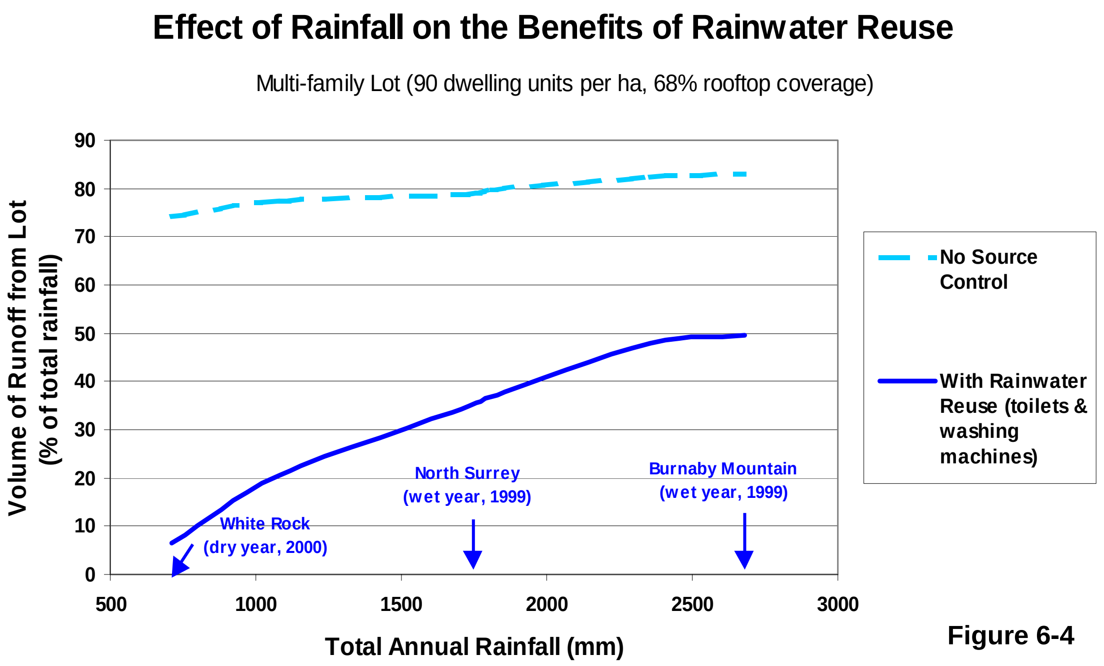


Figure 6-4

6.5 Cost Implications

The design and costs of rainwater reuse 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 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), and at a 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 reuse.

Section 7 - Watershed Retrofit Case Studies

7.1 Context and Overview

Watershed retrofit scenarios were modeled for three developed watersheds in the GVRD: MacKay Creek (North Vancouver), McKinney Creek (Maple Ridge), and Quibble Creek (Surrey). The purpose of the watershed modeling was to answer the questions:

- ☐ Does implementing stormwater source controls on all new developments and re-developments over a long period, on a watershed-wide basis, benefit flood management and urban stream health?
- ☐ Are there specific stormwater source controls that work better in theory than others?

The results presented in this section demonstrate **that it is achievable to significantly improve and potentially restore watershed health over a 50-year timeline by applying combinations of source controls.**

This section provides a broad overview of the potential for source controls, but does not evaluate source control options in the context of an integrated stormwater management plan – that is the next step. The ISMP process will determine what is achievable and affordable in the context of each individual watershed.

Also provided at the end of this section is a case study example from White Rock that shows the potential for source controls to mitigate the impacts of extreme cloudbursts.

A more detailed watershed retrofit case study of the Still Creek Watershed is presented in Appendix A.

7.2 Realizing the Long Term Visions

The ISMP processes must identify critical stream reaches and sub-watersheds where there are significant resources to be protected (or restored), and/or where there are drainage problems, such as erosion of ravines or chronic flooding. A more detailed assessment of the costs and benefits of source control options should focus on the sub-catchments that drain into these critical reaches.

An analysis of the land use in these sub-catchments will provide an estimate of the time frame for re-development (or new-development) over the next 50-years. If there is substantial old development in these sub-catchments (e.g. pre-1960's), there may be opportunities to apply source controls in the short-term and solve immediate problems.

The costs and benefits of implementating source control options in these sub-catchments must be evaluated based on more detailed information on soil conditions, hydrogeology, rainfall, streamflow, drainage infrastructure, and site design.

Adequate soils information is currently a missing link. None of the municipalities that participated in the case study modeling had access to good soils information.

7.3 Indicators of Watershed Restoration

The watershed retrofit scenarios were evaluated based the following indicators of success:

- ☐ **Total Runoff Volume** - The primary watershed restoration target is to *limit total runoff volume to 10% (or less) of total rainfall volume.* As discussed in Section 1, this target is based on the water balance of a healthy watershed.
- ☐ **Number of times the natural MAF exceeded** – Ideally, the peak runoff rates from developed areas should only exceed the natural MAF about once per year, on average (more often during wet years).
- ☐ **Peak runoff rate from extreme rainfall events** – Reduction of peak runoff rates (e.g. from a 5-yr storm) reduces watercourse erosion and flooding risk.

The first two indicators show how well stream health is being restored, and the third provides an indication of how well flood risk is being managed over time. These are simply *indicators of potential benefits.* A more detailed evaluation of source control benefits for a particular watershed must consider the value of aquatic resources and the condition of drainage infrastructure in the watershed.

The watershed restoration scenarios presented in this section show the reduction in peak runoff rates from a typical winter storm with a 5-yr return period. In general, the level of peak flow reduction from more extreme rainfall events (e.g. 25-yr or 100-yr storms) is likely to be less.

Note that the return period of a given size storm varies from place to place. For example, the 24-hr rainfall depth that corresponds to a 5-yr return period in North Vancouver would be closer to a 100-yr return period storm in South Surrey.

In order to evaluate the opportunities to manage flood risk in a given watershed through the application source control, the characteristics of rainfall and drainage infrastructure specific to that watershed must be considered. Applying source controls through re-development may be able to maintain or improve the level of service provided by the drainage infrastructure in a particular watershed.

7.4 Source Control Scenarios

The following source control scenarios were modeled for each case study watershed, and evaluated relative to the above indicators:

- **Scenario 1: Unmitigated** – Re-development occurs according to the standard practice of land development and stormwater management (i.e. no source controls applied).
- **Scenario 2: Unmitigated with Climate Change** – Same as Scenario 1, except that the anticipated effect of climate change on rainfall patterns is factored into the future scenarios.
- **Scenario 3: Absorbent Landscaping + Infiltration Facilities** – For all future re-development projects: undeveloped areas are covered by absorbent landscaping, and infiltration facilities are provided for all impervious surfaces – infiltration swales on all roads, and bioretention facilities on all building lots (infiltration facility designs are as described in Section 4.5). The size of infiltration facilities used for each land use type and road type were adjusted until the 10% runoff volume target was achieved or until the feasibility threshold was exceeded.
- **Scenario 4: Intensive Green Roofs + Absorbent Landscaping + Infiltration Facilities** – Same as Scenario 3, except that all re-developed multiple family and commercial buildings are designed with intensive green roofs (300 mm of soil depth) instead of. The runoff from green roofs is directed to infiltration facilities (as described in Scenario 3). All re-developed single family building have land uses have impervious roofs connected to infiltration facilities. Intensive green roofs are not considered feasible for single family land uses.
- **Scenario 5: Rainwater Reuse + Absorbent Landscaping + Infiltration Facilities** – Same as Scenario 3, except that all re-developed buildings (including single family) incorporate rainwater reuse cisterns (300 m^3 of storage per hectare of rooftop, water reused for toilets and washing machines). Overflow from the reuse cisterns is directed to infiltration facilities (as described in Scenario 3).

The cumulative hydrologic benefits (or impacts) associated with implementing these source control scenarios were modeled over a 50-year timeline.

7.5 Information and Assumptions

The source control scenarios were modeled based on information and assumptions regarding:

- **Land use within the watersheds -** The local government partners (District of North Vancouver, the District of Maple Ridge, and the City of Surrey) provided statistical data on the distribution of land use types within their respective watersheds. Surrey provided information on both existing zoning and future OCP zoning, which provided a basis for quantifying future land use change (densification). The site design characteristics for each land use type were estimated based on information on zoning bylaws and development standards (also provided by local government partners).
- **The expected timeframe for re-development** – For the MacKay and McKinney watersheds, the age of existing development within the watersheds was estimated based on discussion with the local government partners and field investigation. For the Quibble Creek watershed, the City of Surrey provided data showing the date of servicing for individual development parcels (a good approximation of building age). A 50 year re-development cycle is assumed for all the watersheds.
- **Soil conditions** – There was limited soils information available for the case study watersheds. Conservative assumptions were made regarding the hydraulic conductivity of soils, which is appropriate because this results in conservative findings regarding what is achievable with infiltration.
- **Rainfall** - Rainfall data from the GVRD gauges closest to each case study watersheds was used to simulate the performance of the source control scenarios. A year of continuous rainfall data from a very wet year (1999) was used to simulate the scenarios for each watershed.
- **Climate change** - Climate change scenarios were generated by applying climate change factors (developed by the Canadian Centre for Climate Modelling and Analysis) to the rainfall data for each watershed (1999 rainfall).

7.6 McKinney Creek Watershed, Maple Ridge

Land Use

The majority of the 517 hectare McKinney Creek watershed (about 72%) is single family. With the exception of a small amount of housing in the northern portion of the watershed, most of this single family housing is relatively old (pre 1980s) with relatively low levels of lot coverage (around 30%). The remaining watershed area comprises some multi-family housing (about 8% of the watershed), some commercial land uses along the highways (about 6%), and some other land uses (about 14%), including agricultural areas, schools and community parks.

Rainfall

Hourly rainfall data from GVRD rainfall gauge DM44 in Maple Ridge was used to simulate the performance of the source control scenarios. 1999 rainfall was used (total annual rainfall = 1811 mm).

Soils Information

The available soils information included Geologic Survey of Canada mapping, and some soils mapping that was done in conjunction with a sub-surface drainage assessment (at a fairly coarse level). Based on this information the conservative assumptions was made that soils have poor to medium hydraulic conductivity (6 mm/hr). There was little basis for estimating the variability of soil conditions throughout the watershed.

The District of Maple Ridge has reports that indicate the potential for relatively high water table conditions (in a localized region of the watershed). The depth of all infiltration facilities was reduced to reflect this information.

Results

The primary form of re-development that is likely to occur in the McKinney Creek Watershed is the re-development of older (relatively low coverage) single family lots to higher coverage single family lots. This will likely be the result of larger homes and driveways being placed on existing lots and/or existing large lots being subdivided into smaller lots.

Without source control (Scenarios 1 and 2), this re-development can be expected to increase total runoff volume, peak runoff rates, and the number of times the natural MAF is exceeded (as shown in Figures 7-1a, 7-1b and 7-1c). The effects of climate change are likely to exacerbate the increase in runoff.

The 10% runoff volume target can be achieved with infiltration facilities and absorbent landscaping (source control Scenario 3) for all residential land uses but not for commercial land uses. Since commercial land uses represent a small portion of the total watershed area, the application of absorbent landscaping and infiltration facilities could come very close to achieving the 10% runoff volume target at the watershed scale.

At the watershed scale, there is little additional benefit gained by adding rainwater reuse or green roofs.

The addition of green roofs does significantly improve the reduction in peak runoff rates from multiple family and commercial land uses. However, this translates into a relatively small benefit at the watershed scale because most of the watershed is single family.

Similarly, the addition of rainwater reuse improves the reduction runoff volume from commercial land uses, but this translates into a small benefit at the watershed scale.

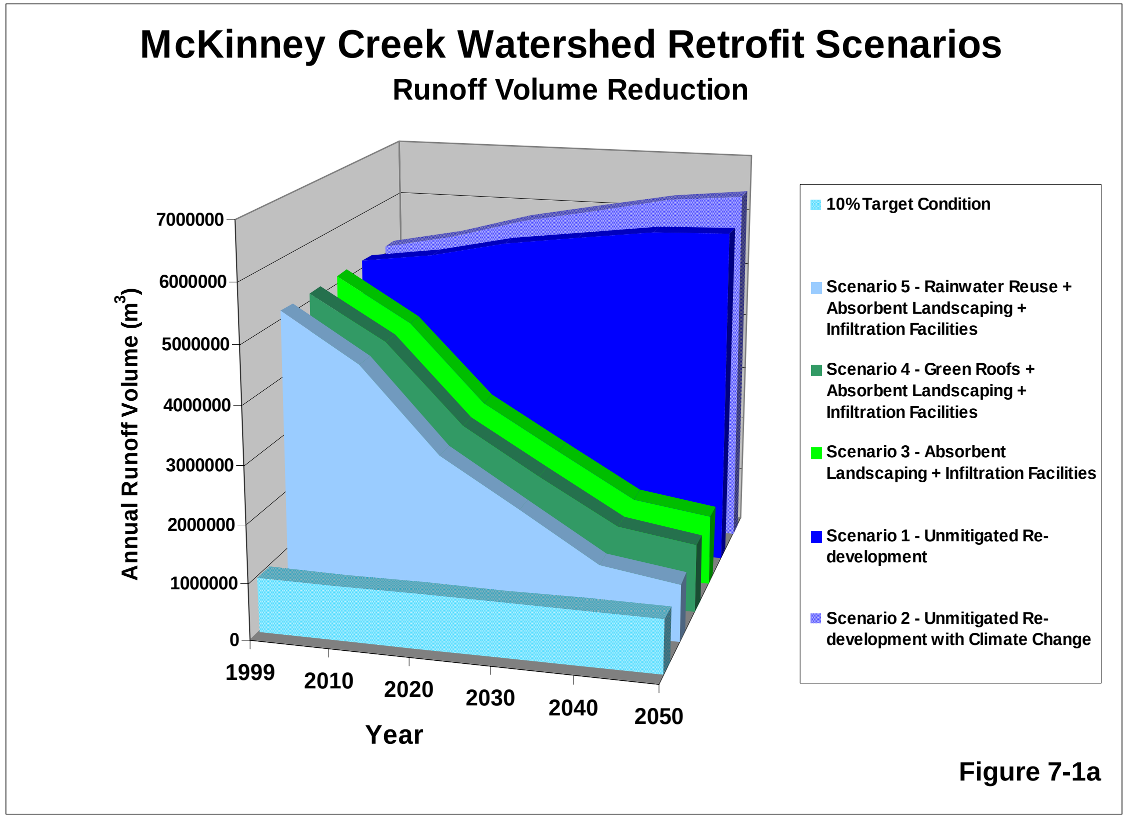


Figure 7-1a

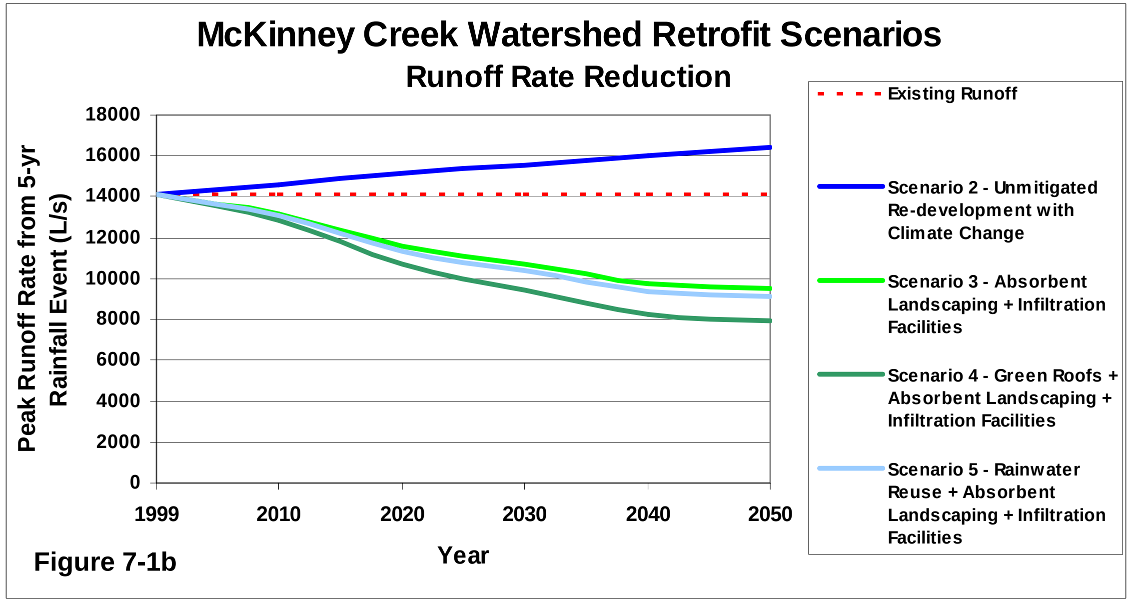


Figure 7-1b

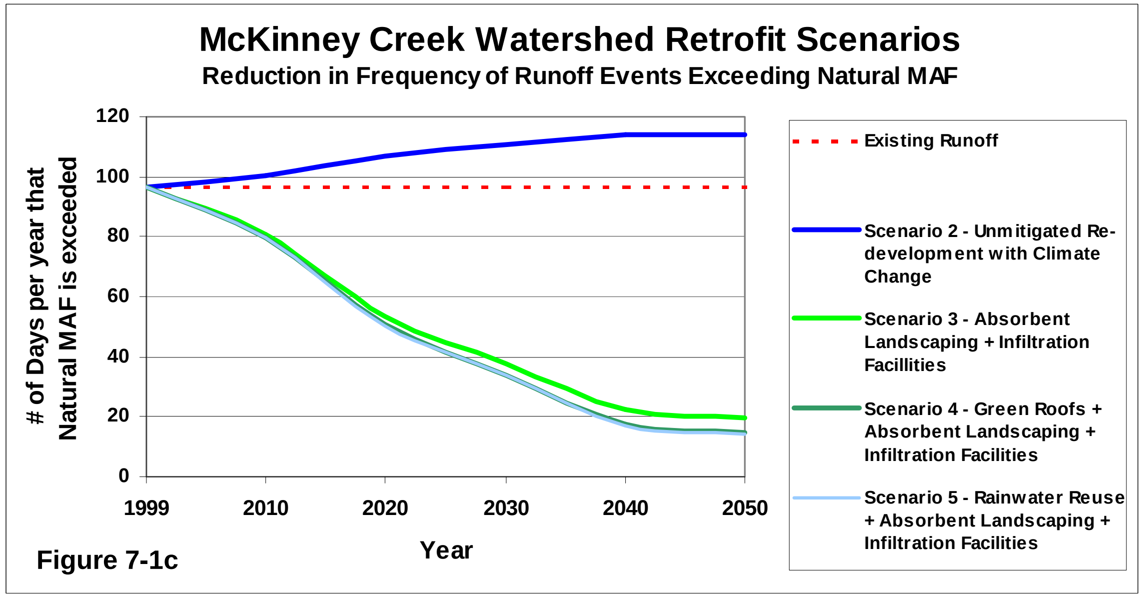


Figure 7-1c

7.7 MacKay Creek, North Vancouver

Land Use

The substantial portion of the 771 hectare MacKay Creek Watershed (about 34%) is undeveloped land, most of which is in the upper watershed on Grouse Mountain and will likely remain undeveloped. The dominant land use in the watershed is single family residential (about 45% of the watershed). Most of this single family housing is quite old (pre 1970s) with relatively low levels of lot coverage (around 30%). A significant amount of the single family housing (about half) is very old (pre 1960s) and can be expected to re-develop within the next 10 years. The remaining watershed area comprises, some commercial land uses in the lower watershed (about 16% of the watershed area), and some multi-family housing (about 5%).

Rainfall

Hourly rainfall data from GVRD rainfall gauge DN25 in North Vancouver was used to simulate the performance of the source control scenarios. 1999 rainfall was used (total rainfall = 2355 mm).

Soils Information

The only soils information available was the Geologic Survey of Canada soils mapping (1:50,000 scale). This mapping shows most of the watershed to be high conductivity soil, however discussions with District staff indicate that much of the surface soil in the watershed is highly compacted. Based on this information the conservative assumptions was made that soils have poor to medium hydraulic conductivity (about 6 mm/hr). There was no basis for estimating the variability of soil conditions throughout the watershed.

Results

The primary form of re-development that is likely to occur in the MacKay Creek Watershed is the re-development of the older (relatively low coverage) single family lots to higher coverage single family lots. This will likely be the result of larger homes and driveways being placed on existing lots and/or existing large lots being subdivided into smaller lots.

Without source control (Scenarios 1 and 2), this re-development and the effects of climate change can be expected to increase total runoff volume, peak runoff rates, and the number of times the natural MAF is exceeded (as shown in Figures 7-2a, 7-2b and 7-2c on the following page).

The increase in runoff is not as significant as that observed for McKinney Creek because the single family land area is a smaller proportion of the overall MacKay Creek watershed. However, MacKay Creek is currently an unstable system, which is not surprising given the wide gap between the 10% target condition and existing conditions.

The 10% runoff volume target can be achieved with infiltration facilities and absorbent landscaping (source control Scenario 3) for residential land uses but not for commercial land uses. Adding rainwater reuse could bring commercial land uses much closer to the 10% target, but this is less significant at a watershed scale since commercial land uses represent a relatively small portion of the total watershed area. Since residential land uses represent the greatest portion of the developed watershed area, the application of absorbent landscaping and infiltration facilities could come very close to achieving the 10% runoff volume target at the watershed scale.

At the watershed scale, there is relatively little additional benefit gained by adding rainwater reuse or green roofs (although slightly greater benefit than for McKinney Watershed), because single family is the dominant land use.

The addition of green roofs to multiple family and commercial buildings does provide some benefit at the watershed scale, particularly in terms of reducing peak runoff rates from extreme rainfall events. The addition of rainwater reuse on commercial land uses also provides some benefit, particularly in terms of reducing total runoff volumes.

Figures 7-2a, 7-2b and 7-2c show that there is opportunity to achieve significant runoff reduction in the MacKay Creek watershed over the next 10 years, as the pre 1960s single family houses re-develop. If the standard practice of land development and stormwater management is not changed in the near future, this opportunity will be lost.

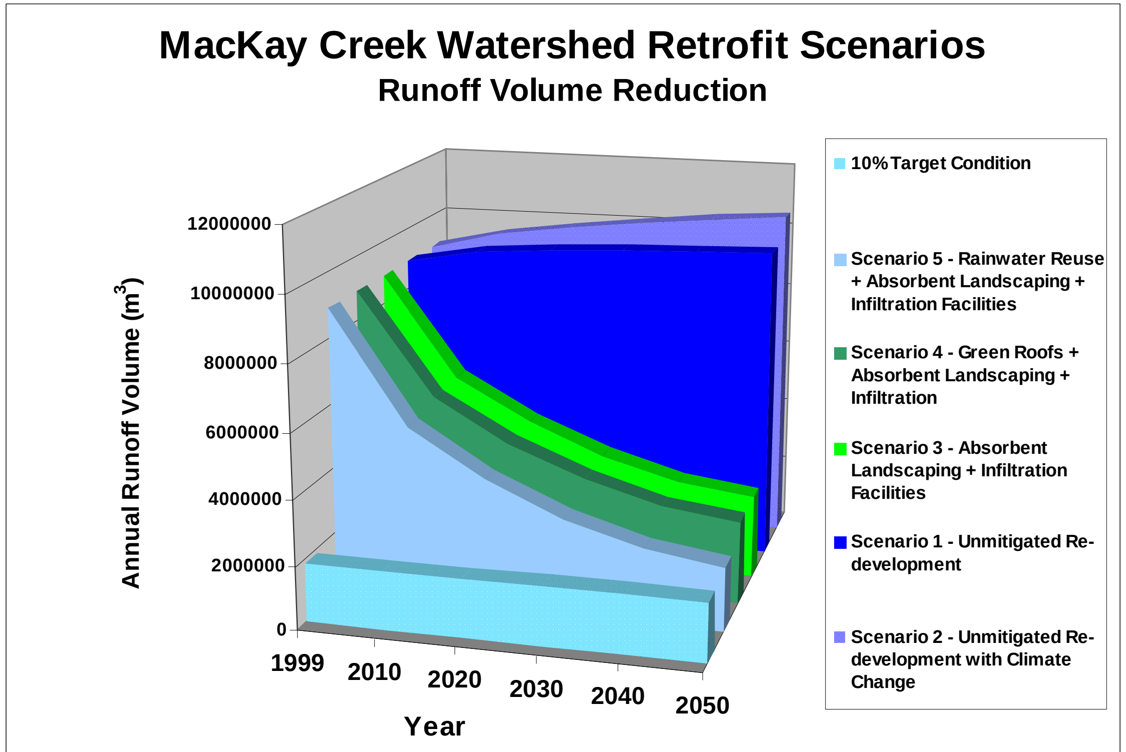


Figure 7-2a

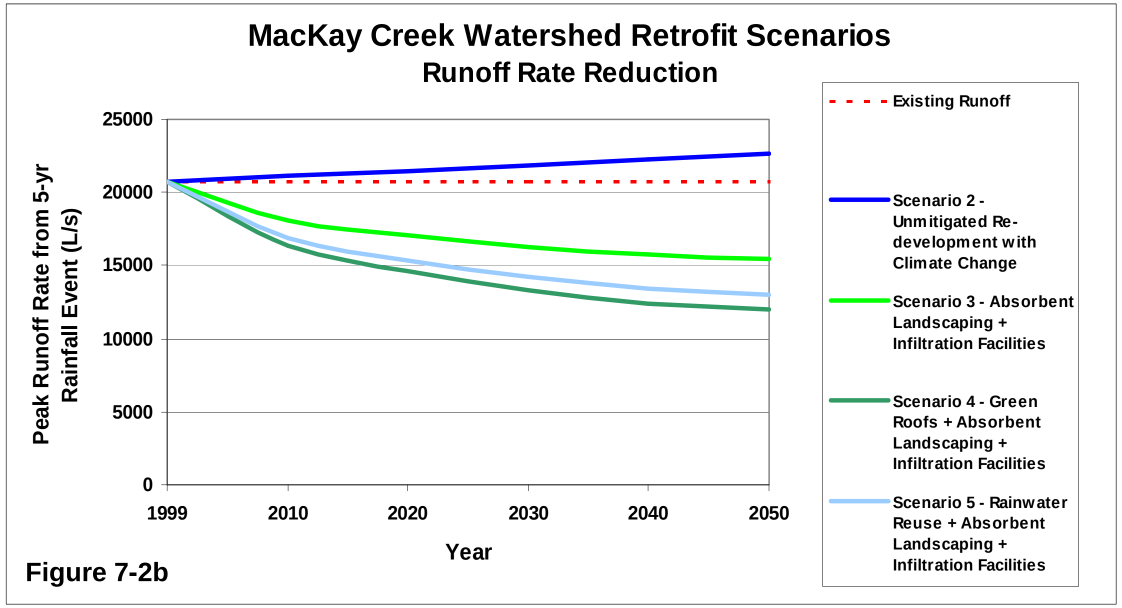


Figure 7-2b

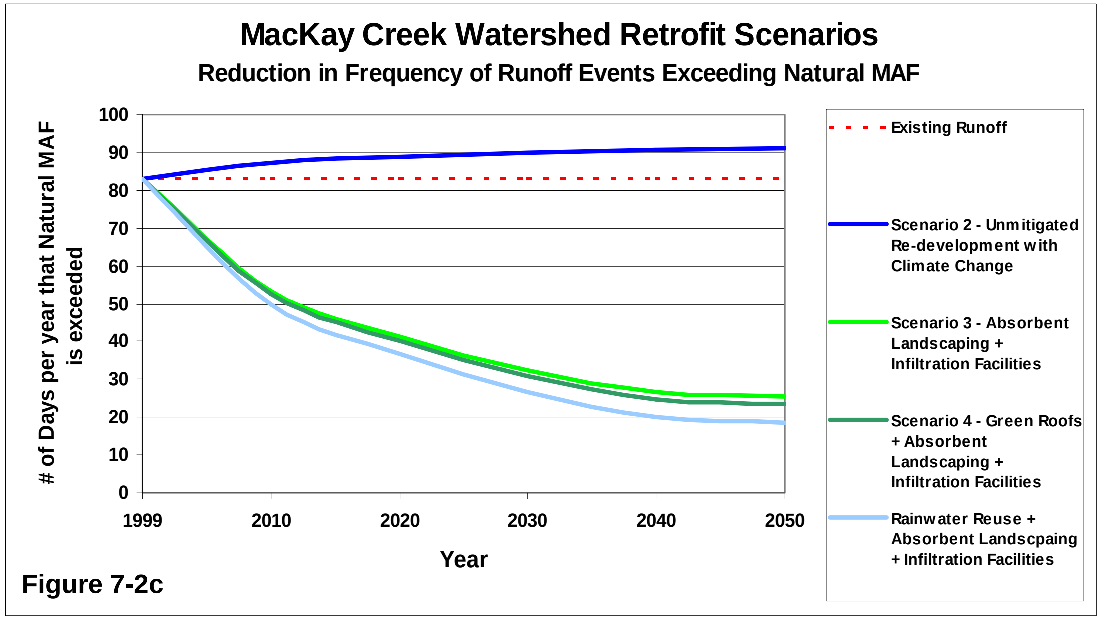


Figure 7-2c

7.8 Quibble Creek, Surrey

Land Use

The substantial portion of the 622 hectare Quibble Creek Watershed (about 54%) is currently single family land use. A significant portion of the single family houses are relatively new (post 1980). The remaining watershed area comprises commercial land uses (about 20% of the watershed area), some multi-family housing (about 8%), and conservation areas (about 18%) that are not likely to develop in the future.

The City of Surrey's Official Community Plan calls for significant densification in the Quibble Creek Watershed. About two thirds of the existing single family housing in the watershed is expected to re-develop as multiple family land uses (a range of densities). The amount of commercial land is not likely to increase substantially, but existing local and community commercial land uses are expected to re-develop as higher density town centre commercial.

Rainfall

Hourly rainfall data from GVRD rainfall gauge SU56 in North Surrey was used to simulate the performance of the source control scenarios. 1999 rainfall was used (total rainfall = 1733 mm).

Soils Information

The only soils information available was the Geologic Survey of Canada soils mapping (1:50,000 scale). This mapping shows about half of the watershed to be high conductivity soil and the other half to be low conductivity soils. Based on this information the conservative assumptions was made that soils have poor hydraulic conductivity (2.5 mm/hr). Aside from the coarse level GSC mapping there was no basis for estimating the variability of soil conditions throughout the watershed.

Results

The primary impact of densification in the Quibble Creek Watershed is likely to result from the re-development of the single family land uses to multi-family land uses with higher impervious coverage. Commercial densification also increases impervious coverage but to a lesser extent (even local commercial land uses have relatively high level of impervious coverage).

Without source control (Scenarios 1 and 2), densification and the effects of climate change can be expected to increase total runoff volume, peak runoff rates, and the number of times the natural MAF is exceeded (as shown in Figures 7-3a, 7-3b and 7-3c on the following page).

The 10% runoff volume target can be achieved with infiltration facilities and absorbent landscaping for all land uses except those with greater than about 80% impervious coverage (includes the highest density multi-family land uses and nearly all commercial land uses). At a watershed scale, the application of absorbent landscaping and infiltration facilities (Scenario 3) could come fairly close to achieving the 10% target (reduce runoff volume to about 20% of total rainfall). In order to achieve the 10% target, it would be necessary to apply rainwater reuse to these high coverage land uses (i.e. Scenario 5).

Green roofs and rainwater reuse would have more significant runoff reduction benefits for the Quibble Creek Watershed (than for MacKay or McKinney) because high coverage land uses (high density multi-family and commercial) represent a larger portion of the total watershed area. The benefits of rainwater reuse are most significant in terms of reducing runoff volume. The benefit of green roofs are most significant in terms of reducing peak runoff rates from extreme rainfall events.

In general, development in the Quibble Creek Watershed is newer than the development in MacKay and McKinney, and therefore, there will likely be less re-development in the short term. This is why Figures 7-3a, 7-3b and 7-3c show less runoff reduction over the next 10-years than the corresponding graphs for the other case study watersheds.

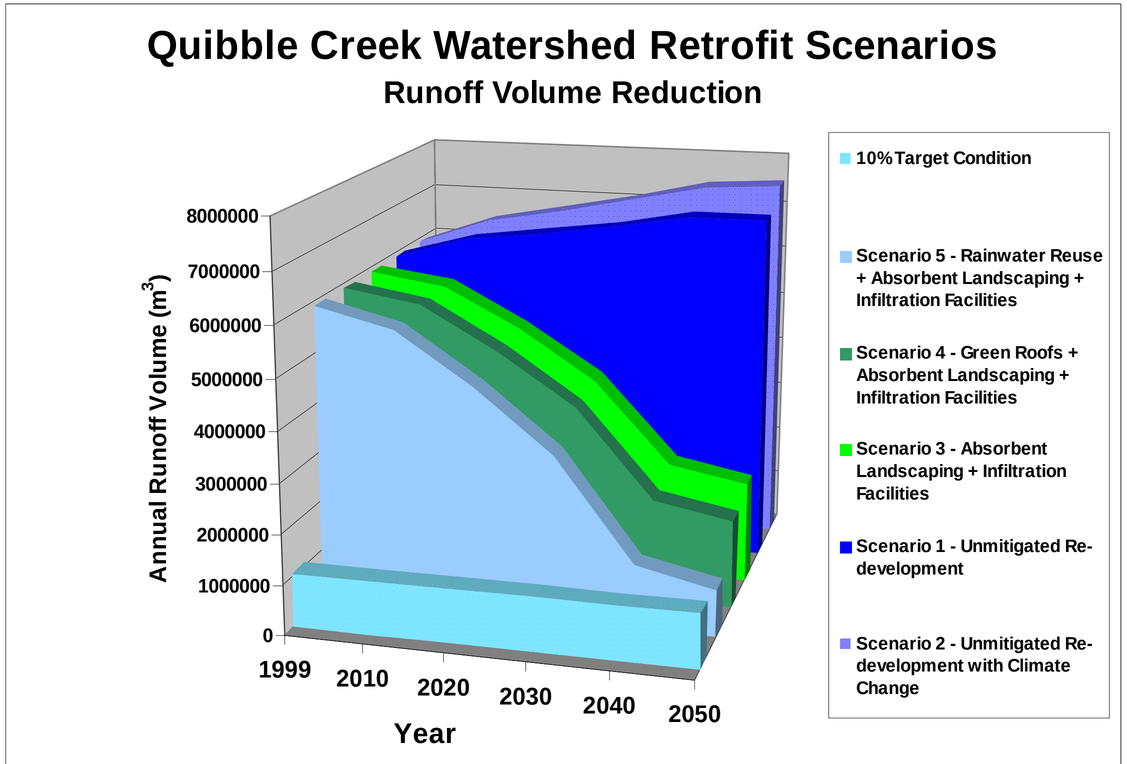


Figure 7-3a

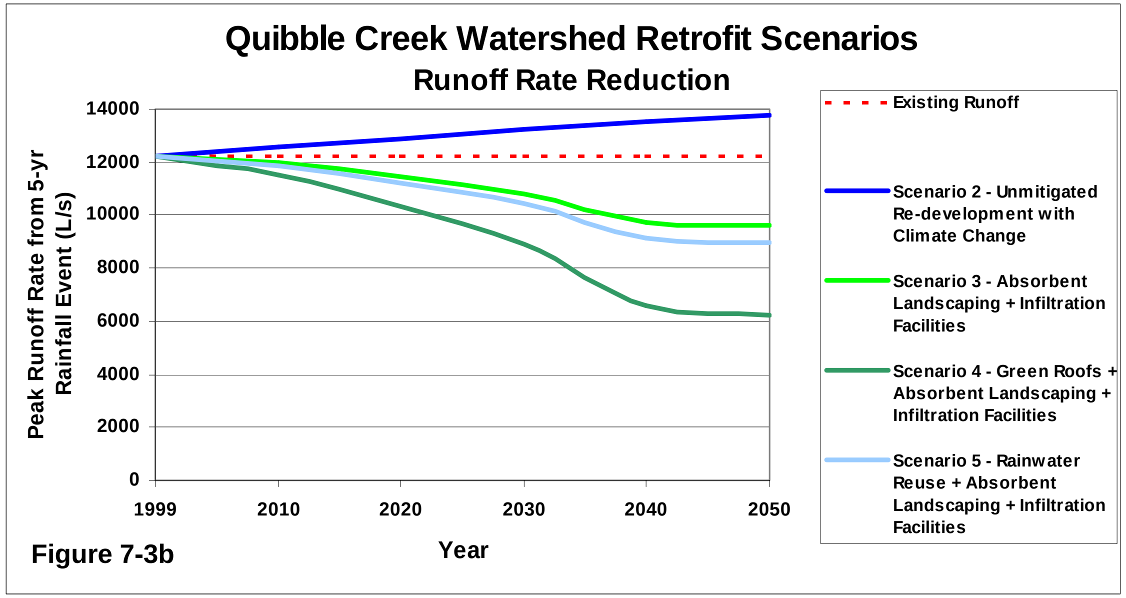


Figure 7-3b

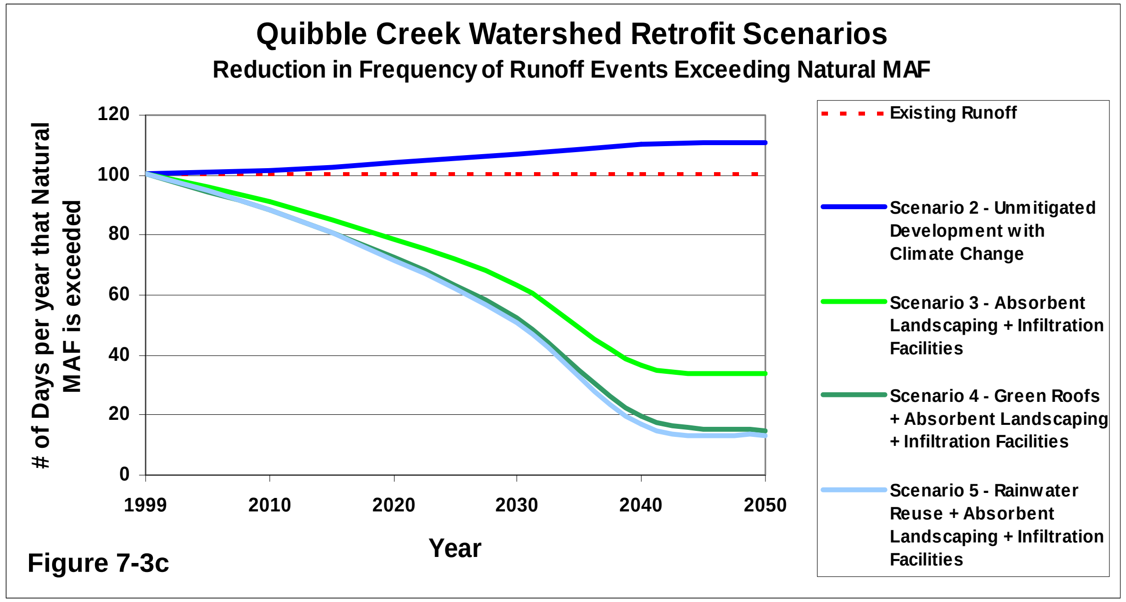


Figure 7-3c

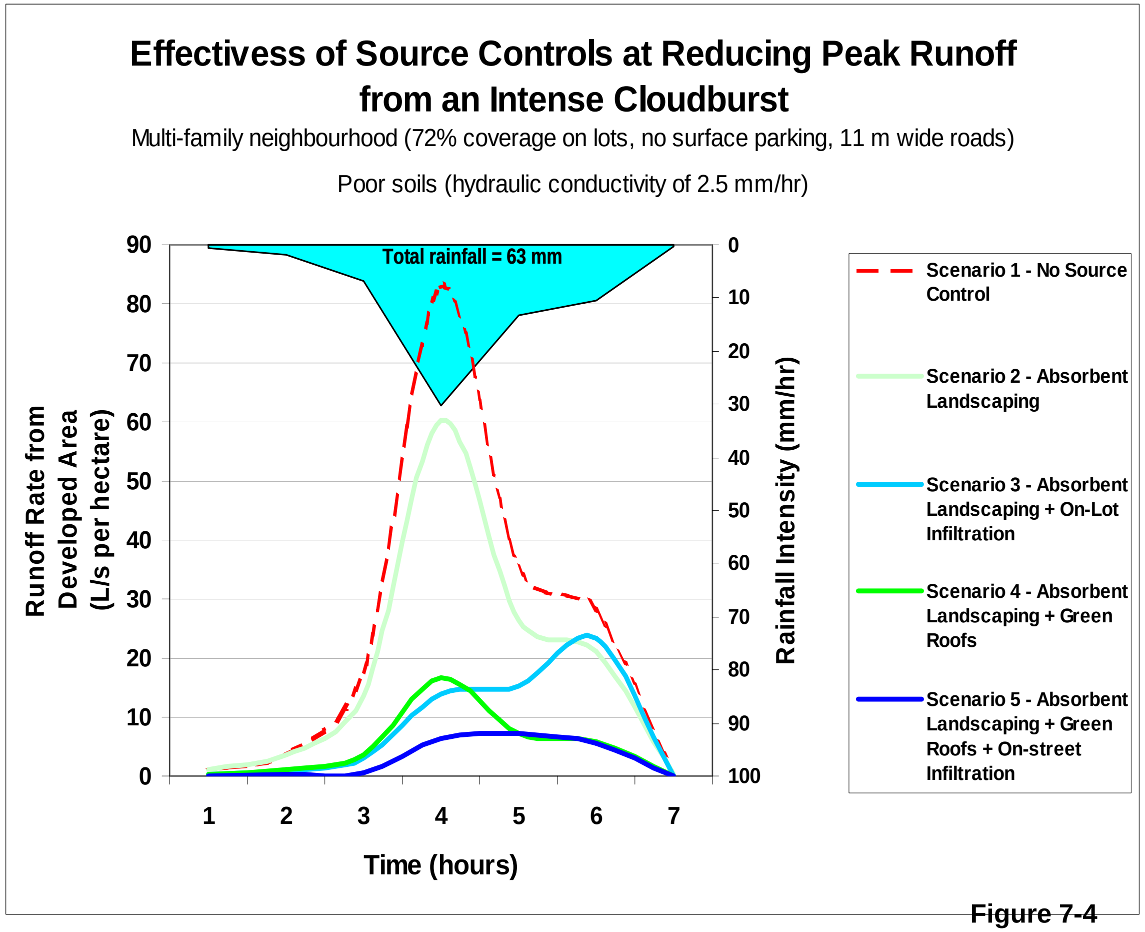
7.9 Case Study Example - Mitigating Extreme Cloudbursts

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 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 7-4 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 reduced by about 27%)*.
- **Scenario 3: Absorbent Landscaping + On-Lot Infiltration Facilities** – Same as Scenario 2 except that all lots have bioretention facilities (150 mm of surface ponding on 1 m of absorbent soil) covering 10% of lot area *(peak runoff rate reduced by about 70%)*.
- **Scenario 4: Absorbent Landscaping + 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 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 5.1).
- **Scenario 5: Absorbent Landscaping + Intensive Green Roofs + On-Street Infiltration Facilities –** Same as Scenario 4 except that all roads have one 3 m wide infiltration swale/trench (as described in Section 4.5) within road right-of-ways *(peak runoff rate reduced by about 92%)*

This case study example 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.



Effectivess of Source Controls at Reducing Peak Runoff from an Intense Cloudburst

Multi-family neighbourhood (72% coverage on lots, no surface parking, 11 m wide roads)

Poor soils (hydraulic conductivity of 2.5 mm/hr)

Figure 7-4

Section 8 – Moving from Planning to Action

8.1 Build the Vision, Create a Legacy

An ISMP may identify needed changes to land use and sub-division regulations, and possibly building design, in order to implement a source control strategy. A combination of public and institutional support as well as the ability of the development community to adapt to new standards will set the pace of change and influence the pace of ISMP implementation.

This support can only happen if there is a broad understanding among all players, the development community in particular and public in general, about the changes in standard practices—why they are needed, what they are, and how they can be practically accomplished.

A shared long-term vision is needed to focus effort. This vision provides a context for all planning, data collection, sensitivity analyses, capital expenditures, and regulatory changes. Prioritizing goals and actions (ideally through consensus) provides a roadmap for moving towards the long-term vision.

Long-term visioning, as applied in this report, integrates stormwater management with land use planning: illustrating a way local governments can enhance their stormwater management services through the application of stormwater source controls. The core objective is to identify options to change the way that land is developed and redeveloped, so that people, property and natural systems can be better protected; and over time, infrastructure can be managed more efficiently and watersheds can become healthier.

8.2 Watershed-Specific Performance Targets

Performance targets provide a common sense foundation for source control evaluation and implementing source control solutions. This may be generalized as a three-step process:

- **Step 1: Objectives and Constraints** – Establish preliminary science-based performance targets to guide early action in catchments of concern

  (e.g. How much runoff volume is desirable for a given watershed? 10%, 20%, more? How should the hydrologic regime behave? Do open and piped systems have different targets? Is the area already heavily urbanized? What are the ecosystem, flood management and infrastructure management objectives?).

- **Step 2: Analyses and Vision** – Develop scenarios to evaluate the consequences of the most likely ‘what ifs’, and use the results to integrate back into the ISMP and other planning processes for evaluation of how various stormwater management goals and visions can be achieved

  (i.e., What can be done at the site level given constraints such as hydrogeology, topography, climatic and growth scenarios, and land values? What scenarios are required to reach some goals? How do these compare with status quo? What needs to be changed?).

- **Step 3: Action –** Translate these performance targets into design criteria that can then be applied at the site level to mitigate the current and anticipated conditions.

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8.3 Facilitating Stormwater Source Control Applications

The first large-scale applications of stormwater source controls and supporting policies may be implemented as demonstration projects. Local governments (independently or collectively) will need to take the lead in implementing and monitoring the initial demonstration projects (*e.g.* public works projects, neighbourhood concept plans, progressive ISMPs, *et cetera*).

Local government leadership is important for demonstrating to developers, the community, and senior government regulators that proposed actions at the site level are both effective and affordable. This will build support for the regulatory, professional and industry changes that will enable the realization of long-term stormwater infrastructure plans and management.

Monitoring demonstration projects provides the foundation for Adaptive Management. The goal is to *learn from experience* and *constantly improve* land development and stormwater management practices. Hydrologic monitoring is at the heart of Adaptive Management – because it is the monitoring of hydrologic indicators that provides the information needed to improve the way we develop land and manage stormwater at the site level.

In order to *build and maintain trust* between local governments, landowners, developers and senior government agencies, the *Rules of Adaptive Management* must be established at the ISMP stage. These rules must define *requirements* and *consequences*. In many instances, either prior or concurrent with the first demonstration projects, there will likely need to be changes to current standards and administrative process to accommodate new standards. The following step-by-step measures will facilitate this process of change:

- ☐ **Step 1 - Establish an enabling regulatory framework –** Make regulatory changes that will facilitate the approval process for development and re-development projects that capture rainfall at the source for infiltration, evapo-transpiration and/or reuse.
- ☐ **Step 2 - Ensure that any new design standards reflect the design options that are most effective in the context of local conditions -** Through the implementation and monitoring of demonstration projects, establish the design options for source control that would be most effective in the context of the site-specific conditions (*i.e.* soils, precipitation, planned land use, *et cetera*).
- ☐ **Step 3 - Adopt a collaborative approach to change –** Consult with citizens and the development industry to determine:
  - preferred design options for stormwater source control;
  - appropriate implementation strategies for regulatory change;
  - appropriate financing strategies for rainfall capture and runoff control
- ☐ **Step 4 - Incorporate the most effective and acceptable design options into Engineering Standards –** Revisions to Engineering Standards should reflect local conditions as well as the preferences of the community and the development industry. Although, new Engineering Standards for source controls can be incorporated into the relevant development regulations (Subdivision Bylaw, the Building Bylaw, Zoning Bylaw, Development Permit Guidelines), it is possible that Standards may be based on performance level only; leaving the selection of source control strategies to be determined by the proponent as part of their development application.
- ☐ **Step 5- Make the details of new design standards readily available -** Create a technical manual of options for on-lot stormwater source control, including details and specifications of design standards, and make it available on-line.
- ☐ **Step 6 - Facilitate procurement of materials needed to implement new design standards** – Implement a bulk purchase/resale program that makes it easy and affordable for developers to obtain the specialty products needed to implement stormwater source control. Also, provide a cheap source of material for absorbent soils through a local government composting program.
- ☐ **Step 7 - Build support through education** - Implement education programs to inform city staff, the development community, and the general public about the need for the changes in the built environment through the inclusion of stormwater source controls in development practices and how to implement them.

In summary, these seven initiatives form the basis for an Action Plan – this provides the roadmap for removing barriers and reaching the target condition over a period of years.

8.4 Implementing Integrated Solutions

The ISMP process is expected to result in integrated long-range stormwater management plans for all urban and suburban watersheds. However, an ISMP can only work if implemented.

Similarly, a stormwater source control can only be considered successful if it is applied in its appropriate context, and not abused by being blindly tied to generic regulations and policies. Hence, a key objective of any ISMP is to tailor a source control strategy so that the integrated solution is watershed-specific.

The integrated approach emphasizes the importance of having a shared watershed long-term vision. A challenge is to communicate that vision in words and pictures that will be easily and clearly understood. This is essential to gaining acceptance.

The application of site-level stormwater source controls is only effective in managing stormwater when applied at the watershed scale. It is therefore essential that this scale and timeline of source controls be effectively communicated as well. Key to successful source control application is the appreciation and acceptance that they must be applied on time horizons measured in decades.

Planning at Three Scales

Finally, it is necessary to plan at three scales to ensure that solutions are both integrated and cascading. The three scales and associated scope are listed below:

- ☐ **At the watershed scale**– establish a shared vision, stormwater objectives and priorities
- ☐ **At the neighbourhood scale** – integrate objectives into community and neighbourhood planning
- ☐ **At the site scale** – apply site design practices that reduce both the volume and rate of runoff, and improve water quality

Each successive level provides more specific details as to *what* is to be accomplished *(What do we have?* and *What do we want?)*, and *how* to achieve the watershed vision *(How do we get from here to there?*).

8.5 Constant Improvement

An Action Plan is the ‘road map’ for striving over time to move impacted watersheds towards a healthier condition. In the final analysis, the objective may not be to restore all urban watersheds. Rather, achievable and affordable performance targets for constantly improving individual watershed health will be set as part of a stakeholder visioning process.

Appendix A

Still Creek Case Study

Section A-1

Case Study Overview

The Still Creek watershed comprises the western portion of the Brunette Basin (see Figure A-1). The watershed covers a 2834 ha area, of which 65 percent is in the City of Burnaby and 35 percent is in the City of Vancouver.

Figure A-1: Still Creek – Brunette River Basin

The Still Creek watershed is a highly urban watershed (about 61 percent impervious), which is mostly connected to storm sewers. As a result, it exhibits large volumes of surface runoff into the Still Creek system, and high peak runoff rates, especially from high-intensity storms.

This causes a variety of problems, including:

- ☐ chronic flooding
- ☐ risk of a large, destructive flood
- ☐ watercourse erosion
- ☐ sedimentation (reduced capacity of channels, Burnaby Lake)
- ☐ limited aquatic habitat value and low base flows

There is little or insufficient land area available for in-stream or traditional flood control solutions (e.g. large ponds). Challenging soil conditions in the lowlands (peat bog) also limit the feasibility of structural solutions. A diversion of peak flows to the Fraser River is perhaps the most promising flood control option that has been identified, and it's cost has been estimated at $25 million. Therefore, other options, such as source control, need further exploration.

The effects of climate change and land use densification are likely to increase runoff volumes and exacerbate existing problems.

Objective of the Case Study

The purpose of this case study is to evaluate the potential effectiveness of source control retrofit strategies, with respect to:

- ☐ reducing or eliminating existing drainage-related problems
- ☐ counteracting the future effects of climate change and densification
- ☐ restoring watershed health over a 50-year timeline

The Still Creek case study provides an overview, which is intended to:

- ☐ make the case for source control by quantifying the potential benefits
- ☐ provide direction regarding which strategies make sense, and where

Watershed Planning Context

As part of the GVRD Liquid Waste Management Plan (LWMP) process, the municipalities in the Brunette River Basin agreed to undertake a pilot watershed-based planning project. This resulted in the Brunette Basin Watershed Plan, which establishes overall management objectives and strategies for the Basin.

Following up on the Brunette Plan, Integrated Stormwater Management Plans (ISMP) are being developed for each watershed within in the Brunette Basin. An ISMP for the Still Creek watershed is currently starting. This case study is intended to provide direction for the source control component of this ISMP.

Section A-2

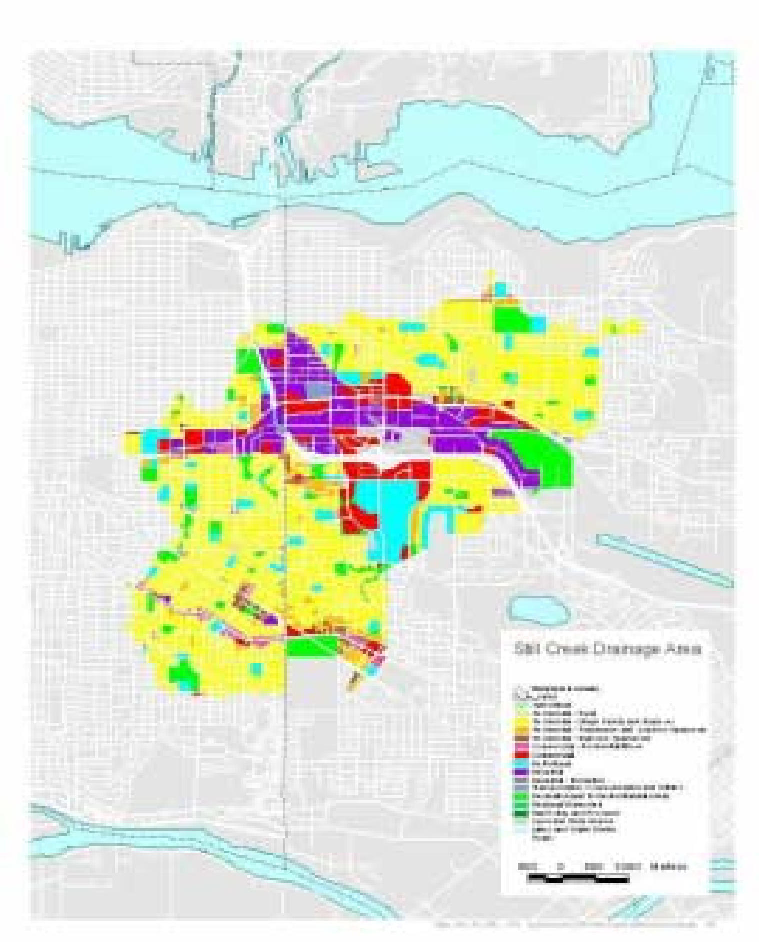
Watershed Overview

Existing Land Use

There is a wide range of land use types in the Still Creek Watershed. Currently, over half of the watershed is single family residential (53%). There is also a relatively large amount of industrial land in the watershed (10%). Other significant land uses in the watershed include commercial, institutional, higher density residential, parks/protected areas, transportation corridors, and some mixed use.

Figure A-2 shows the distribution of land use in the Still Creek watershed. Figure A-3 shows the breakdown of watershed area by land use type. A large portion of the total watershed area (about 29 percent) is taken up by road right-of-ways.

Figure A-2: Still Creek Land Use



Expected Future Land Use

The expected change in land use within the Still Creek watershed over the next 50 years was estimated, based on:

- ☐ discussion with staff from the City of Burnaby and City of Vancouver.
- ☐ 50-yr population projections from the GVRD.

The total amount of single family residential area is expected to decrease (53-42%), and the impervious coverage of many single family areas is likely to increase. Industrial area is also expected to decrease (10-6%). There is expected to be an increase in multi-family residential area (low-rise: 4-10%, high-rise: 1-4%), mixed commercial/residential area (2-4%), and commercial high tech/ business centres (2-7%). Other types of commercial land uses, especially storage type uses (e.g. warehouses), are expected to decrease (6-3%). Institutional areas and parks/protected areas are expected to increase slightly.

Figure A-4 shows the expected land use distribution in 2052.

Based on these projected land use changes, the percentage of impervious area is likely to increase slightly (from 61 to 65 percent) over the next 50 years.

Figure A-3: Still Creek Watershed Distribution (Existing)

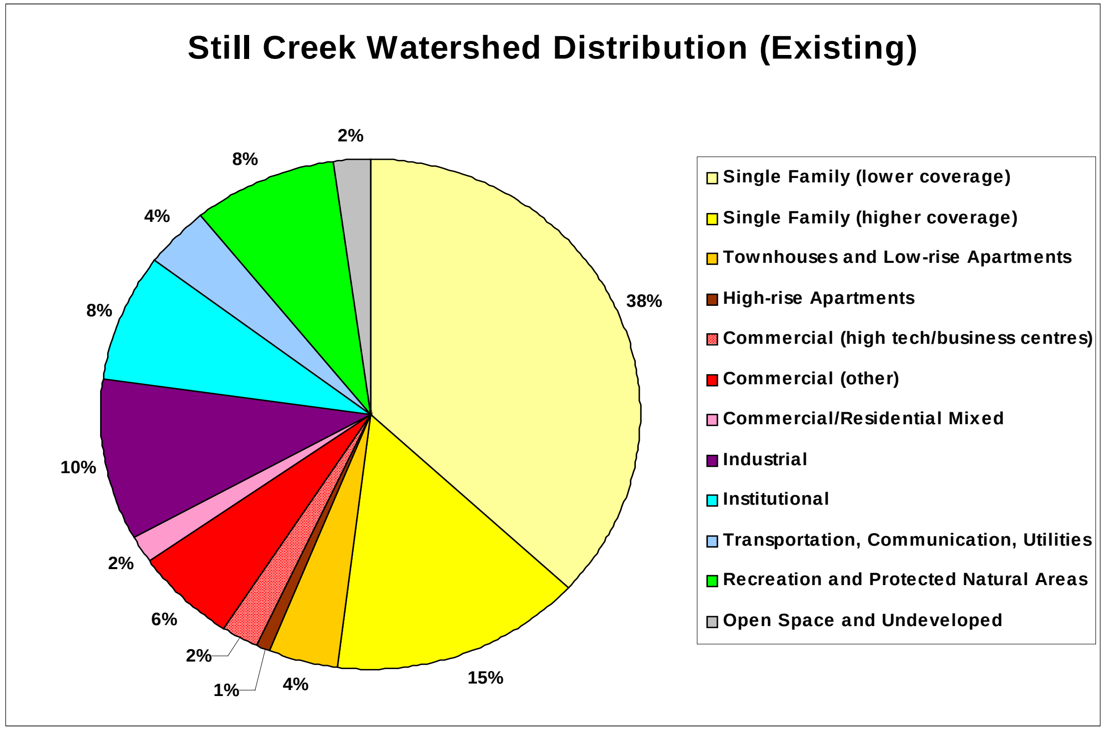
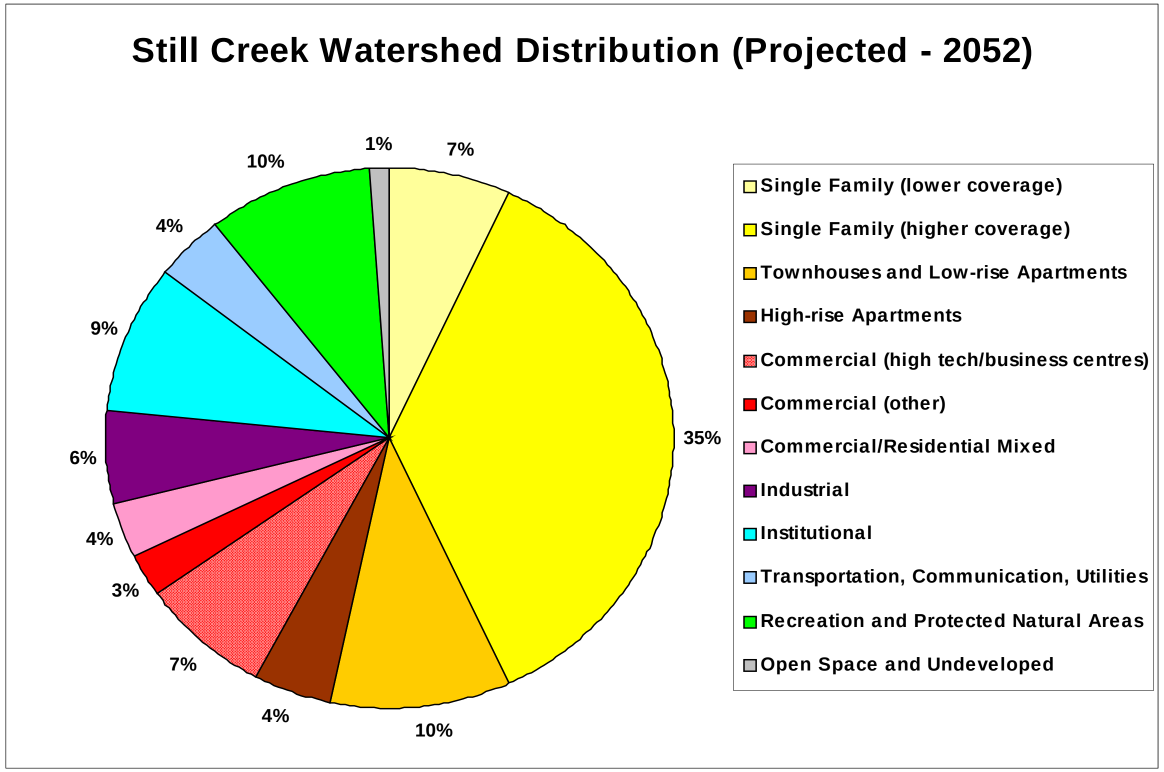


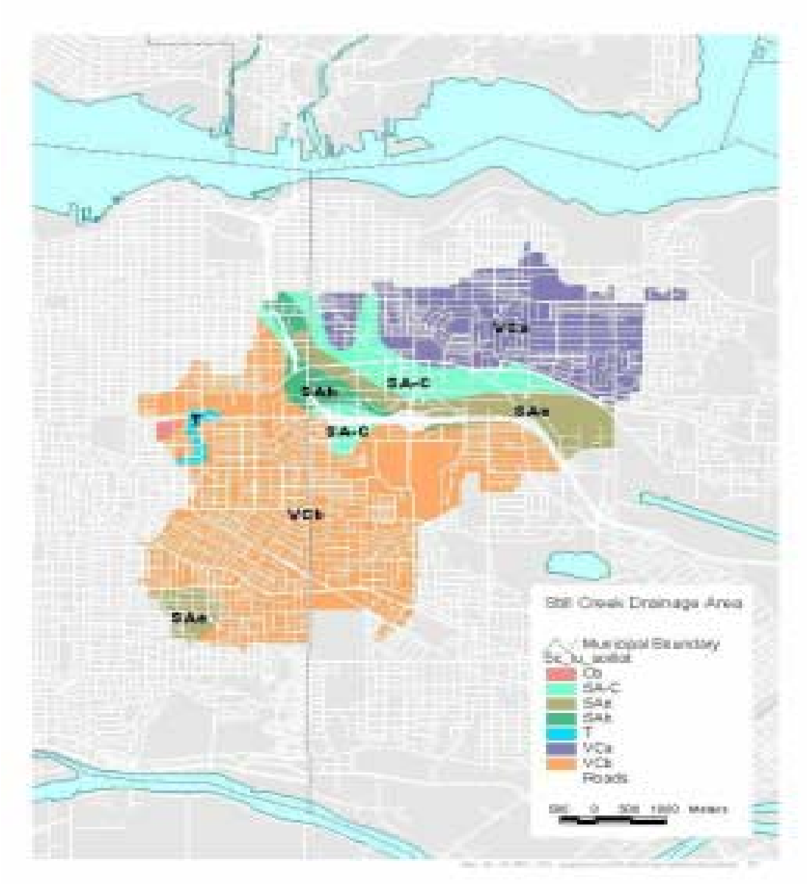
Figure A-4: Still Creek Watershed Distribution (Projected - 2052)



Soil Conditions

Figure A-5 shows the distribution of soil types in the Still Creek watershed. This information is based on fairly coarse level Geologic Survey of Canada mapping (1:50,000 scale). Figure A-6 shows the breakdown of watershed area by soil type.

Figure A-5: Still Creek Watershed Soil Types



Soils types in upland portions of the watershed, which comprise about 75 percent of the total watershed area typically have good infiltration potential. Surficial soils in upland areas are glacial tills which were deposited during the most recent glacial recession (VCa and VCb). These consist primarily of sandy loam, sand and gravel.

Soils types in lowland portions of the watershed consist of peat (SAe) and fluvial deposits (silt and sand) much of which is overlying peat (SAh and SA-C). These types of soils are much more challenging for infiltration. These surficial soils are underlain by silty clay, which is typically softy and highly sensitive to disturbance.

High groundwater tables may also limit the feasibility of stormwater infiltration in some lowland areas.

Soil parameters that were used for modeling purposes (e.g. hydraulic conductivity, maximum water content, fieldcapacity, wilting point) were obtained from the GVRD. However, the assumed hydraulic conductivity values were reduced substantially to account for the highly disturbed nature of soils.

Source control implementation would require more detailed analysis of site-specific soil, groundwater, and impacts of stormwater infiltration. This is beyond the scope of this study.

Distribution of Land Use Relative to Soil Conditions

For the Still Creek analysis, the spatial variability of soil conditions within the watershed was considered (whereas, previous case studies assumed a homogeneous soil type across the watershed). This is important for the Still Creek watershed, because it provides guidance regarding which land use types to target for stormwater infiltration strategies.

The majority of residential and institutional land is located in the upland portions of the watershed, where the potential effectiveness of infiltration strategies is good (see Figures A-7a & b).

Most of the industrial land, a large portion of the commercial land, and most of the transportation, communication, and utility corridors are located in the lowland portions of the watershed, where infiltration strategies are likely to be much less effective (refer to Figures A-7c, d & e).

Figure A-7a: Soil Summary (Institutional)

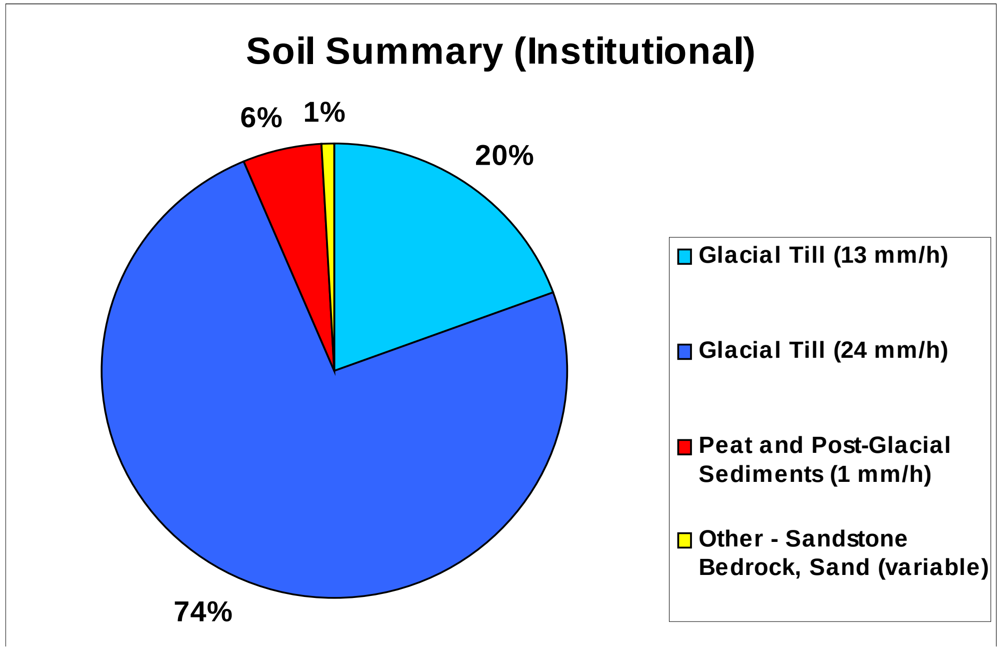


Figure A-7b: Soil Summary (Residential Land Uses)

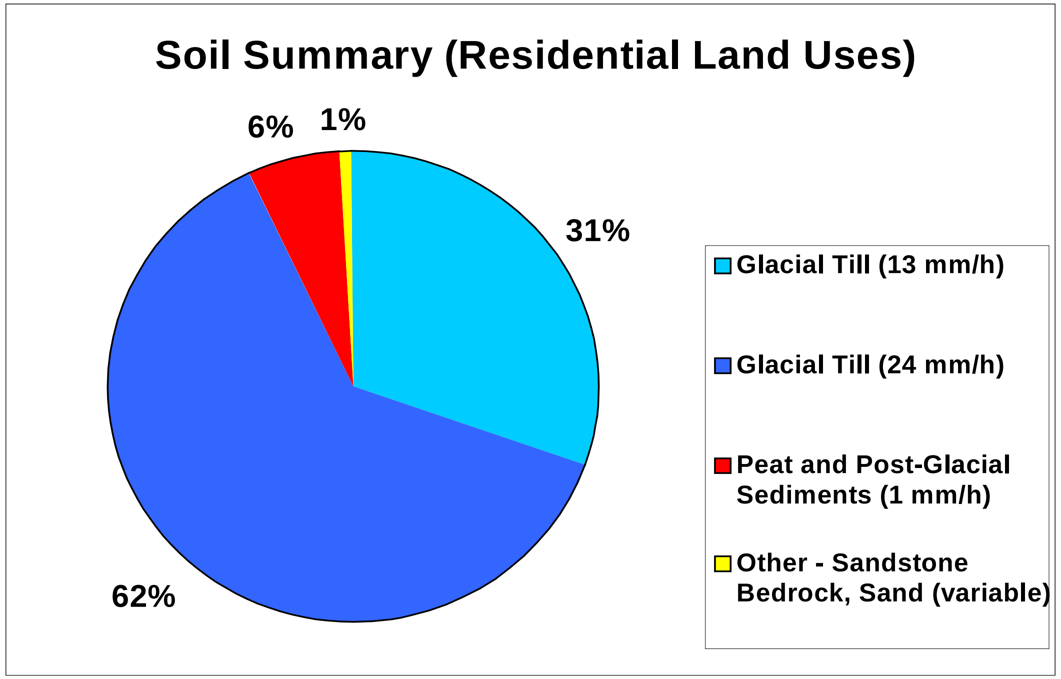


Figure A-7c: Soil Summary (Industrial)

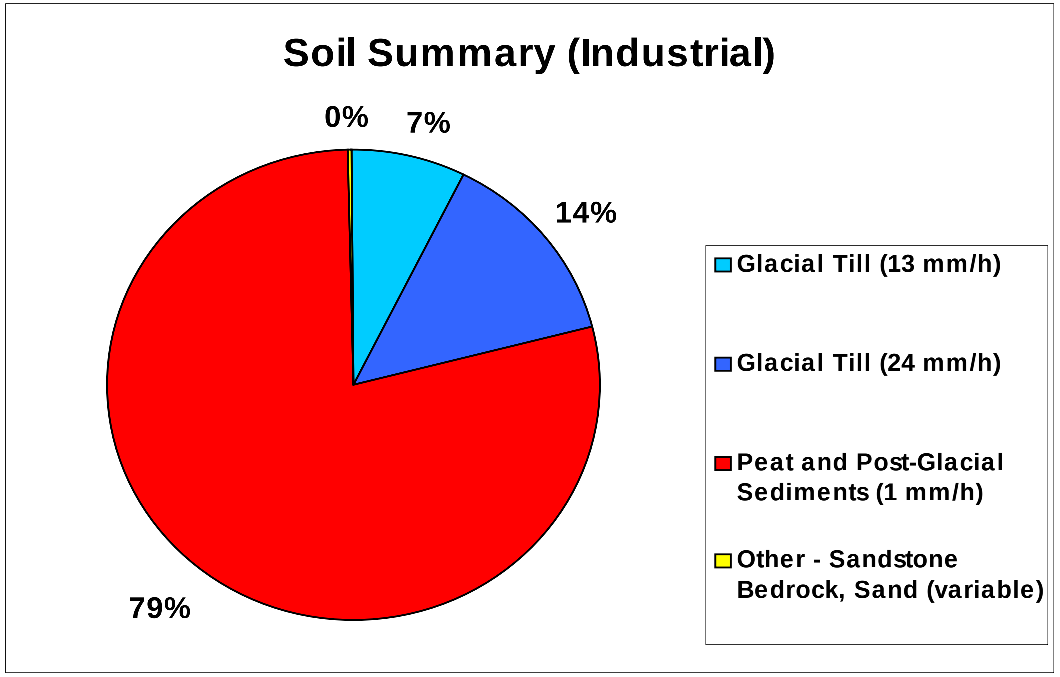
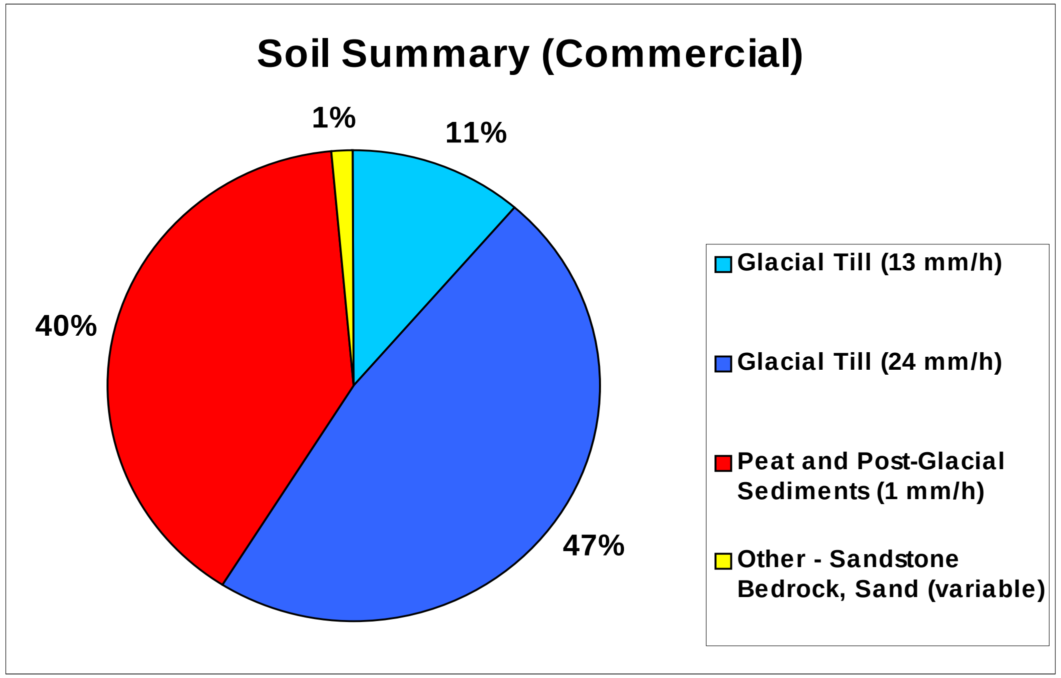


Figure A-7d: Soil Summary (Commercial)



Section A-3

Summary of Key Findings

Potential Effectiveness of Source Control Retrofit

An effective source control retrofit strategy for the Still Creek watershed could potentially achieve significant benefits such as: reducing flood risk, reducing erosion, and creating favourable conditions for aquatic habitat restoration.

A long-term (50-year) watershed retrofit strategy that incorporates absorbent landscaping, infiltration facilities on roads, and combination rainwater reuse/infiltration systems on lots could potentially:

- ❑ reduce total runoff volume to less than 10 percent of total rainfall
- ❑ significantly reduce the number of days per year that the total surface runoff exceeds the magnitude of a natural mean annual flood (from 120 to 15)
- ❑ reduce peak rates of surface runoff from the critical high- intensity storms (2-hour duration) by:
    - 88 percent for 5-year storm (from 101 m^3/s to 12 m^3/s)
    - 82 percent for 25-year storm (from 136 m^3/s to 24 m^3/s)
    - 80 percent for 200-year storm (from 177 m^3/s to 35 m^3/s)

Note that the results presented in this study are for short duration, high-intensity storms. Previous sections of this report illustrate that source controls are less effective in terms of reducing peak runoff rates from longer duration storms.

In the absence of a source control retrofit strategy, the existing problems are likely to worsen in the future due to:

- ❑ increased runoff volume
- ❑ more frequent high-intensity storms

Opportunities for traditional flood control solutions are limited.

Stormwater infiltration is the most effective type of source control in areas of the Still Creek watershed that have till soils (most residential and institutional land). In this case, implementation of stormwater infiltration may potentially:

- ❑ reduce runoff volume to less than 10 percent of total rainfall volume (for all but the high coverage commercial and industrial land uses)
- ❑ greatly reduce surface runoff from 5-year storm (also greatly reduce 25-year storm runoff from single family land uses)
- ❑ significantly reduce runoff rates from higher intensity storms

Where soils consist of peat and sediments (most industrial and commercial land) other on-lot source control strategies are more effective, such as:

- ❑ rainwater reuse (most effective at reducing runoff volumes, especially for high water use commercial, and high density residential land uses)
- ❑ green roofs (most effective at reducing peak runoff rates from high intensity storms, especially for land uses with high rooftop coverage).

Combining infiltration with green roofs or rainwater reuse, achieves the greatest overall benefit, especially where soil conditions limit the effectiveness of infiltration alone (i.e. peat/sediments). On-lot source control combinations are also most effective in terms of reducing peaks from very high intensity storms (25-year, 200-year).

Infiltration (and absorbent landscaping) is the only option for roads. This source control strategy is:

- ❑ very effective where soils are till (majority of local roads):
    - road runoff volume can be reduced to < 10 percent of total rainfall on ROW
    - peak runoff rates from critical storms can be eliminated or significantly reduced.
- ❑ much less effective where soils are peat/sediments (most of highway, many industrial and commercial roads).

Limitations of Source Control Strategies

The modelling results show that, theoretically, source control strategies could be very effective in the Still Creek Watershed. However, it is important to understand the limitations of this study:

- ☐ the results are based on modelling of hypothetical scenarios and have not been verified through actual performance monitoring.
- ☐ the results show that stormwater infiltration strategies have good potential for runoff reduction, but the potential impact on groundwater and interflow have not been evaluated as part of this study. It is important for the Still Creek ISMP to consider the potential impact that infiltrated stormwater could have on building foundations, roads, and other utilities (e.g. sanitary sewer system).
- ☐ The results assume that everyone in the watershed will comply with the implementation of the source control strategies. This may not be the case, since the implentation of some source control strategies may be difficult to monitor or enforce, or may not be feasible in certain situations
- ☐ Even if everyone were to comply with source control implementation, it would still take a long time to fully implement any source control strategy. The results assume that complete watershed retrofit can be achieved in 50 years, but it could take even longer.. Source control retrofit is a long term solution, not an overnight fix.

Section A-4

Methods for Evaluating Effectiveness of Source Control Scenarios

Continuous Simulation for a Wet Year

The potential effectiveness of various source control options has been evaluated with the Water Balance Model (WBM) using rainfall data from a wet year (1997). The GVRD provided the following input data for continuous simulation modelling:

- Hourly rainfall data from the GVRD's Sperling Avenue rain gauge (BU07) for the wettest year on record (see Figure A-8).
- Daily evapotranspiration data for the same year (see Figure A-9), which was calculated based on climate data from the Vancouver Airport.

The WBM simulations have been used to estimate:

- reduction in total runoff
- reduction in the number of days per year that surface runoff rates exceed the typical magnitude of mean annual flood under natural conditions (~ 2 L/s per ha).

Figure A-8: 1997 Still Creek Rainfall

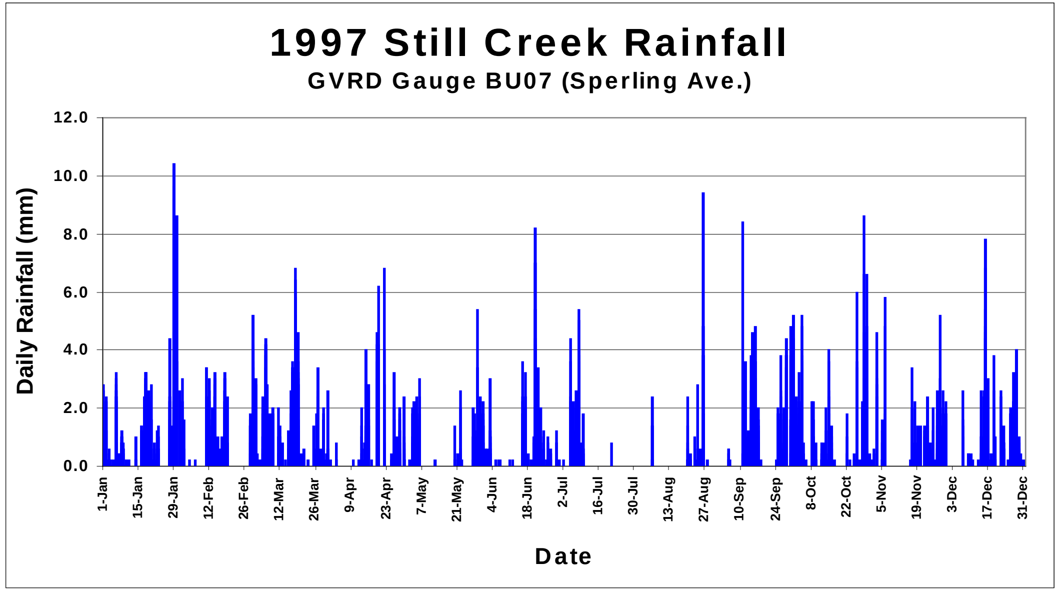
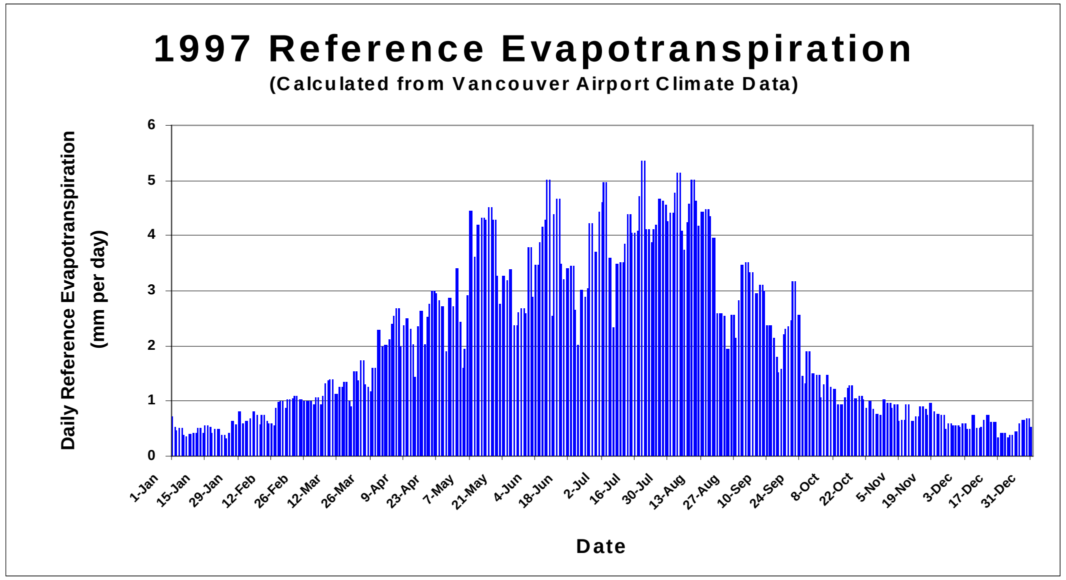


Figure A-9: 1997 Reference Evapotranspiration



Simulation of Critical Design Storms

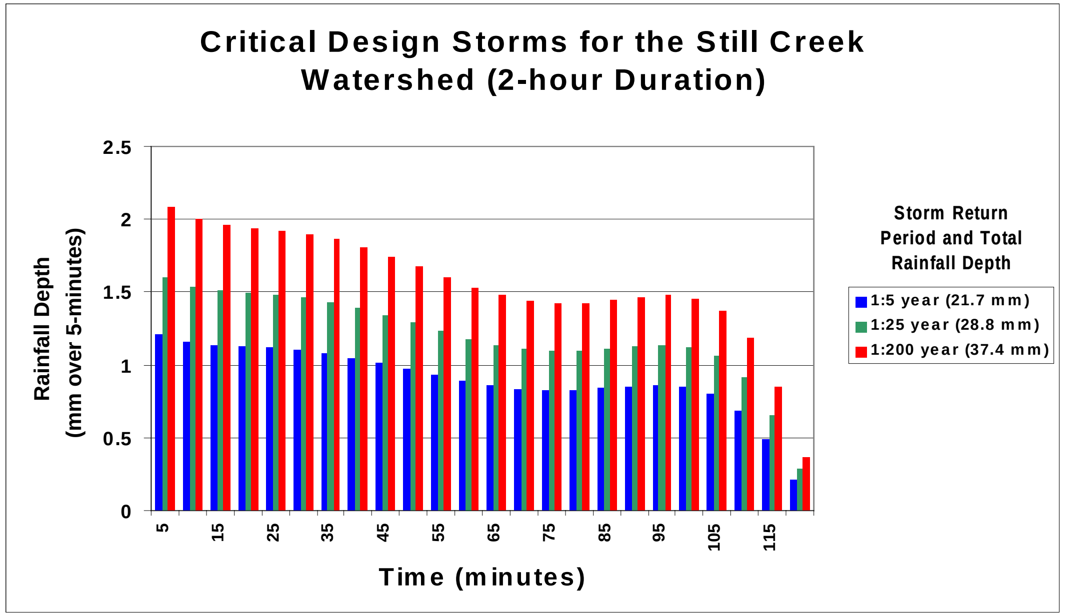
Since the Still Creek watershed has a large amount of impervious cover and extensive storm sewer drains, the highest flood risk arises from short duration (2-hour) high intensity storms.

For this reason, 2-hour storms were simulated using the WBM to evaluate the potential effectiveness of source controls in reducing peak runoff rates from:

- 5-year 2-hour storm
- 25-year 2-hour storm
- 200-year 2-hour storm

The GVRD provided design storms that have been developed for the Still Creek watershed (refer to Figure A-10).

Figure A-10: Critical Design Storms for the Still Creek Watershed (2-hour Duration)



Antecedent Moisture Conditions

Moisture conditions prior to a simulated storm event have a big impact on predicted runoff rates from the WBM. For the Still Creek case study, average winter (October to March) moisture conditions for a wet year were used as model inputs. Estimates of average winter conditions were based on continuous simulation results.

For example, Figures A-11a and A-11b show the continuous water level simulations for bioretention facilities on two typical single family lots, one on till soils (having good infiltration) and one on peat/sediments (having poor infiltration).. The simulations demonstrate that a bioretention facility constructed on till soil drains relatively quickly following rainfall events and rarely has standing water on the surface, whereas a similar facility constructed on peat/sediments drains much more slowly and has standing water more than half the year.

The design storm simulations for these two scenarios would assume antecedent moisture conditions in the bioretention facilities of 42 percent saturated and 90 percent saturated, respectively.

Figure A-11a: Single Family Lot on Till (13mm/h)

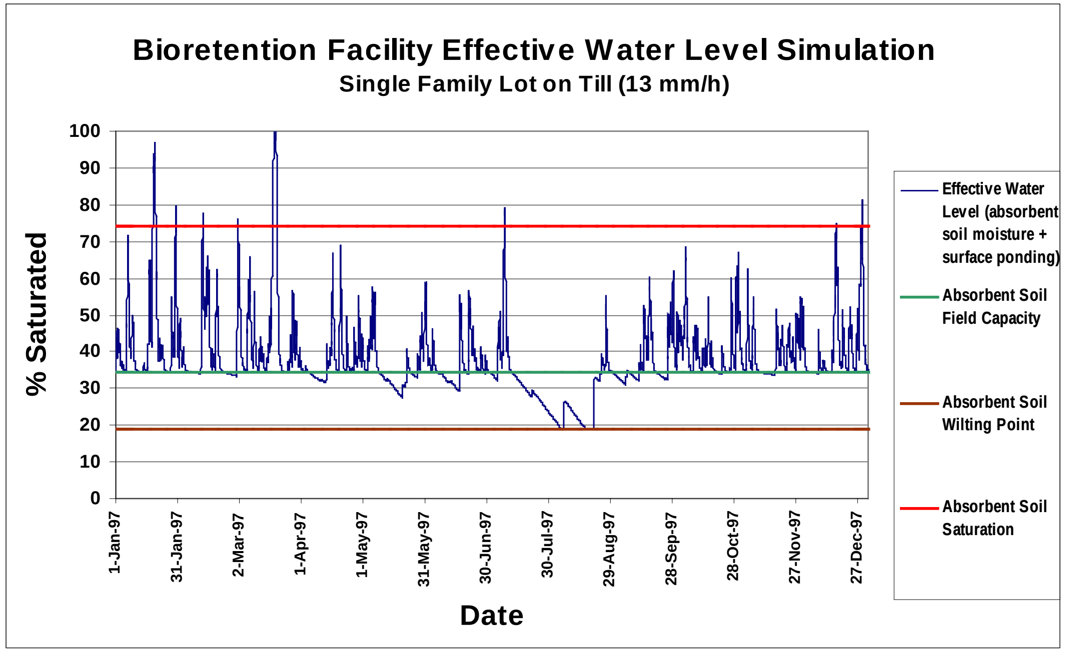
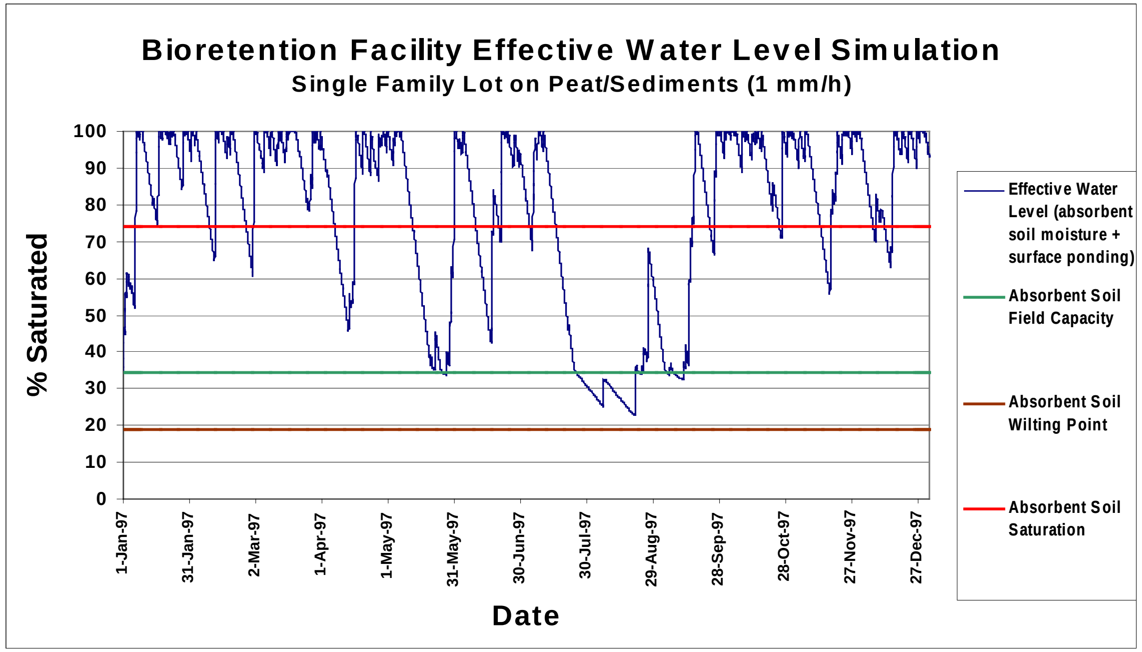


Figure A-11b: Single Family Lot on Peat/Sediments (1mm/h)



Section A-5

Source Control Scenarios for Lots

The WBM has been used to estimate the effectiveness of source control strategies for lots. Strategies including: absorbent landscaping, on-lot infiltration, green roofs, and rainwater reuse have been considered.

Absorbent Landscaping and On-Lot Infiltration

The following scenarios have been modelled:

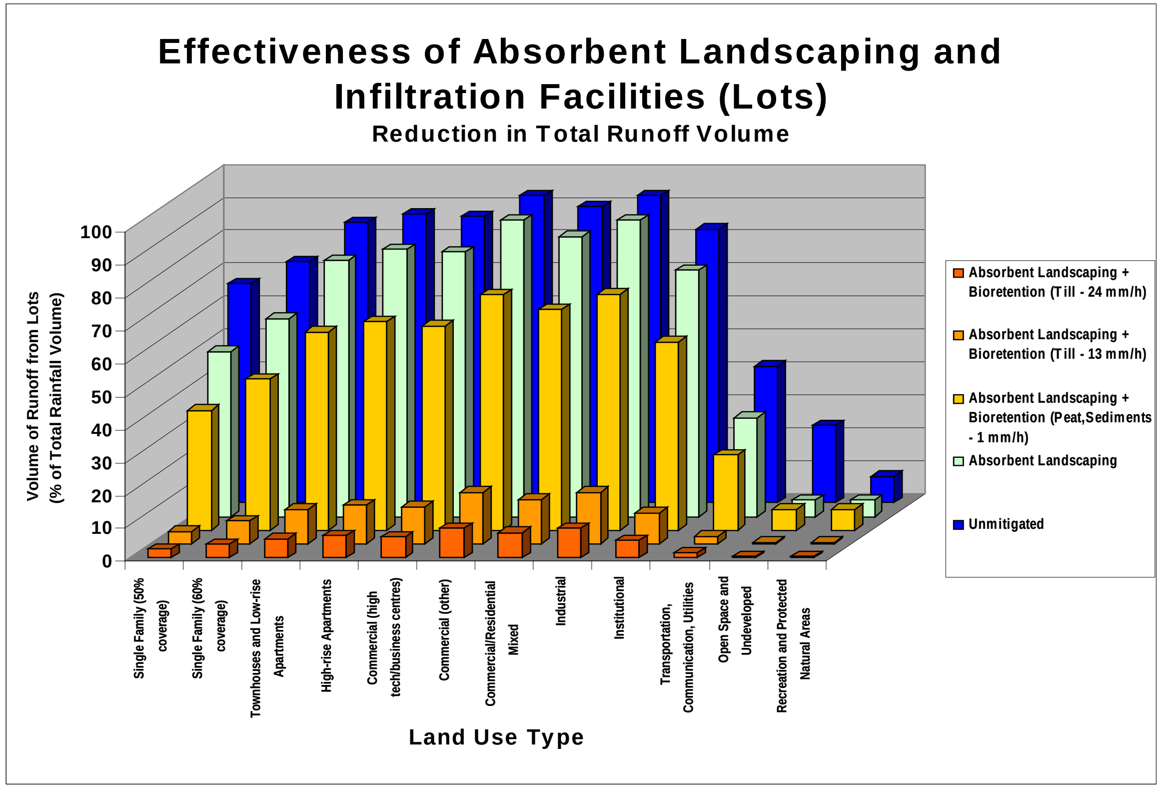
- **Absorbent Landscaping**: All open space on redeveloped or retrofitted land (for all land use types) would be covered with absorbent landscaping consisting of soil and vegetation having a rooting depth of 300 mm.
- **On-Lot Infiltration**: In addition to absorbent landscaping, all on-lot impervious area would be disconnected from storm sewers, and runoff would be diverted to bioretention facilities, which consist of:
    - 1000 mm of absorbent soil
    - up to 150 mm of ponding on the surface
    - appropriate surface vegetation: flood-tolerant plants (e.g. sedges or rushes) in low points planted, streamside or upland species (hardhack or shrub rose) in higher areas.
- **Lot Space for Bioretention**: Amount of lot space provided for bioretention is assumed to be:
    - 5 percent of single family lots
    - 6 percent of lots for all other land uses

Projected Runoff Volume Reduction

Figure A-12 shows the projected runoff volume reduction that may be achievable using absorbent landscaping and on-lot infiltration (i.e. bioretention), for the range of land uses and soil types in the Still Creek watershed.

Volume reductions achieved by using absorbent landscaping alone would be relatively modest. Volume reductions projected for absorbent landscaping plus on-lot infiltration are much more substantial. For till soils, runoff volume could potentially be reduced to less than 10 percent of total rainfall volume for all but the high-coverage commercial and industrial land uses. For peat/sediments, other source control strategies are needed to achieve significant reduction in runoff volumes (e.g. green roofs, rainwater reuse).

Figure A-12: Reduction in Total runoff Volume



Projected Runoff Rate Reduction

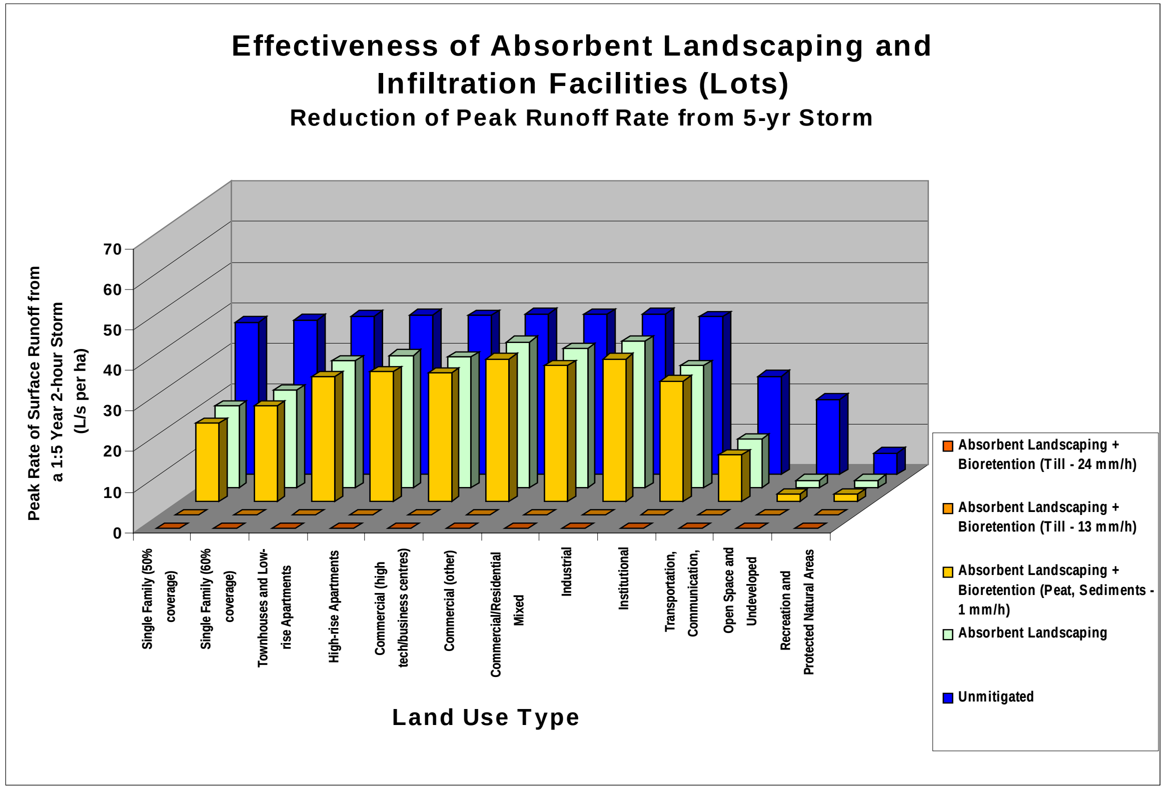
Figures A-13a, b & c show the projected reduction in peak runoff rates that may be achievable using absorbent landscaping and on-lot infiltration.

Using only absorbent landscaping, the WBM predicts that peak flows arising from high intensity storms could be substantially reduced, especially for single family lots.

By incorporating bioretention on till soils:

- surface runoff from 5-yr storms may be greatly reduced from all land use types.
- surface runoff from 25-yr storms may be greatly reduced for lower coverage land uses such as single family.

Figure A-13a: Reduction of Peak Runoff Rate from 5-yr Storm



For bioretention on peat/sediments the potential for reduced runoff rates is much more limited (at most 50% reductions, for single family land uses).

WBM projections indicate that absorbent landscaping and bioretentaion are less effective at reducing peak runoff rates for higher-intensity storms (e.g. 25-year and 200-year return periods).

Figure A-13b: Reduction of Peak Runoff Rate from 25-yr Storm

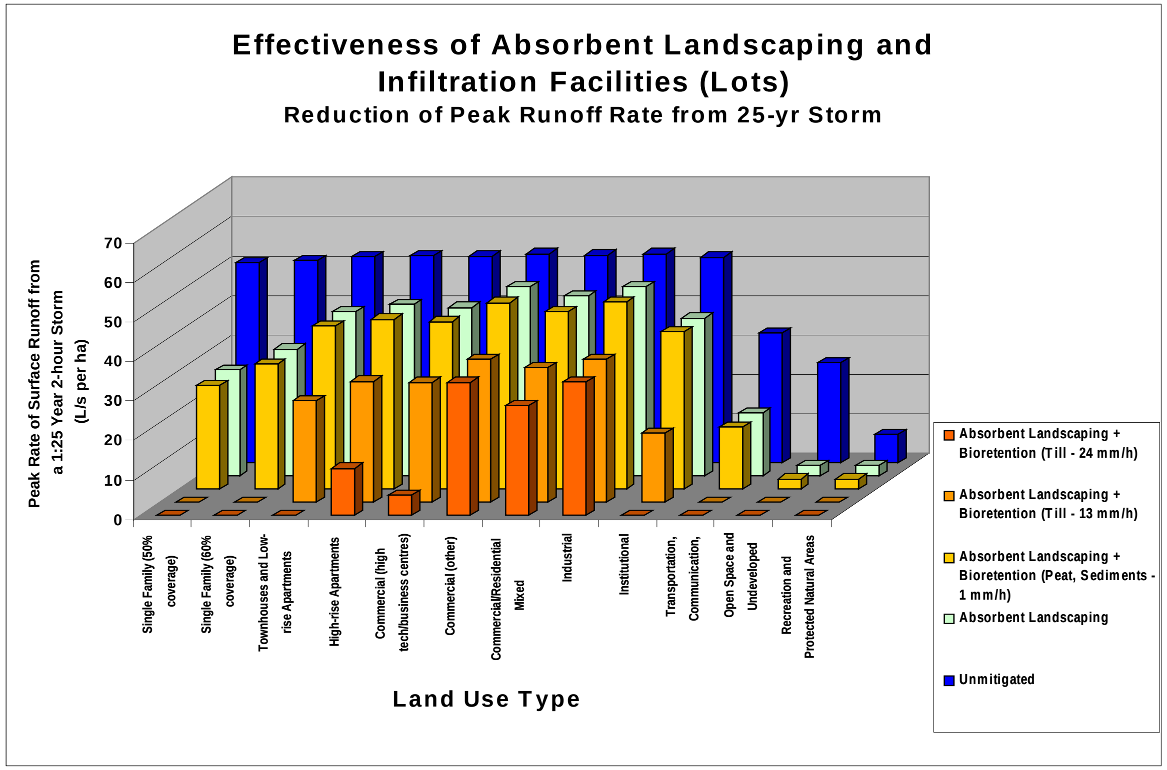
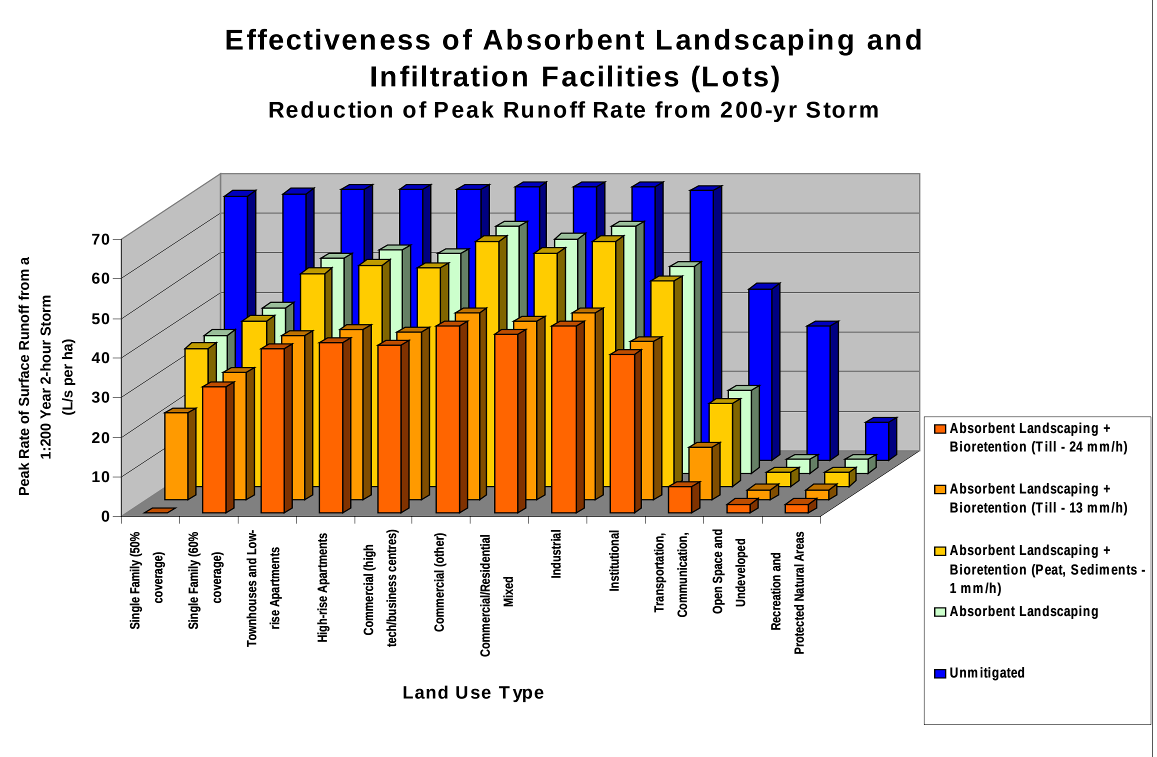


Figure A-13c: Reduction of Peak Runoff Rate from 200-yr Storm



Green Roofs and Rainwater Reuse

The following scenarios have been modelled:

- **Green Roofs**: All re-developed or retrofitted multi-family residential, commercial, industrial and institutional lots would have lightweight extensive green roofs (100 mm soil depth) on building rooftops, and heavier intensive green roofs (300 mm soil depth) on roofs of parking structures and underground parkades. Runoff from green roofs would be collected in an underdrain system and directed to storm sewers.

  For purposes of the watershed retrofit scenarios, green roofs were not applied to single family residential dwellings.

- **Rainwater Reuse**: All re-developed or retrofitted land uses would capture and reuse rooftop runoff for primary greywater uses (e.g. toilets, washing machines, dishwashers). Required rainwater storage capacity would be 300 m^3 per impervious hectare of rooftop. Any overflow from the storage structures would be directed to storm sewers.

  Greywater use for residential properties was based on population density. Greywater use for commercial, industrial, and institutional (ICI) properties are highly variable, but have also been estimated.

- Absorbent landscaping would be applied in conjunction with green roofs and rainwater reuse.

Projected Runoff Volume Reduction

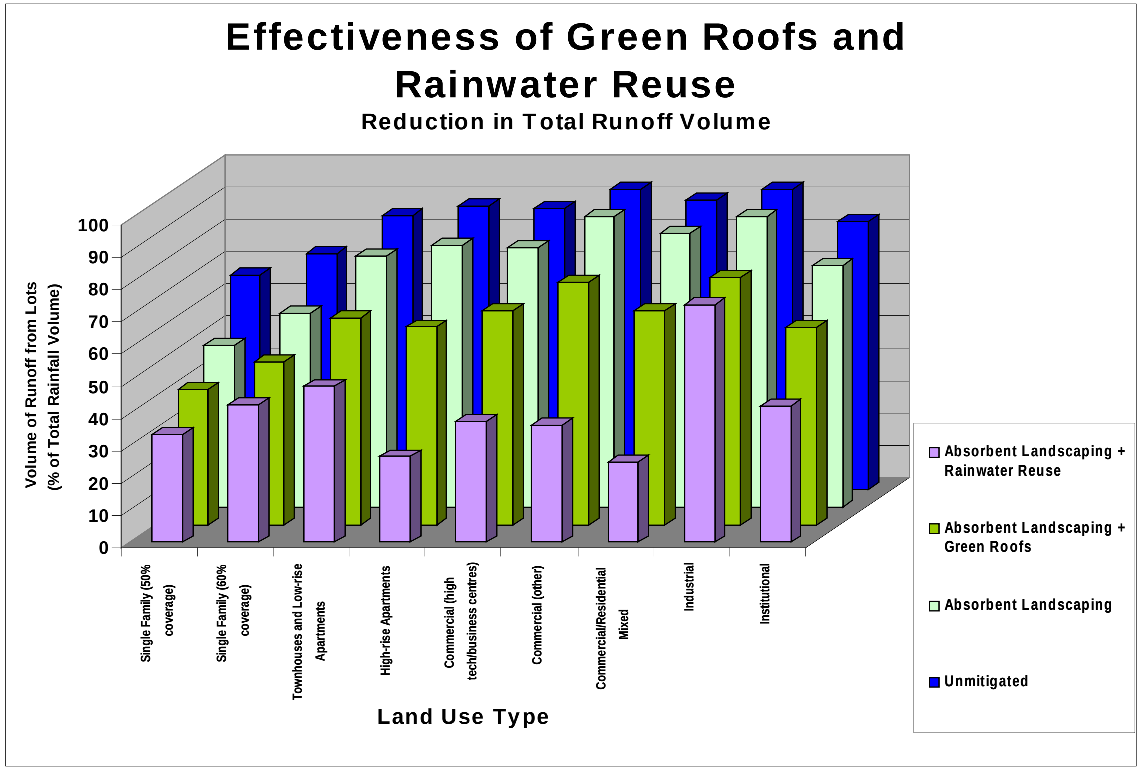
Figure A-14 shows the projected projected runoff volume reduction that may be achievable using green roofs and rainwater reuse. The effectiveness of these source control strategies is not affected by soil type.

Green roofs would achieve a relatively small reduction in total runoff volume. However, green roofs provide attenuation as the runoff passes through a layer of absorbent soil. This results in a significant reduction in peak runoff rates from critical storms (see Figures A-15a, b & c).

Rainwater reuse may potentially offer significant reductions in runoff volume, particularly for high-density residential and commercial, where water use is high.

It is interesting to consider the relative benefits of and stormwater infiltration compared to green roofs and rainwater reuse. Where soil conditions are favourable, infiltration is far more effective at reducing runoff volume than is rainwater reuse and green roofs.

Figure A-14: Reduction in Total Runoff Volume



Projected Runoff Rate Reduction

Figure A-15a, b & c show the projected reduction in peak runoff rates that may be achievable using green roofs and rainwater reuse, for the range of land uses in the Still Creek watershed.

Peak runoff rates from a 5-year storm may be substantially reduced using either green roofs or rainwater reuse.

Even for higher-intensity storms (such as 25-year, 200-year) green roofs provide a benefit, especially for land uses with high rooftop coverage (e.g. high-density residential, mixed commercial/residential).

Rainwater reuse is less effective at reducing runoff rates, for most land uses.

Figure A-15a: Reduction of Peak Runoff Rate form 5-yr Storm

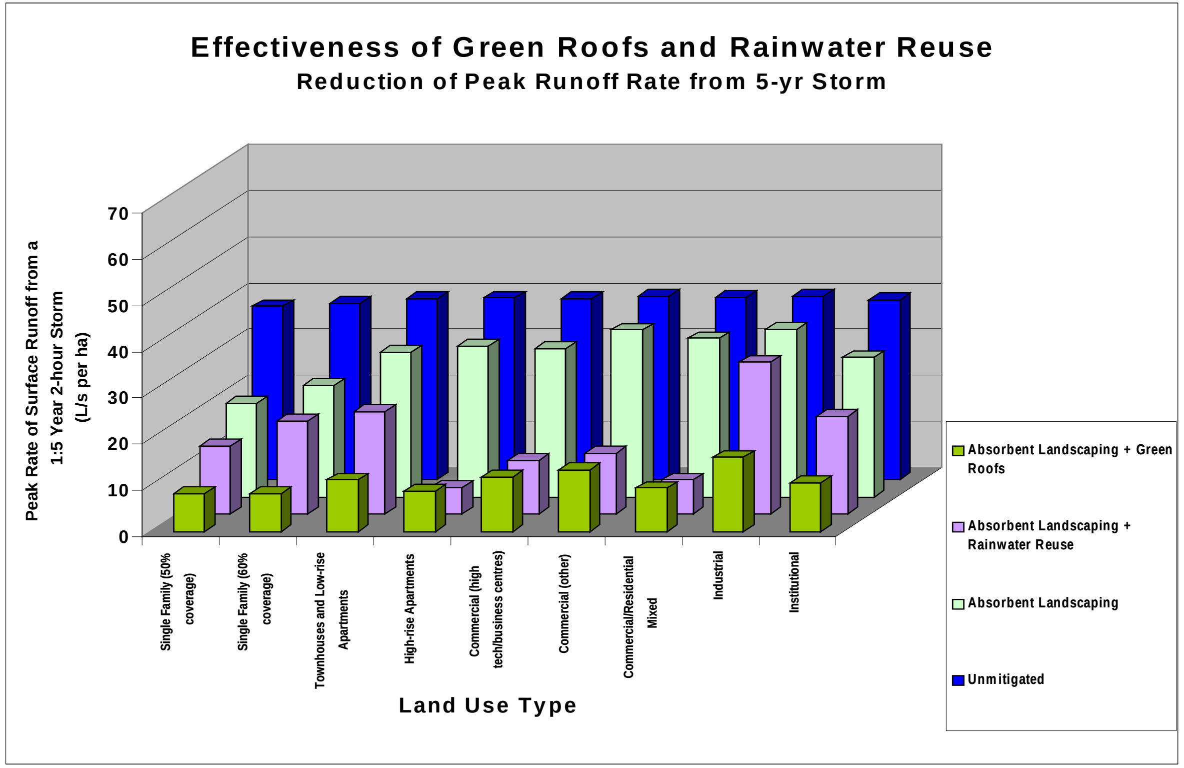


Figure A-15b: Reduction of Peak Runoff Rate from 25-yr Storm

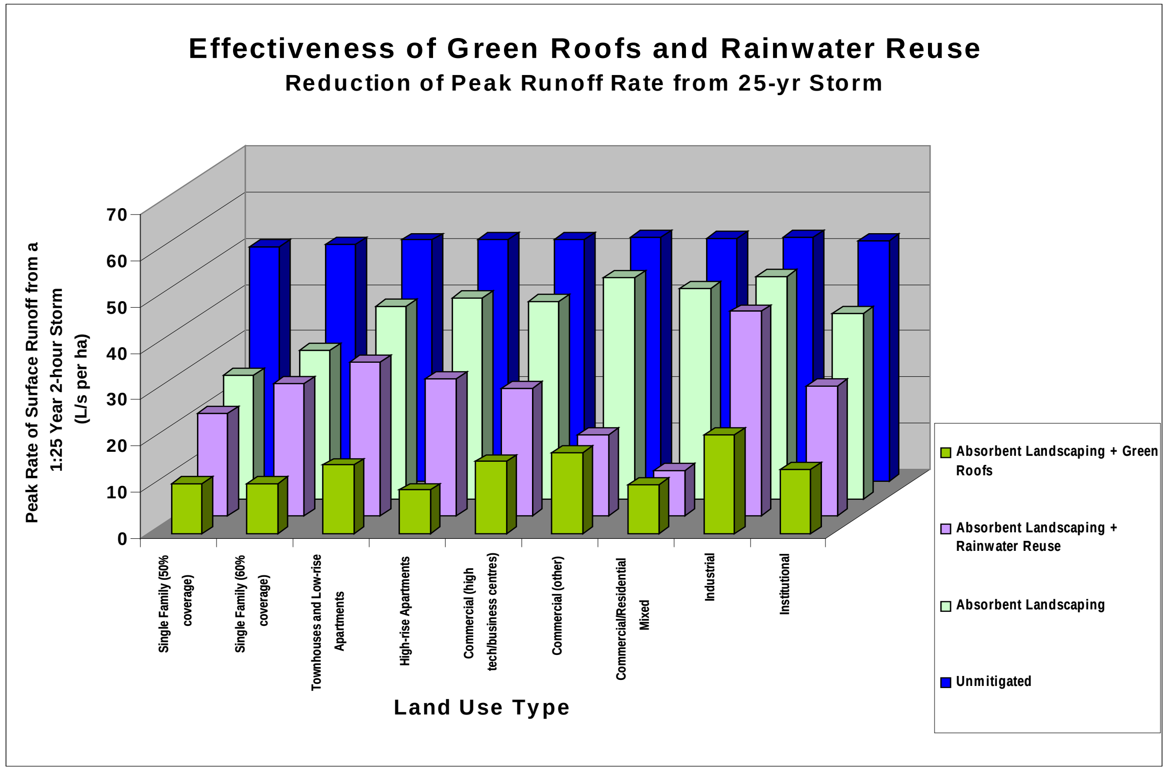
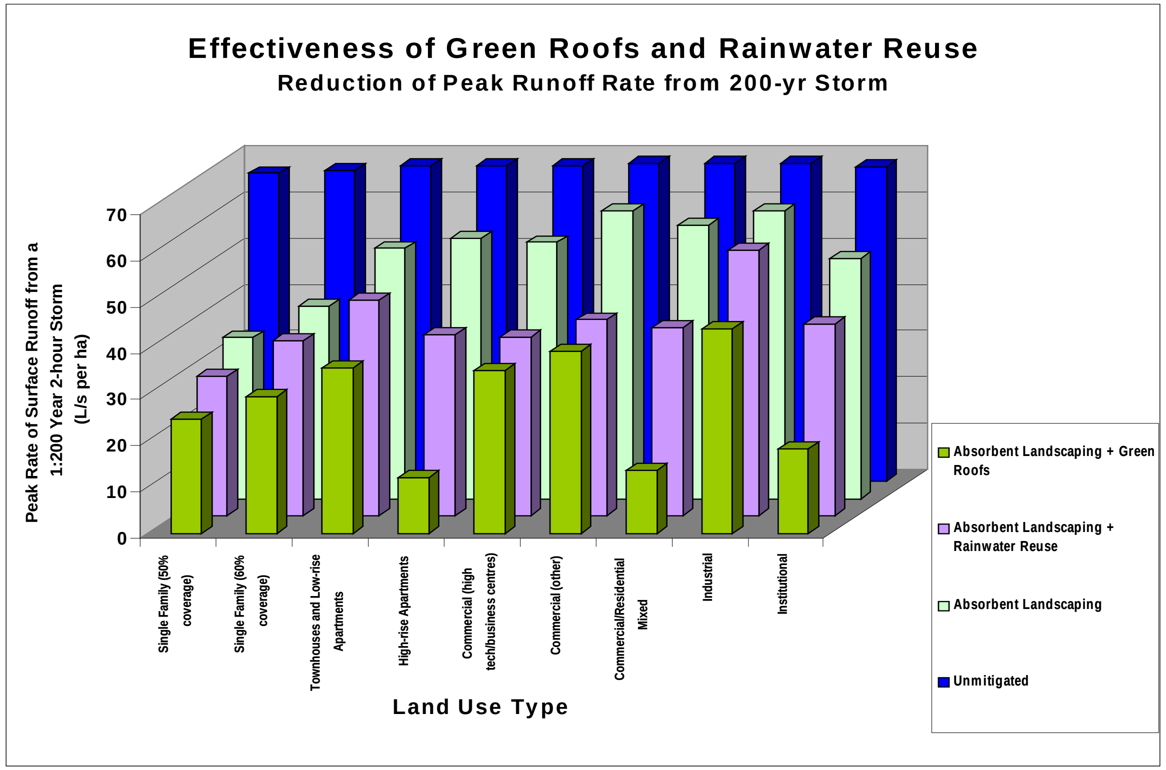


Figure A-15c: Reduction of Peak Runoff Rate from 200-yr Storm



On-Lot Source Control Combinations

The following combinations of on-lot source controls have been evaluated using the WBM.

Green Roofs and Bioretention: With this configuration, runoff from green roofs would be diverted into bioretention facilities rather than into storm sewers.

Rainwater Reuse and Bioretention: With this combination, some of the captured rainfall is reused and the remainder is released to bioretention facilities. A constant rate of release was assumed (0.1 to 3 L/s depending on soil type and land use type). In general:

- higher release rates for good soil conditions and low water use rates.
- lower release rates for poor soil conditions and high water use rates.

Detailed optimization could improve the effectiveness of this strategy, but is beyond the scope of this study**.**
It is assumed that absorbent landscaping is applied in conjunction with both of these source control combinations.

Projected Runoff Volume Reduction

Figures A-16a, b & c illustrate the projected runoff volume reduction that may be achievable using on-lot source control combinations. On-lot source control combinations provide only modest improvements in volume reductions where soil conditions are good. This is chiefly because stormwater infiltration alone is so effective in this situation.

Where soil conditions are poor for infiltration, combining rainwater reuse with bioretention can significantly improve volume reduction.

The green roof/bioretention combination is less effective in terms of reducing runoff volumes.

Figure A-16a: Reduction in Runoff Volume form Lots on Peat/Sediments (1mm/h)

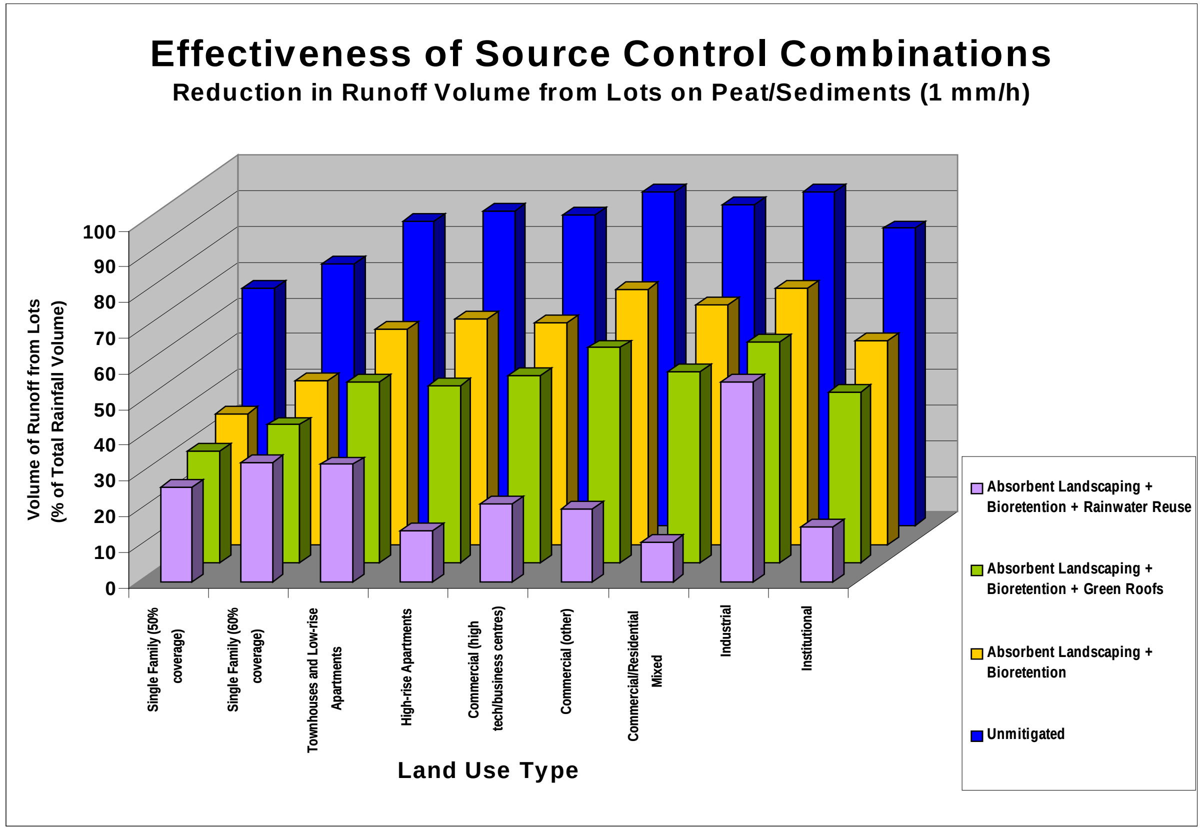


Figure A-16b: Reduction in Runoff Volume from Lots on Till (13mm/h)

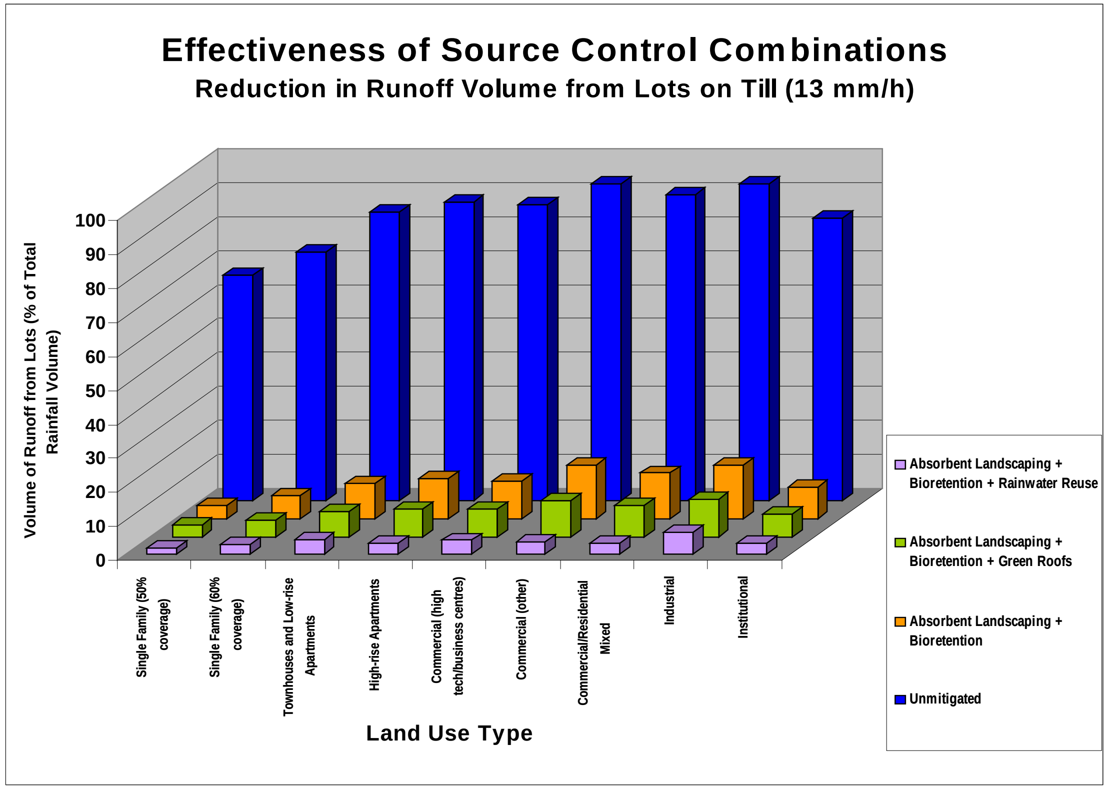
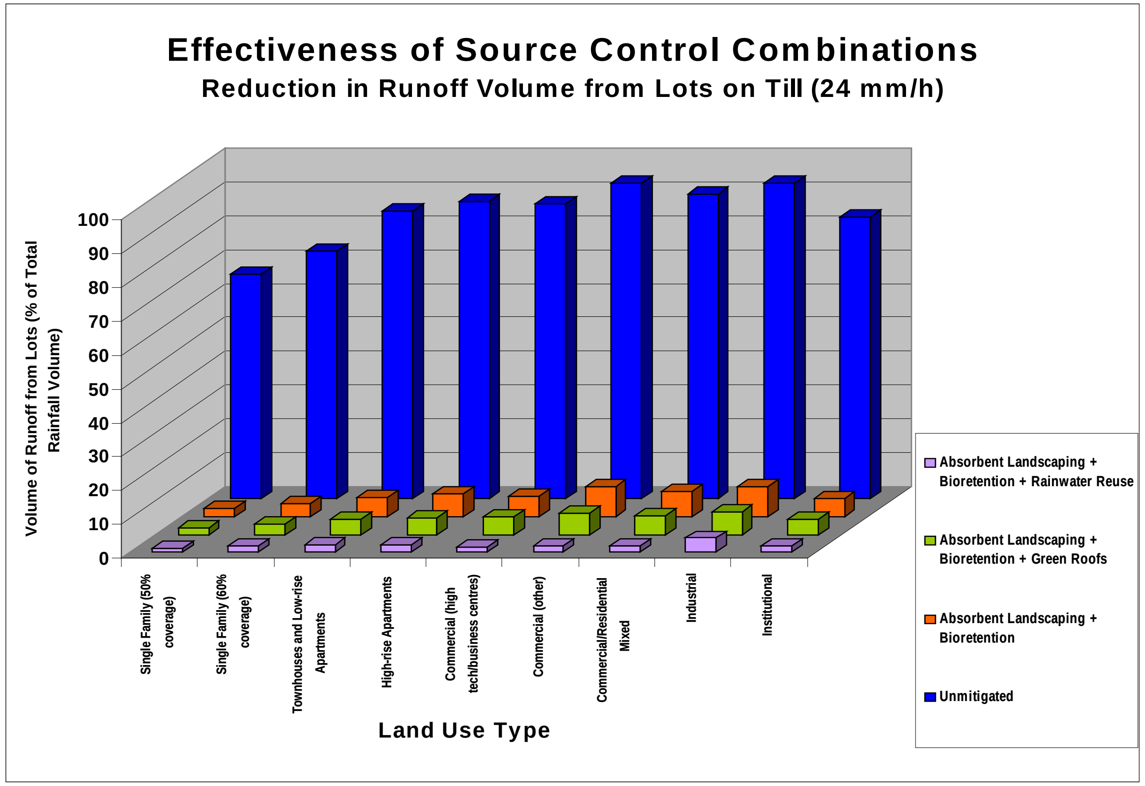


Figure A-16c: Reduction in runoff Volume from Lots on Till (24mm/h)



Projected Runoff Rate Reduction

Figure A-17a-f show the projected reduction in peak runoff rates that may be achievable using on-lot source control combinations, for the various land uses and soil types.

In general, where soil conditions are favourable for infiltration, on-lot source control combinations can greatly reduce peak runoff rates from high intensity (25-year, 200-year) storms. On-lot source control combinations can also significantly reduce peak runoff rates where soil conditions are poor, but to a lesser extent than with favourable soil conditions.

In general, combining green roofs with bioretention is more effective at reducing peak rates than combining water reuse with bioretention.

Figure A-17a: Reduction in Peak Runoff Rate (1:5) from Lots on Peat/Sediments (1mm/h)

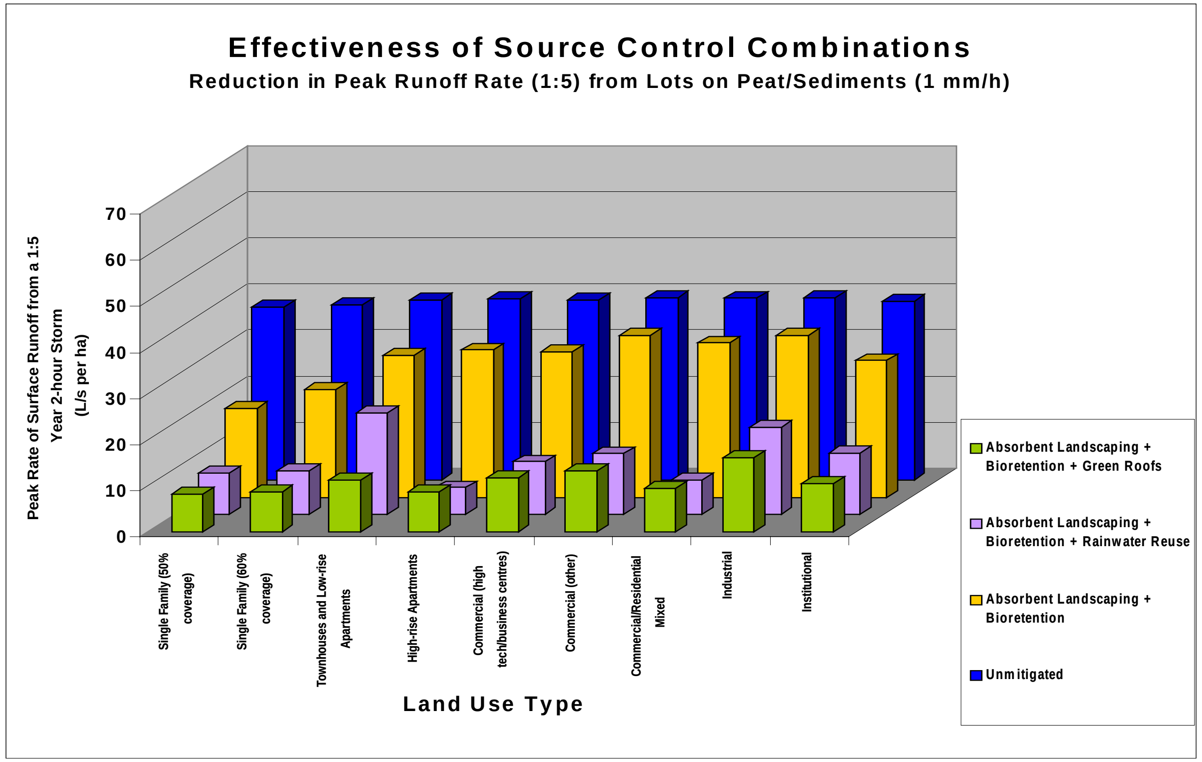


Figure A-17b: Reduction in Peak Runoff Rate (1:25) from Peat/Sediments (1mm/h)

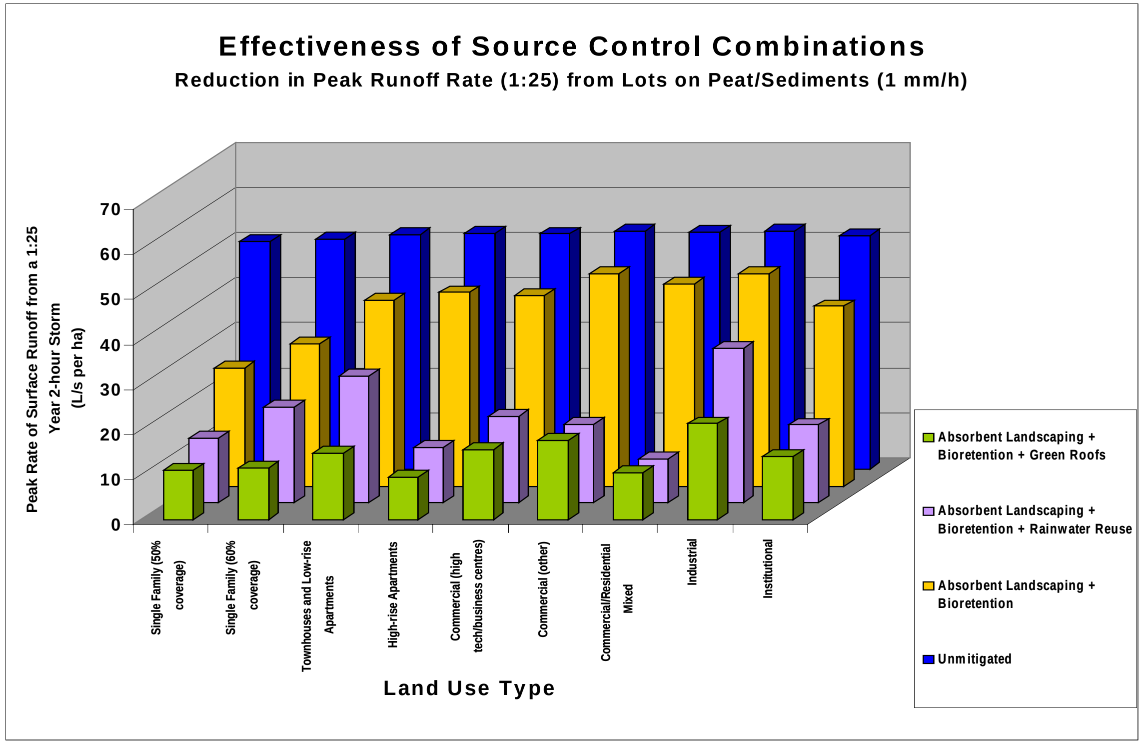


Figure A-17c: Reduction in Peak Runoff Rate (1:200) Lots on Peat/Sediments (1mm/h)

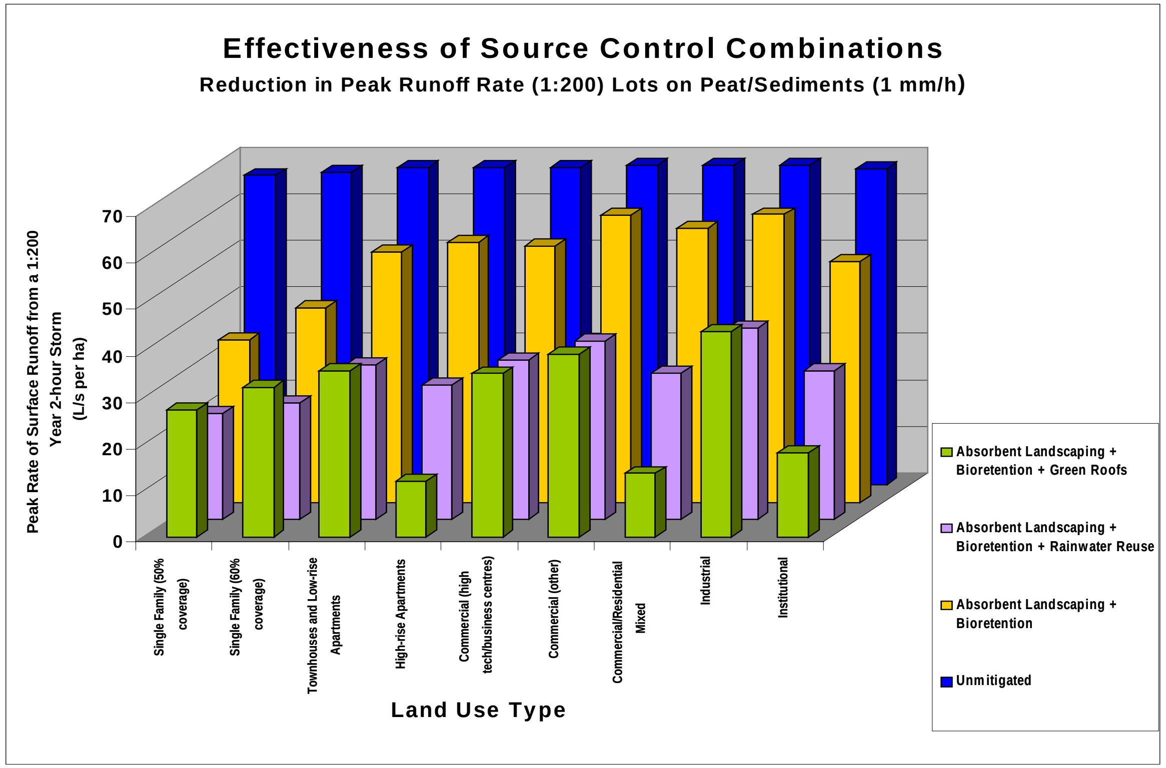


Figure A-17d: Reduction in Peak Runoff Rate (1:25) Lots on Till (13nn/h)

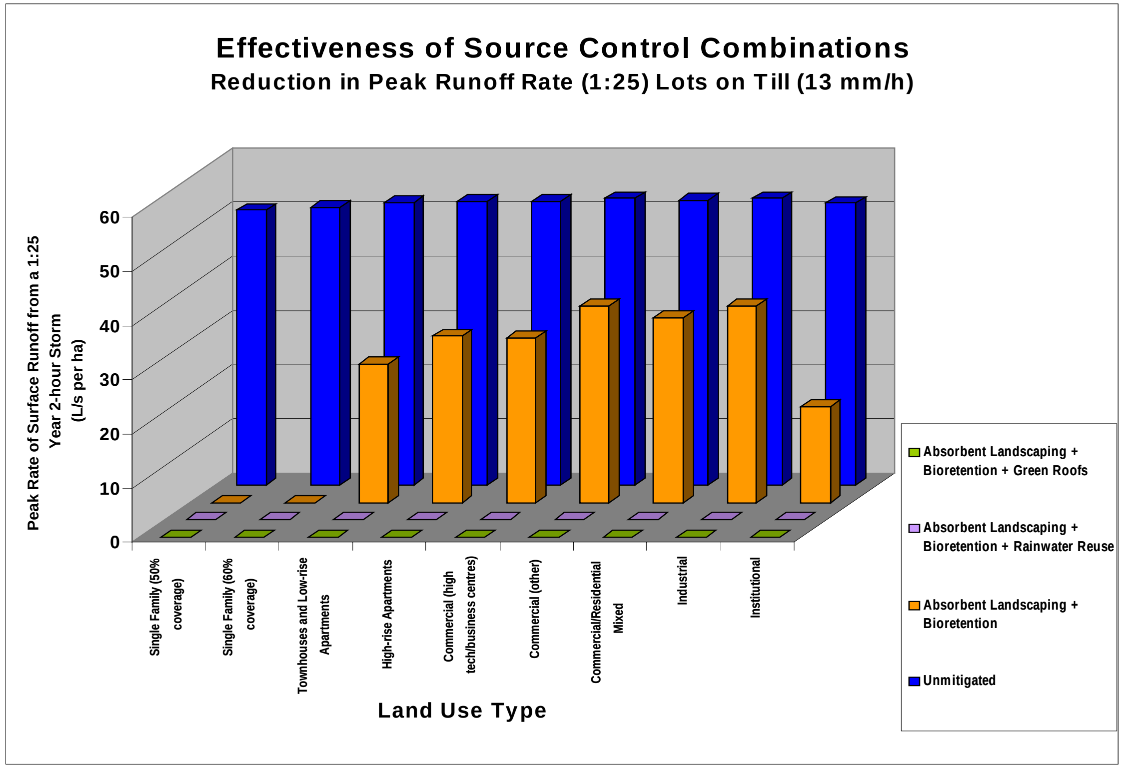


Figure A-17e: Reduction in Peak Runoff Rate (1:200) Lots on Till (13mm/h)

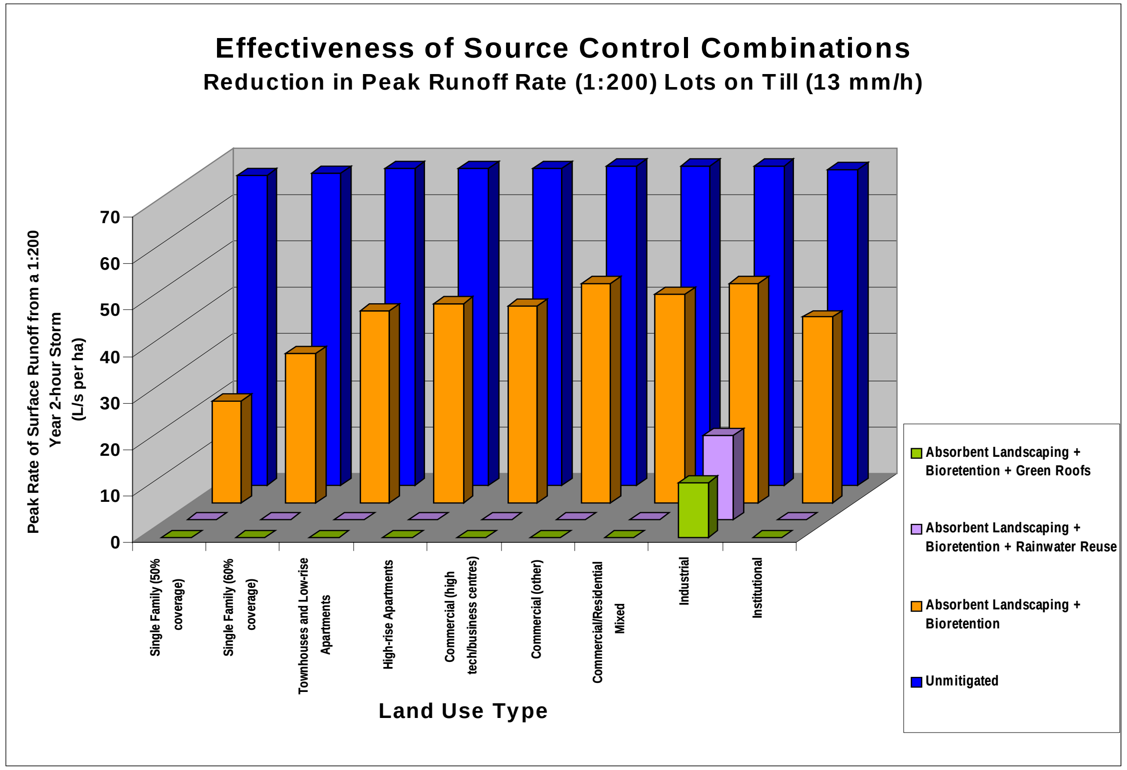
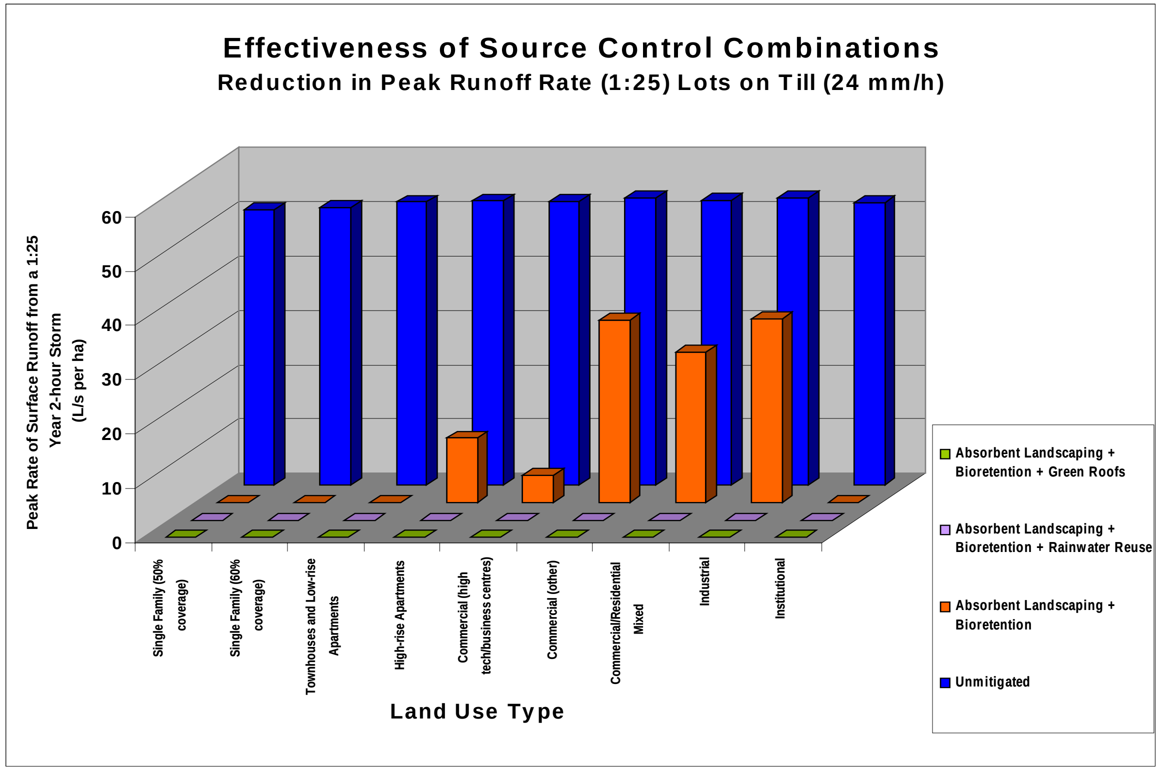


Figure A-17f: Reduction in Peak Runoff Rate (1:25) Lots on Till (24 mm/h)



Section A-6

Source Control Scenarios for Roads

Since road right-of-ways comprise a significant portion of the Still Creek watershed (29 percent) source control strategies for roads is an important part of an overall watershed retrofit strategy. Absorbent landscaping and stormwater infiltration is the only real source control option for roads.

Absorbent Landscaping and Infiltration

The following scenario has been modelled:

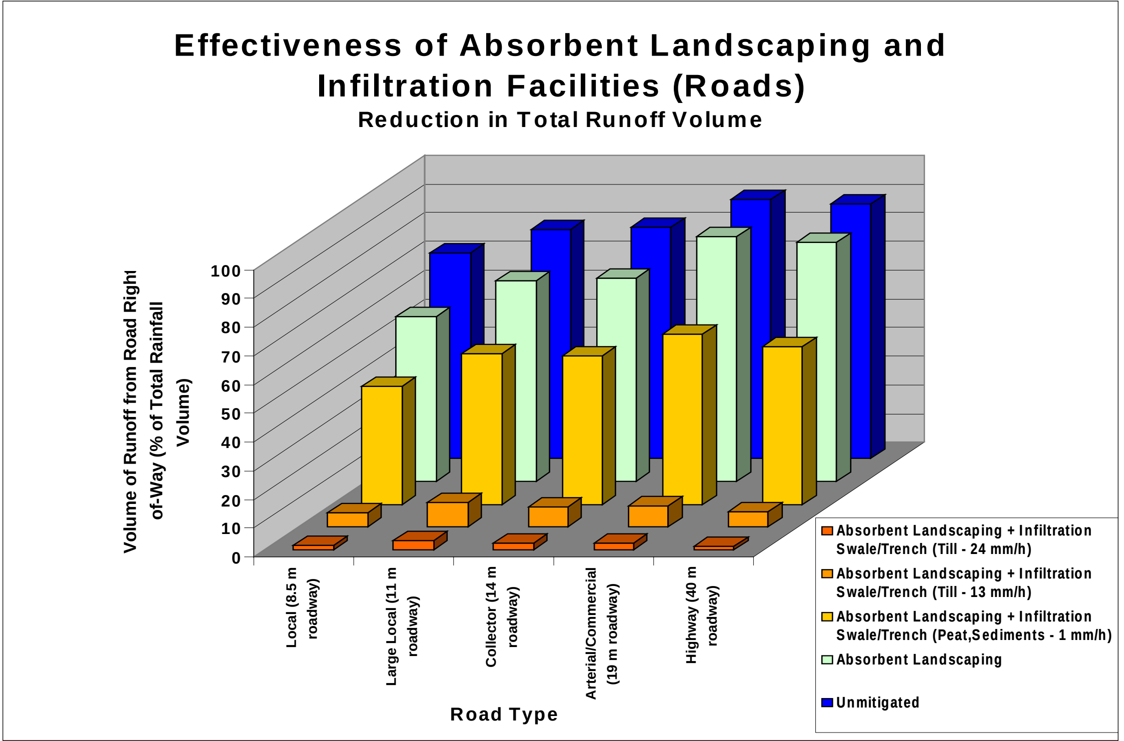
- **Absorbent Landscaping**: all open space on re-developed and retrofitted road right-of-ways is covered with absorbent landscaped soil (soil and vegetation rooting depth of 300 mm).
- **Drainage of Hard Surfaces to Infiltration**: In addition to absorbent landscaping, all impervious area within the ROW is disconnected from storm sewers and runoff is diverted to 2 layer infiltration systems, which consist of:
  - Surface Swale (300 mm of vegetated absorbent soil)
  - Underlying Infiltration Trench (gravel filled with overflow pipe 300 mm above the trench bottom)
- **Road Right-of-Way Space Used for Infiltration**: Amount of road ROW space provided for these infiltration systems is assumed to be ~ 15 percent of the paved roadway width:
  - 1.5 m for local roads (8.5 m roadway)
  - 1.7 m for large local roads (11 m roadway)
  - 2.1 m for collector roads (14 m roadway)
  - 3 m for arterial/commercial roads (19 m roadway)
  - 6 m for highway (40 m roadway)

  All road types except for the Highway are assumed to have impervious sidewalks in addition to the paved roadway

Projected Runoff Volume Reduction

Figure A-18 shows the level of runoff volume reduction that may be achievable using absorbent landscaping and infiltration swale/trench systems, for the range of road types and soil types.

Figure A-18: Reduction in Total Runoff Volume



Volume reductions achievable by absorbent landscaping alone are modest. Absorbent landscaping plus infiltration would be required to achieve significant reduction in road runoff volumes.

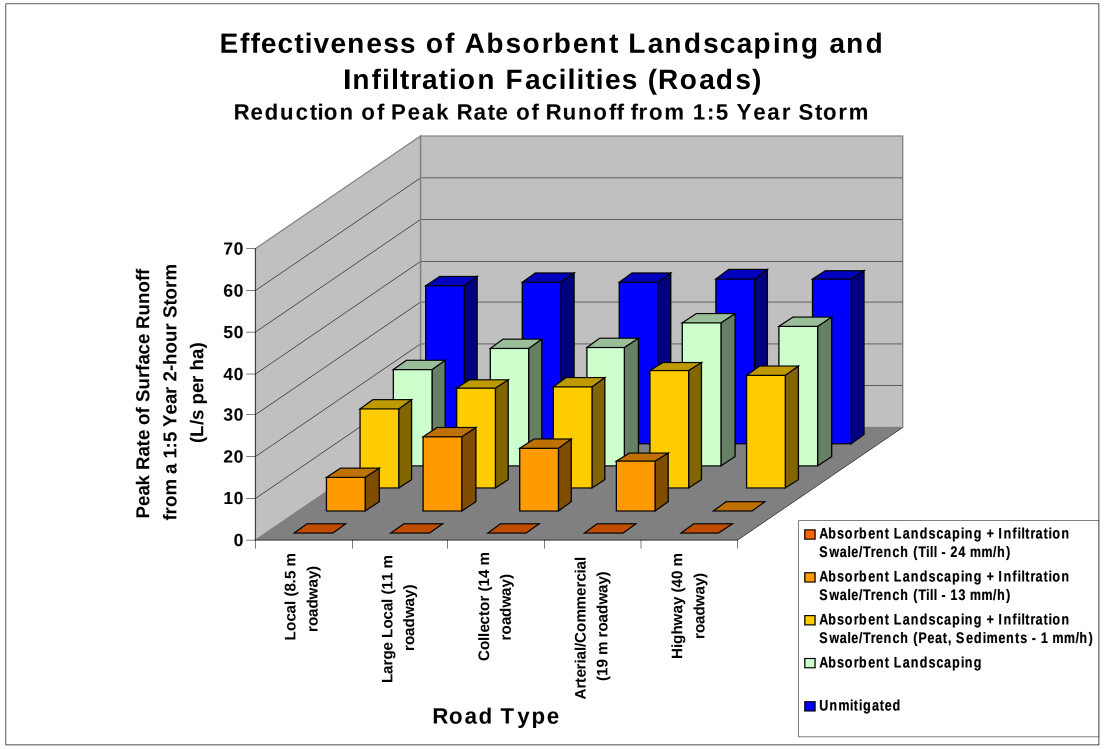
On till soils, runoff volume can be reduced to less than 10 percent of total rainfall volume on the road ROW (for all types of roads) by using infiltration swale/trench systems. On peat/sediments road infiltration facilities would be much less effective.

Projected Runoff Rate Reduction

Figure A-19a, b & c show the level of reduction in peak runoff rates that may be achievable using absorbent landscaping and infiltration swale/trench systems.

Simple absorbent landscaping can have significant benefit in terms of reducing peaks from critical storms, especially for smaller, local roadways.

Figure A-19a: Reduction if Peak Rate of Runoff for 1:5 Year Storm



By incorporating infiltration swale/trench systems on till soils with high sand and gravel content (assumed hydraulic conductivity of 24 mm/hr), surface runoff from a 5-year storm can be greatly reduced. The same is true for till soils with high sandy loam content (assumed hydraulic conductivity of 13 mm/hr), but to a slightly lesser extent. The potential for reduction in peak runoff rates from roads on peat/sediments (e.g. most of the highway) is much more limited.

The level of reduction in runoff rates that can be achieved for higher intensity storms (1:25, 1:200) is much less, but still significant for all types of roads.

Figure A-19b: Reduction of Peak Rate 1:25 Year Storm

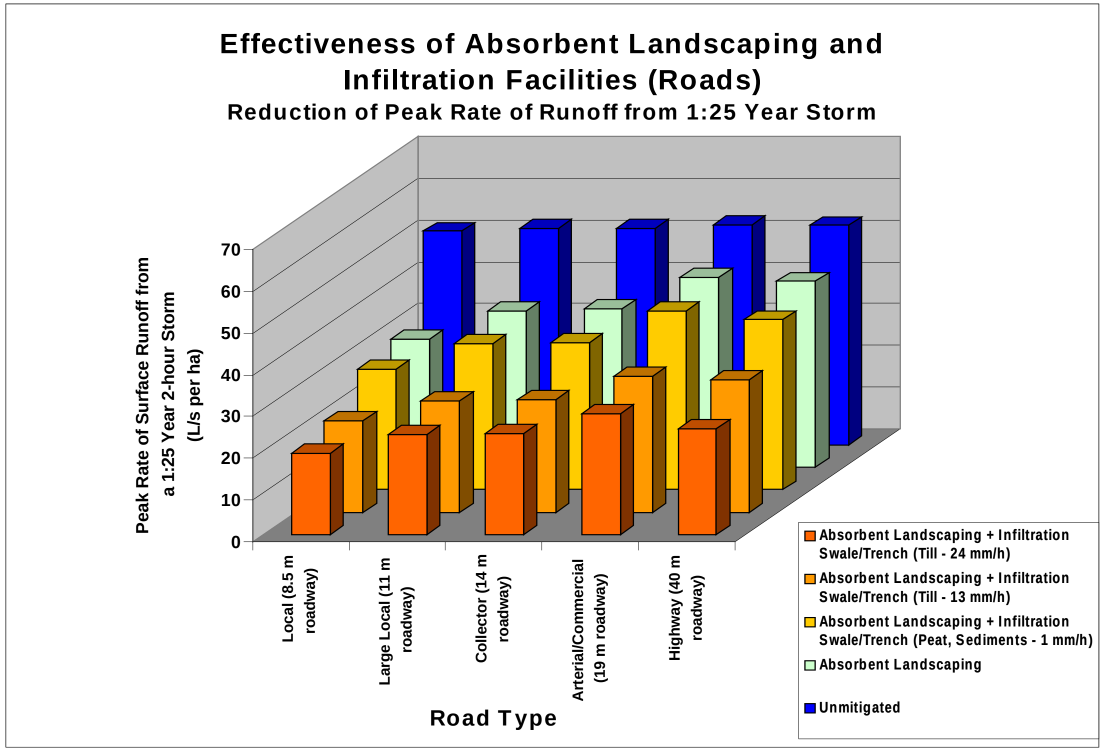
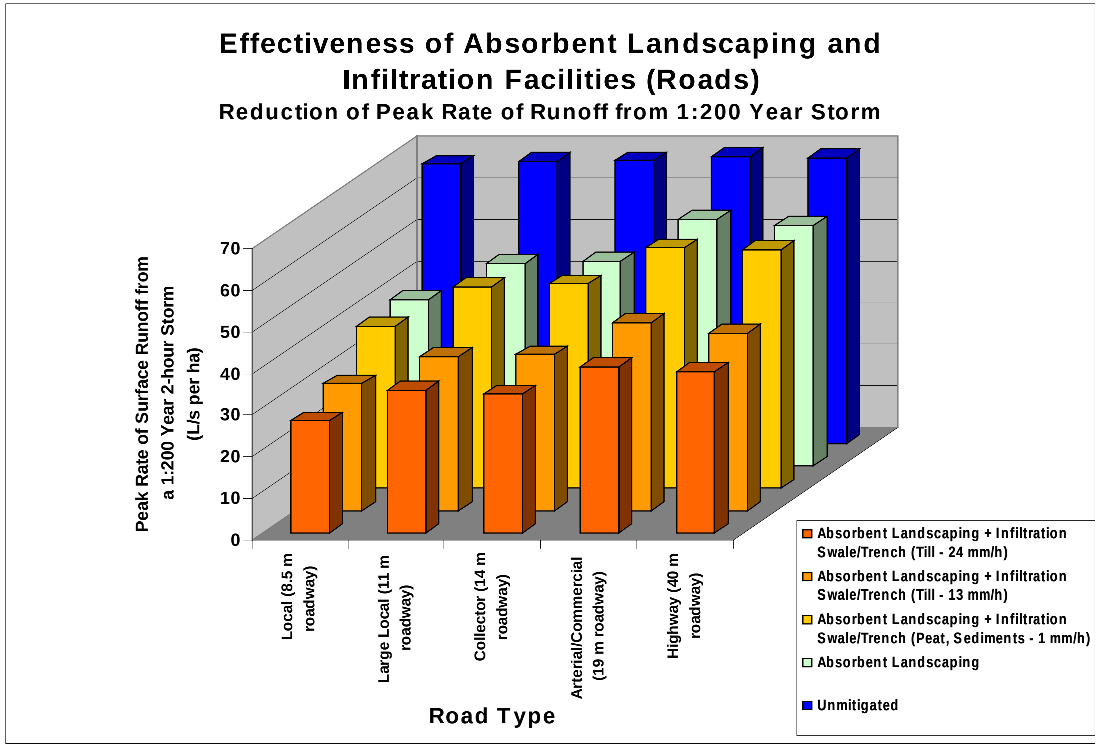


Figure A-19c: Reduction of Peak Rate of Runoff from 1:200 Year Storm



Section A-7

Modelling the Implementation of Source Control Measures Over 50-Year Period

Implementation of source control measures is a large undertaking, and would take time. The WBM has been used to estimate the impact of source control strategies on the volumes and rates of surface runoff from the Still Creek Watershed, as the source controls are implemented over a 50-year time horizon.

Implementation Assumptions

Several assumptions regarding the implementation of source controls have been required in order to perform the WBM modelling at the watershed scale. These assumptions are described below:

- **Source Control Retrofits**: The entire Still Creek watershed would be retrofitted with source controls within a 50-year timeline.
- **Retrofits of Lots**: Older housing developments would be retrofitted sooner than new developments.
- **Retrofits of Roads**: Retrofit of roadways would take place at a rate of two percent per year.
- **Modelling of Source Control Retrofits**: Each of the various source control options has been applied to the entire watershed over a 50-year timeline.
- **Climate Change**: Modelling of climate change has assumed that increases in rainfall occur gradually over the 50-year timeline (based on estimates by the Canadian Centre for Climate Studies). Total increase in rainfall volume over 50 years is expected to be about five percent.

Present Quantity of Surface Runoff

Water Balance Modelling of the Still Creek Watershed has indicated that under present conditions, the quantity of surface runoff which flows into the Still Creek system is equivalent to about 72 percent of the total rainfall that falls within the watershed (this figure is based on a wet year, 1997).

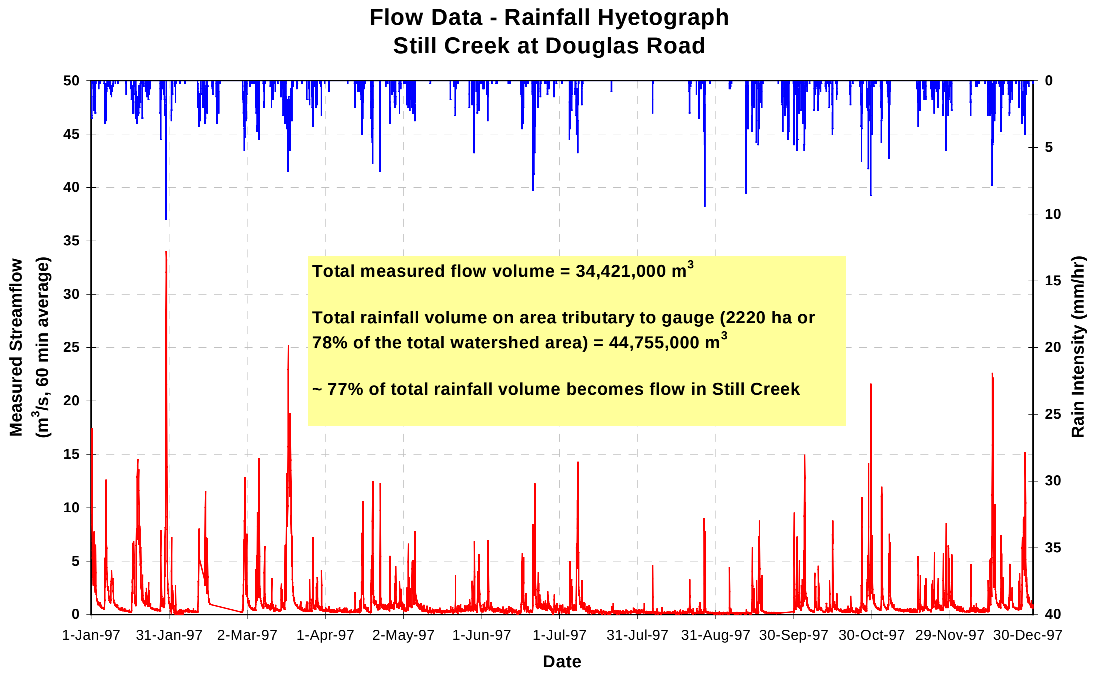
This large quantity of runoff is the underlying cause of many drainage-related problems, as discussed in Section A-1. In addition, the present surface runoff volumes are far greater than the objective of 10 percent, which is considered to be the target for supporting healthy aquatic ecosystems (refer to Section 1).

Comparison with Flow Data

Flow data from the GVRD flow monitoring station on Still Creek (at Douglas Road) was used to establish an approximate calibration for the WBM. About 78 percent of the total watershed area (~2220 ha) drains into Still Creek upstream of this location (refer to Figure A-20).

- Total rainfall volume on tributary area = 44,755,000 m^3
- Total measured flow volume = 34,421,000 m^3

Figure A-20: Flow Data Rainfall Hyetograph Still Creek at Douglas Road



Division of these two figures indicates that that approximately 77 percent of total rainfall in the tributary area ultimately drains into Still Creek. The majority of this flow is surface runoff. Groundwater sources (e.g. interflow) likely contribute a relatively small amount of flow, possibly in the order of 5 to 10 percent of the total flow. This would mean that the total volume of surface runoff is likely about 67 to 72 percent of the total rainfall, which provides a good coarse level verification of the Water Balance Modelling results.

The level of modelling that would be required to support a detailed ISMP would require a more rigorous method of calibration than has been used for the WBM in this case study.

Detailed calibration is important to ensure that a model is accurately reproducing what is going on in the real world. Comparing a model of existing conditions with measured flow data enables the modelling assumptions to be adjusted to better reflect reality. This would then improve confidence in the modelling results for future scenarios, such as those representing long-term source control retrofit strategies. Model verification is done after calibration to confirm that the model is performing adequately.

The level of effort required for model calibration and verification depends on the desired modelling objectives. For this study, the objective was to demonstrate the potential benefits of source control strategies, at an overview level. Therefore a detailed calibration / verification effort was not required.

Effectiveness of Watershed Retrofit Strategies for Lots

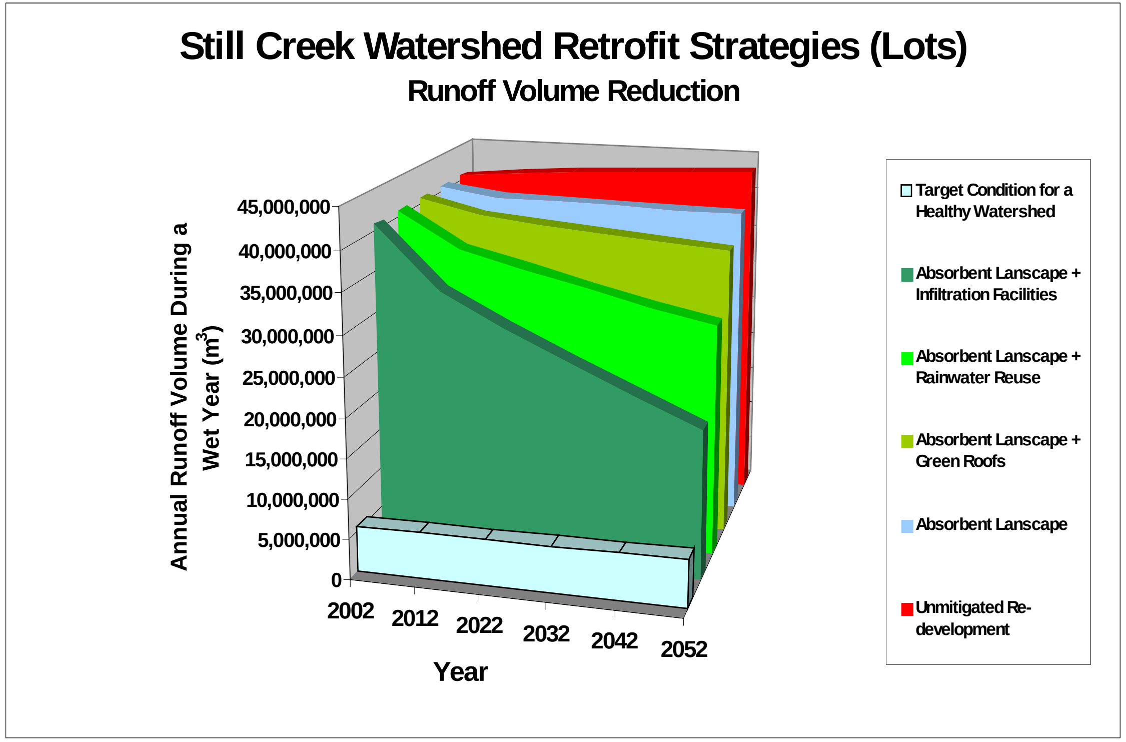
Reduction of Total Runoff

Without source controls, the total volume of surface runoff is expected to increase by about 6 percent over the next 50 years, due to climate change and densification.

Figure A-21 shows the projected reduction in total watershed runoff volume that may be achievable within a 50-year timeline by implementing source control measures in the Still Creek watershed.

Stormwater infiltration is the most effective source control strategy. Retrofitting lots with infiltration facilities could be expected to reduce total runoff volume from the watershed by about 54 percent.

Figure A-21: Runoff Volume Reduction



Significant reduction in total runoff volume can also be achieved through rainwater reuse (29 percent reduction).

Green roofs are less effective for reducing runoff volume, and can be expected to achieve only an 11 percent reduction. (Note that single family dwellings were not considered for green roofs.)

Absorbent landscaping without any other source control measures would result in a slight (4 percent) reduction in total runoff.

Reduction of Streamflows Causing Erosion

Figure A-22 indicates the predicted number of days that the peak rate of surface runoff would exceed the magnitude of a mean annual flood (MAF) under natural conditions. This provides an indicator of the number of streamflow events having the potential to cause erosion, as discussed in Section 1.

The modelling results indicate that retrofitting lots with infiltration systems is the single most effective source control for reducing streamflows having the potential to cause erosion (from 117 to 51 days per year).

Rainwater reuse was also predicted to reduce the frequency of erosive streamflows (from 117 to 84 days per year).

The potential reduction from green roofs was not predicted to be as significant.

Absorbent landscaping alone would result in very little benefit.

Figure A-22: Reduction in Exceedance Frequency of Natural MAF

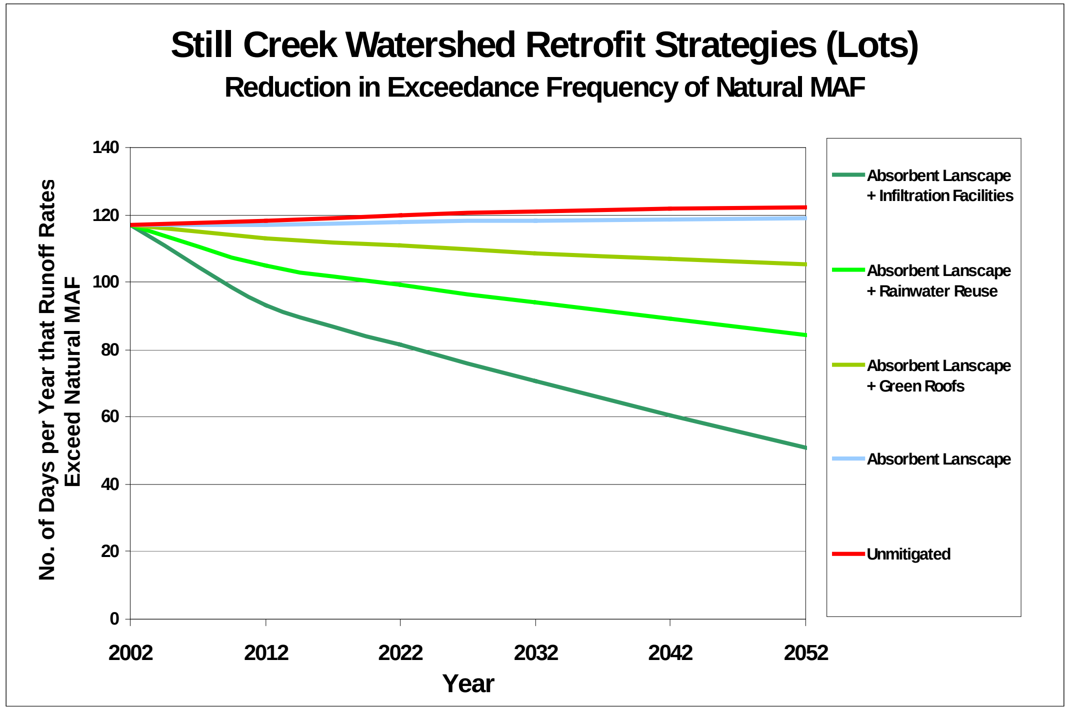
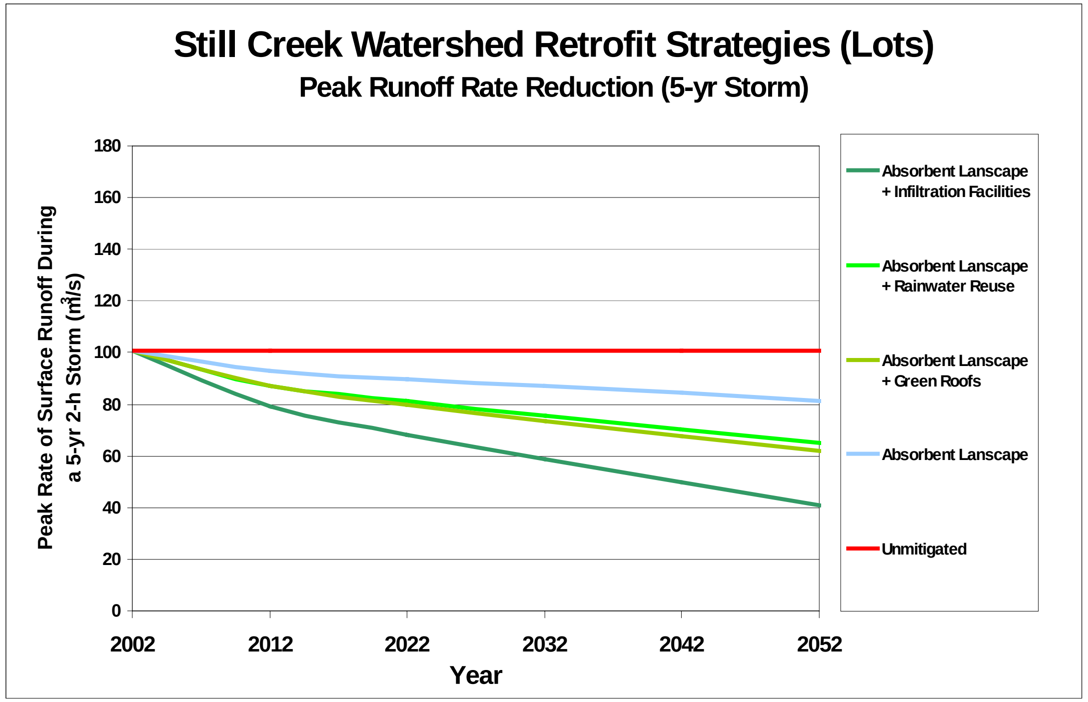


Figure A-23a: Peak Runoff Rate Reduction (5-yr Storm)



Reduction in Peak Runoff Rate from Critical Storms

Figures A-23a, b & c show the predicted reduction in peak surface runoff rates arising from critical storms.

Stormwater infiltration is the most effective source control for reducing peak runoff rates from 5-year and 25-year storms of 2-hour duration). For 200-year storms, green roofs are more effective.

Significant reduction may also be achievable through rainwater reuse.

Figure A-23b: Peak Runoff Rate Reduction (25-yr Storm)

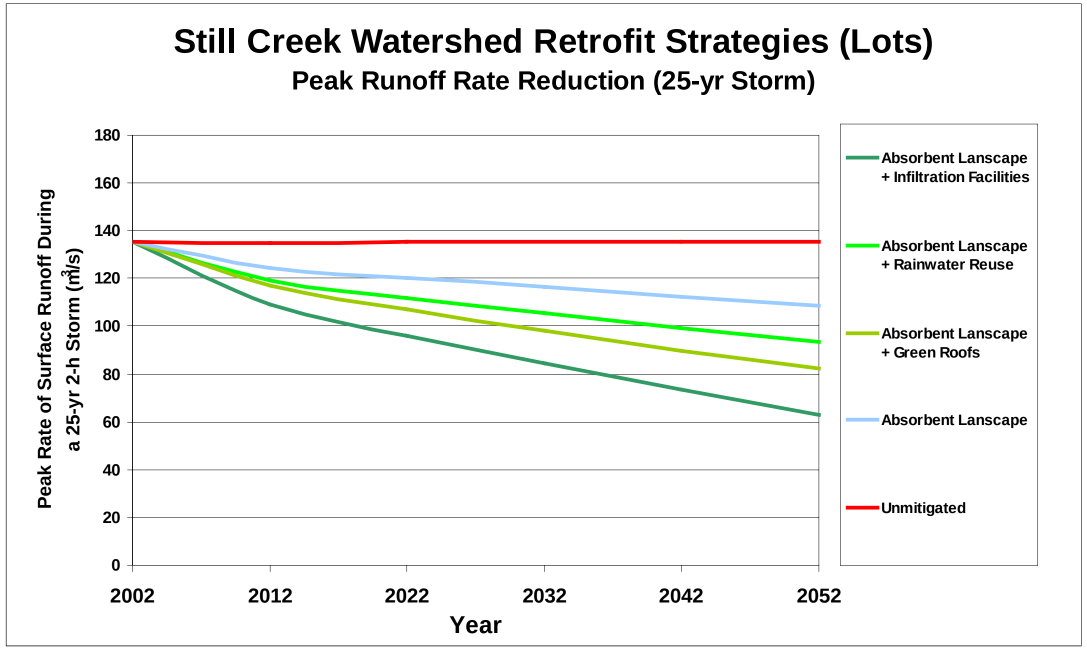
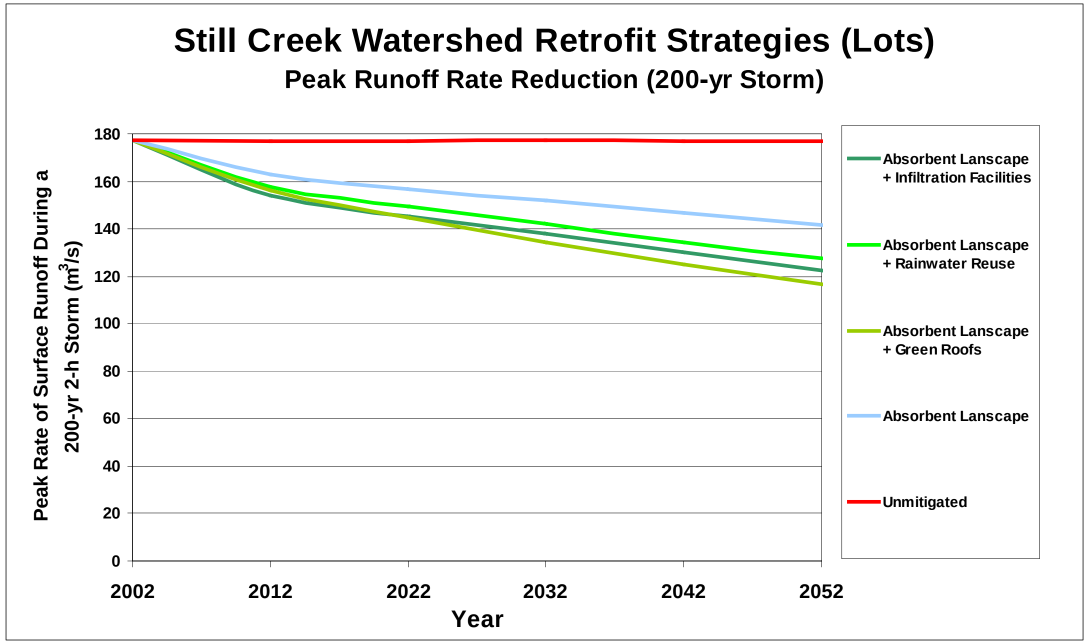


Figure A-23c: Peak Runoff Rate Reduction (200-yr Storm)



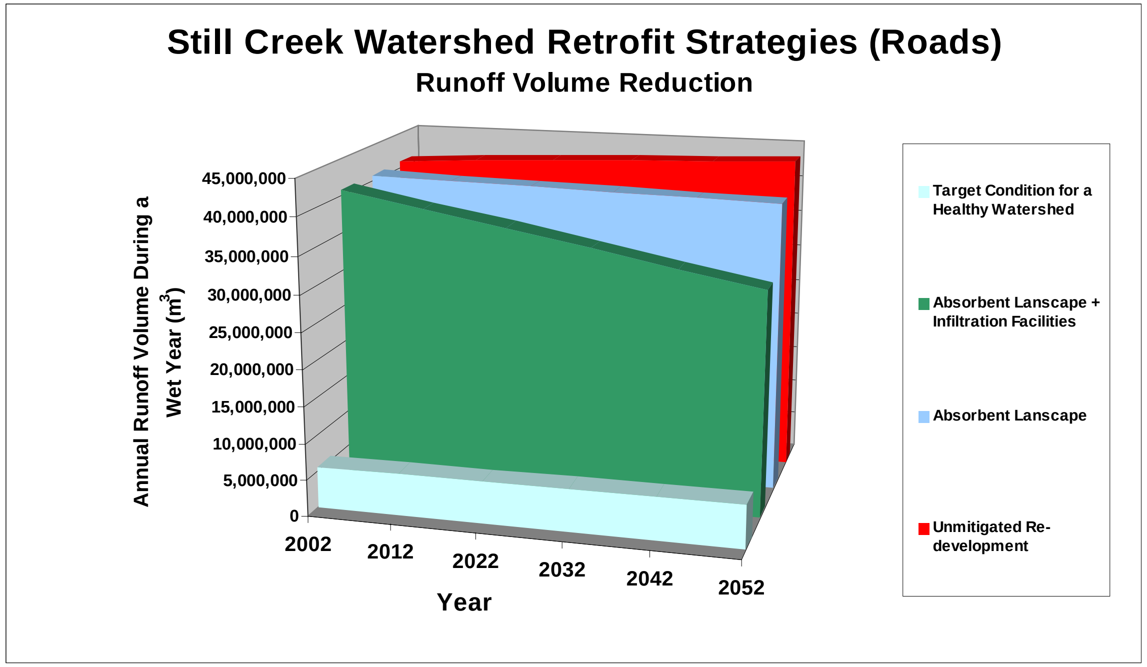
Effectiveness of Watershed Retrofit Strategies for Roads

Reduction of Total Runoff

Figure A-24 shows the predicted reduction in total watershed runoff volume that may be achievable over the next 50 years by retrofitting road right-of-ways with absorbent landscaping and infiltration facilities.

Runoff from roads would be an important part of the overall watershed retrofit strategy. Retrofitting roads with infiltration facilities can be expected to reduce watershed runoff volume by 25 percent at the end of the 50-year timeline.

Figure A-24: Runoff Volume Reduction

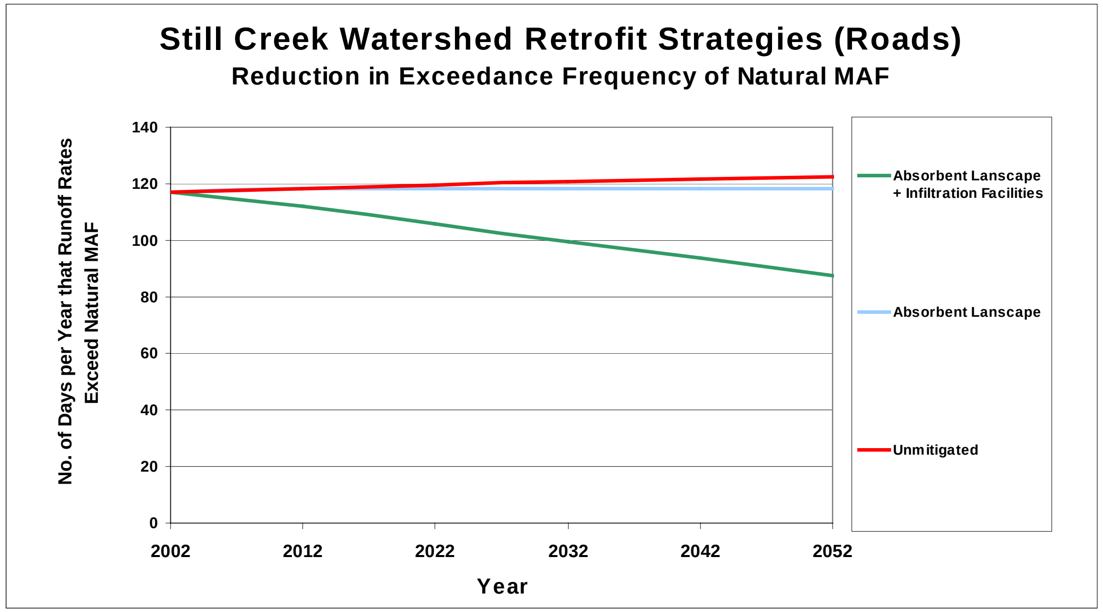


Reduction of Streamflows Causing Erosion

Figure A-25 indicates the predicted number of days that the peak rate of surface runoff would exceed the magnitude of a natural MAF.

The WBM predicts that retrofitting roads with infiltration systems could reduce the number of streamflow events having the potential to cause erosion from 117 to 84 days per year.

Figure A-25: Reduction in Exceedance Frequency of Natural MAR



Reduction in Peak Runoff Rate from Critical Storms

Figures A-26a, b & c show the predicted reduction in peak surface runoff rates from critical storms that could be achieved over time by retrofitting roads with infiltration facilities.

Road retrofit can be expected to reduce the peak runoff rates from the watershed in the order of about 20 percent.

Figure A-26a: Peak Runoff Rate Reduction (5-yr Storm)

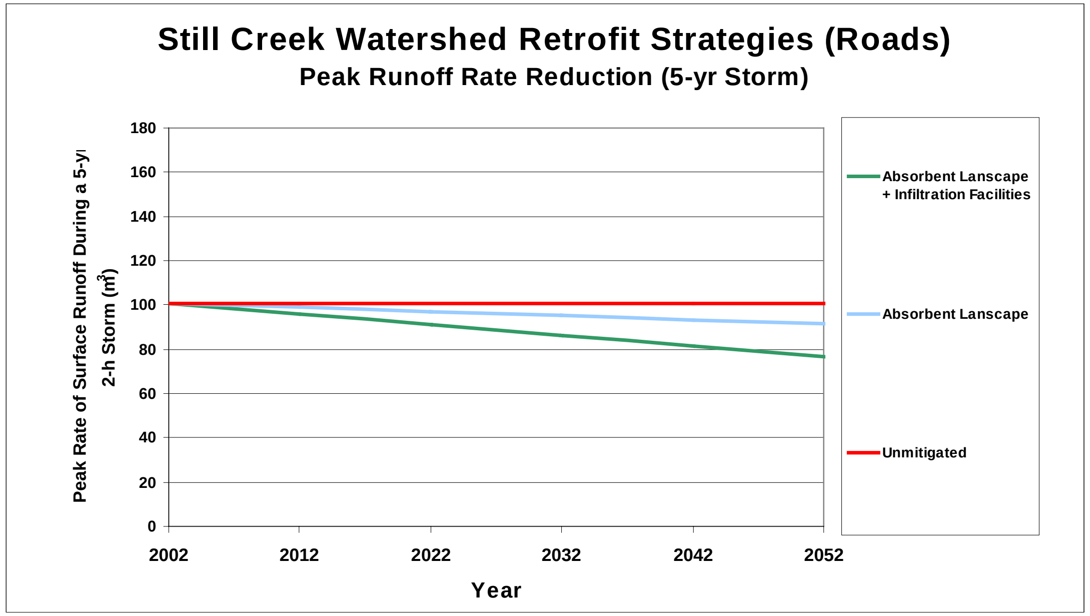


Figure A-26b: Peak Runoff Rate Reduction (25-yr Storm)

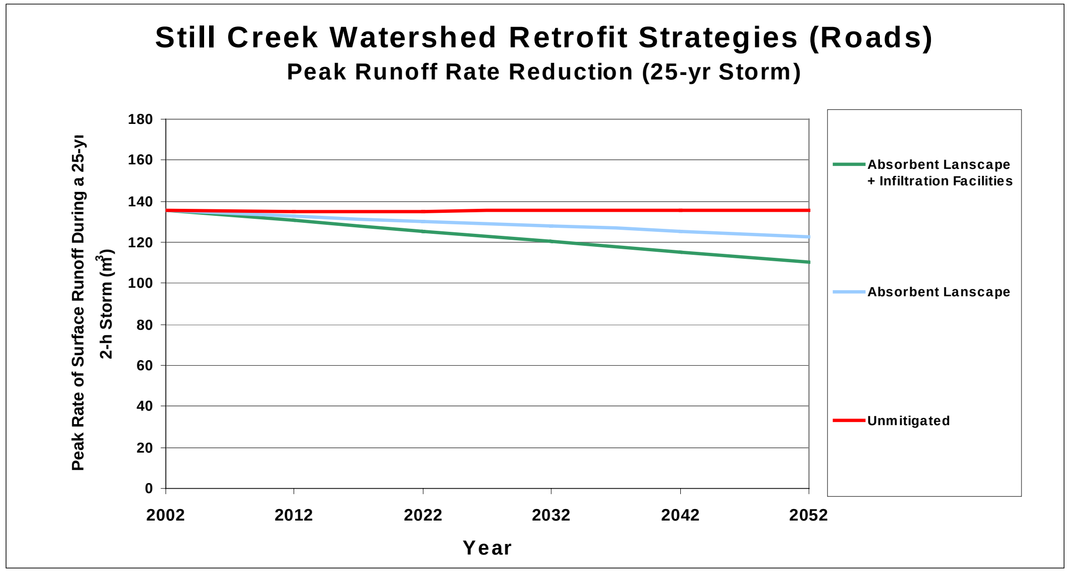
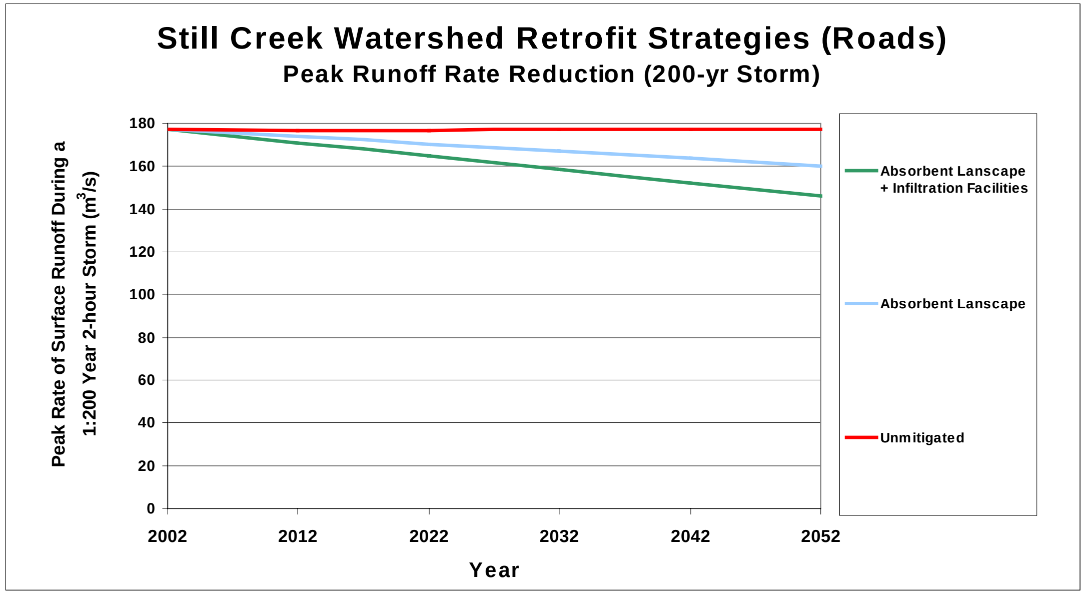


Figure A-26c: Peak Runoff Rate Reduction (200-yr Storm)



Overall Effectiveness of Watershed Source Control Strategies (Lots and Roads)

Reduction of Total Runoff Volume

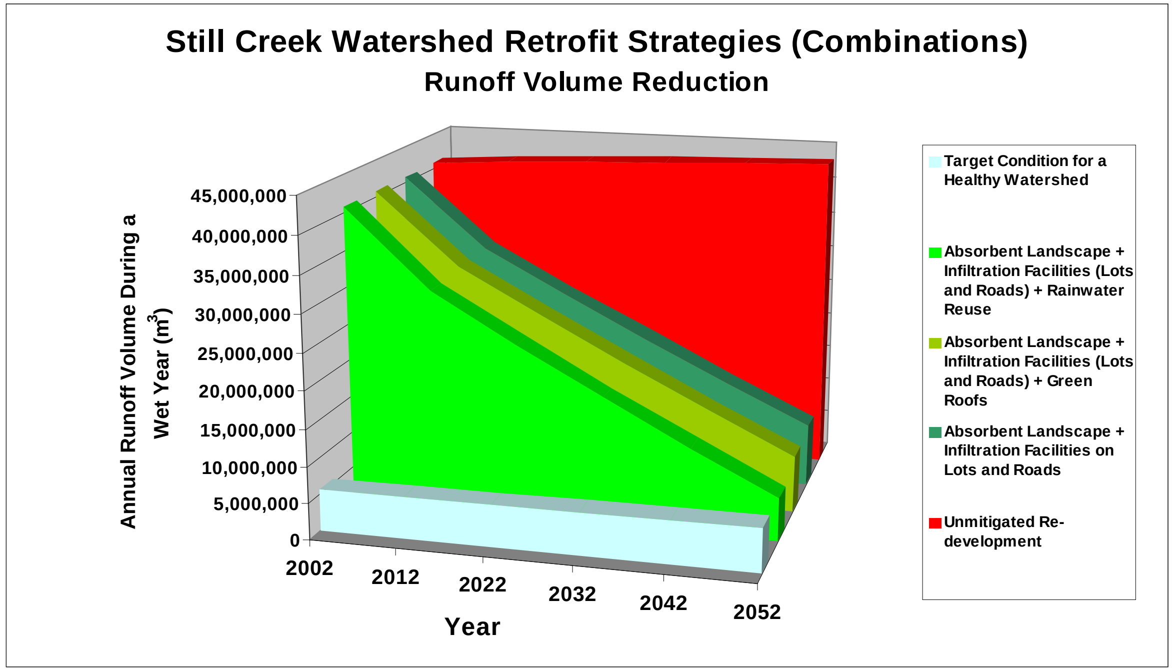
Figure A-27 shows the WBMs predicted reductions in total watershed runoff volumes that may be achievable over the next 50 years by retrofitting lots and road rights-of-way with various combinations of source controls.

Implementing infiltration source control strategies alone (on lots and roads) may potentially reduce runoff volume to about 14 percent of the total rainfall.

To achieve the target of 10 percent runoff, rainwater reuse measures would also need to be implemented:

- **Infiltration and rainwater reuse for lots**: Lots in the Still Creek watershed would be retrofitted with infiltration and rainwater reuse.
- **Infiltration for roads**: Roads in the Still Creek watershed would be retrofitted with infiltration facilities.

Figure A-27: Runoff Volume Reduction

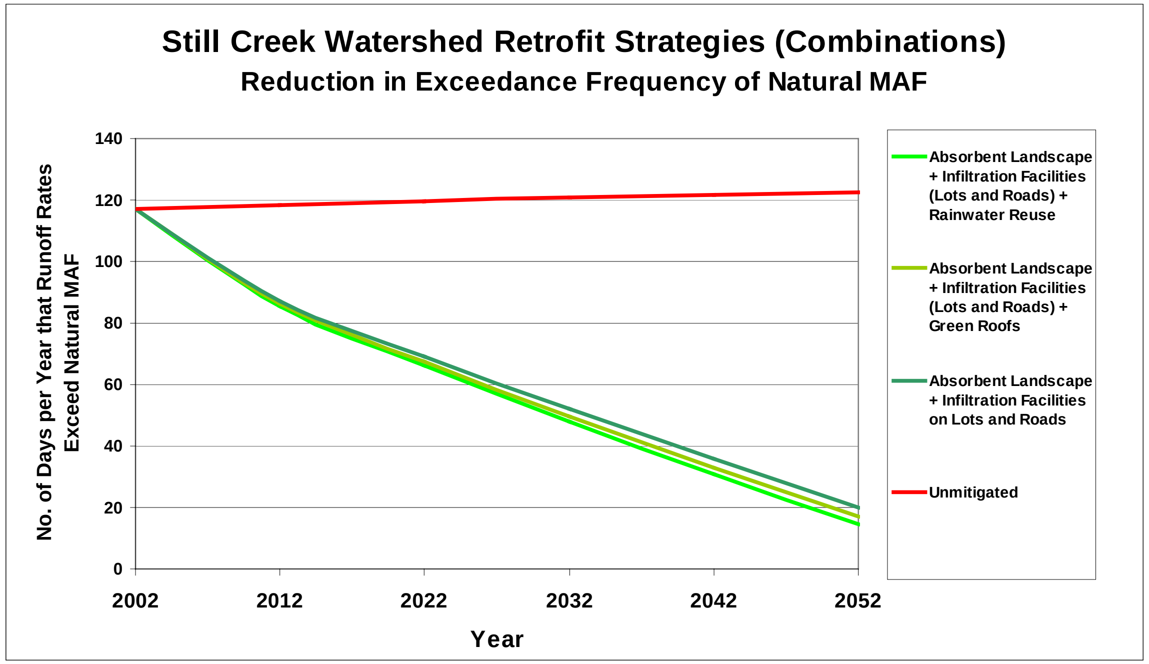


Reduction in Streamflows Causing Erosion

Figure A-28 indicates the predicted number of days that the peak rate of surface runoff from the total watershed would exceed the magnitude of a natural MAF, under different source control scenarios.

The WBM predicts that implementing infiltration and rainwater reuse for lots, and infiltration for roads would be expected to reduce the number of streamflow events having the potential to cause erosion from 117 to about 20 days per year.

Figure A-28: Reduction in Exceedance Frequency of Natural MAF



Reduction in Peak Runoff Rate from Critical Storms

Figures A-29a, b & c show the predicted reductions in peak surface runoff rates from the total watershed arising from critical storms.

Implementing infiltration and rainwater reuse for lots, and infiltration for roads can be expected to achieve a significant reduction of peak runoff rates from 5-year, 25-year storms, and 200-yr storms of 2 hour duration.

Figure A-29a: Peak Runoff Rate Reduction (5-yr Storm)

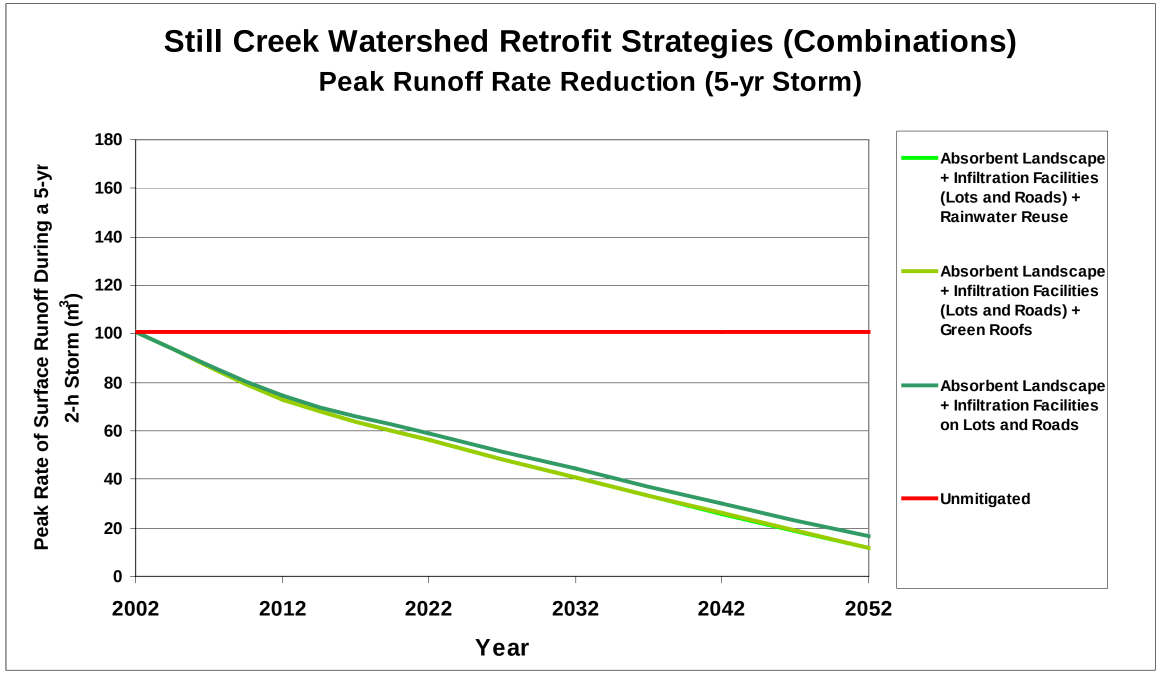


Figure A-29b: Peak Runoff Rate Reduction (25-yr Storm)

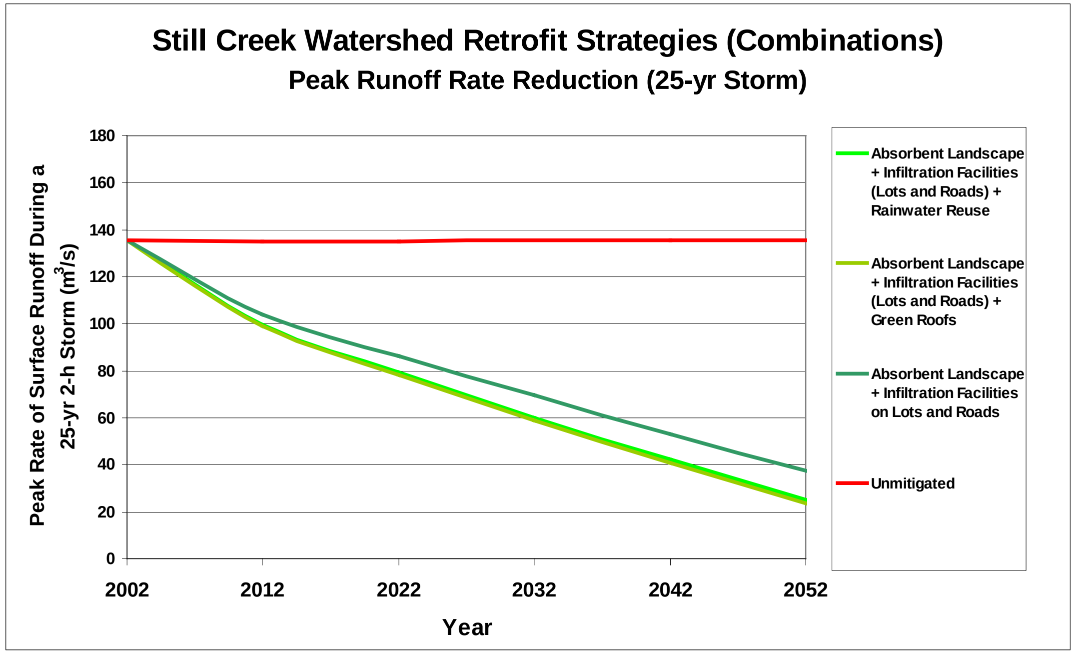
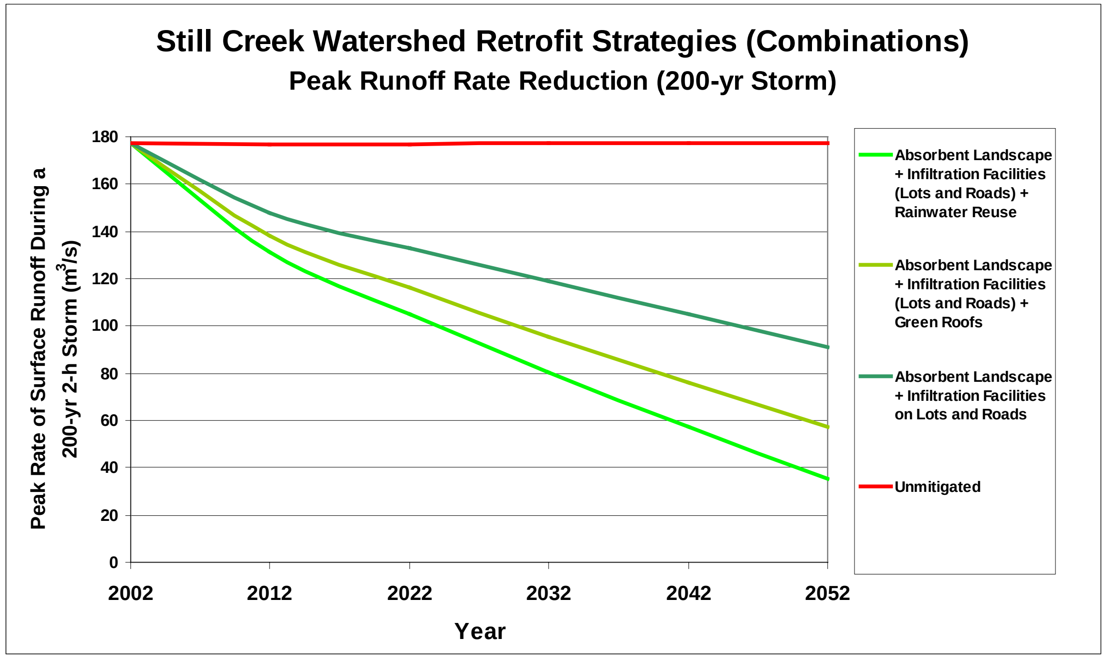


Figure A-29c: Peak Runoff Rate Reduction (200-yr Storm)



Section A-8

Next Steps - Still Creek ISMP Process

The Still Creek case study has used the WBM to evaluate the potential benefits which may be achievable through the implementation of stormwater source control measures in the watershed.

The Water Balance Modelling results in this study are at an overview level. The question of how the various source control scenarios affect flows in different reaches of the Still Creek system is beyond the scope of this study, and would have to be addressed as part of the Still Creek ISMP process. This would involve more detailed modelling that simulates the runoff from individual watershed sub-catchments into specific creek reaches and incorporates flow routing to generate streamflow hydrographs. This catchment-specific modelling should:

- generate hydrographs from each watershed sub-catchment
- incorporate groundwater flow pathways (interflow, aquifer outflow). Note that this study deals only with surface runoff.
- incorporate more detailed information on catchment-specific soil conditions, groundwater conditions, and land use
- integrate Water Balance Modelling output with a suitable flow routing model.

Catchment specific modelling enables evaluation of costs and benefits of specific source control options. It is important to consider the location of catchments relative to critical stream/channel reaches (e.g. where there is erosion or flooding problems, potential habitat value). This spatial context is key to translating hydrologic benefits (e.g. reduction in runoff volume, rates) into observed benefits (e.g. less erosion, less flooding, improved aquatic habitat)

As part of the ISMP process it is also important to evaluate source control costs/benefits relative to (and in combination with) other stormwater management options.

An ISMP would also include a source control implementation program, which would address issues such as:

- ☐ review/update of development bylaws, regulations, guidelines
- ☐ operation and maintenance (procedures, responsibilities)
- ☐ financing mechanisms
- ☐ demonstration projects
- ☐ monitoring and adaptive management