

## Setting Performance Targets and Design Guidelines



### Chapter Six

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## 6.1 The Role of Performance Targets

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Performance targets provide the foundation for implementing common sense solutions that eliminate the source of stormwater related problems. This chapter presents a cost-effective framework for local governments to:

- ❑ establish performance targets that reflect science-based understanding to guide early action in at-risk catchments (see Chapter 5)
- ❑ translate these performance targets into design criteria and guidelines that can be applied at the site level to design stormwater systems that mitigate the impacts of land development

Performance targets provide a starting point to guide the actions of local government in the right direction. Site design criteria provide local government staff and developers with practical guidance for moving from planning to action.

For a performance target to be implemented and effective, it must be quantifiable. It must also have a feedback loop so that adjustments and course corrections can be made over time. To be understood and accepted, a performance target needs to synthesize complexity into a single number that is simple to understand and achieve, yet is comprehensive in its scope. A runoff volume-based performance target fulfils these criteria. This chapter presents a methodology for setting volume-based performance targets.

Volume-based thinking is an integral element of a paradigm-shift that views watersheds as a fully integrated system where creek headwaters originate at rooftops and roads. Looking ahead to the GVRD case study results presented in Chapter 7, the implications are far-reaching because a volume-based approach to stormwater management touches on virtually every aspect of land use planning and site design. Volume-based thinking leads directly into landscape architecture, green roofs, urban reforestation, interflow and groundwater recharge, and water re-use.

## Constant Improvement through Adaptive Management

Performance targets and design criteria provide a basis for:

- integrating appropriate stormwater management policies with land use and community planning (see Chapter 4)
- selecting appropriate site design practices to reduce runoff and improve water quality at the source (see Chapter 7)

The policies and site design practices implemented in at-risk catchments become demonstration projects. Monitoring the performance of these demonstration projects provides the foundation for adaptive management, as illustrated in Figure 6-1.

The goal of adaptive management is to learn from experience and constantly improve land development and stormwater management practices over time. This requires ongoing monitoring of demonstration projects to assess progress towards performance targets and the shared watershed vision. The details of adaptive management are discussed further in Section 6.5.

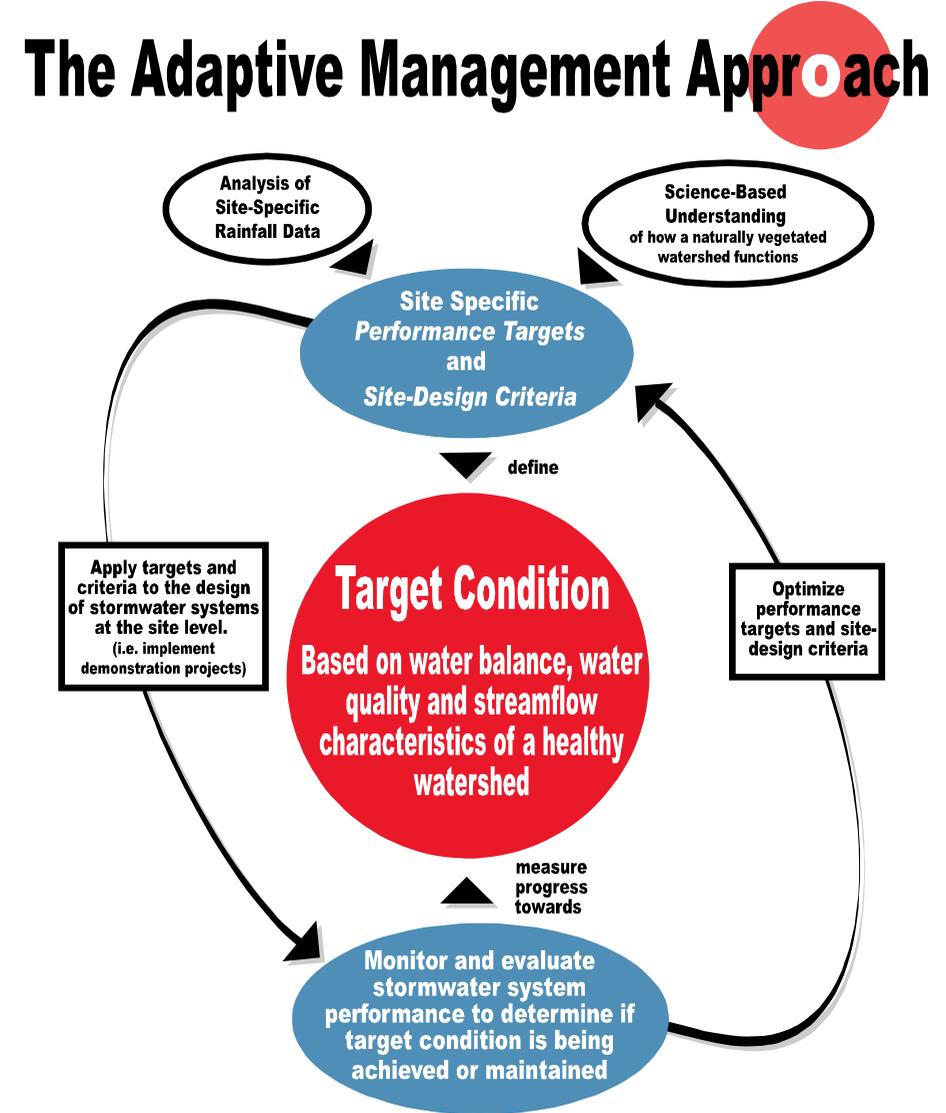


Figure 6-1

## 6.2 Defining a Target Condition

A biophysically-based target condition can be established based on an understanding of the characteristics of a healthy watershed.

In order to be achievable, a biophysically-based target condition must be translated into performance targets that can be applied to stormwater management practice.

Since changes in Water Balance and hydrology are the primary source of stormwater related impacts on watershed health (see Chapter 2), it is especially important to establish performance targets for managing:

- **Runoff Volume**, and
- **Runoff Rate**

### Defining a Runoff Volume Target

Recent research from Washington State shows that stormwater related impacts on stream health start to occur once the impervious percentage of a watershed exceeds about 10% (see Chapter 2). Therefore, to ensure the health of aquatic systems, developments should be planned and built to function like watersheds with less than 10% total impervious area.

Stormwater-related impacts are a direct result of runoff from impervious surfaces that are directly connected to a storm drainage system or to downstream watercourses (often defined as effective impervious area (EIA)).

The Washington State research is based on data from watersheds with traditional ditch and pipe systems designed to remove runoff from impervious surfaces as quickly as possible, and deliver it to receiving waters.

When the impervious area of watersheds with traditional ditch and pipe systems reaches the 10% threshold, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation. Note that there is virtually no surface runoff from the naturally vegetated portion of a watershed, but nearly all rain that falls on directly connected impervious surfaces becomes runoff.

An appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be returned to natural hydrologic pathways, through infiltration, evapotranspiration or re-use on the development site. Managing 90% of the rainfall volume throughout a watershed should achieve the biophysical target condition for the watershed. Managing 90% of rainfall volume therefore becomes the volume-based performance target.

### Defining a Runoff Rate Target

As discussed in Chapter 2, the Mean Annual Flood (MAF) is defined as the channel-forming event; as the MAF increases with development, stream channels erode to expand their cross-section, thereby degrading aquatic habitat. Therefore, an appropriate runoff rate target is to ensure that streamflow rates that correspond to the natural MAF occur no more than once per year, on average.

In order to achieve this target, stormwater systems should be designed to limit the frequency that the natural MAF is exceeded.

The MAF correlates roughly with the runoff from a Mean Annual Rainfall (MAR), which is defined as the rainfall event that occurs once per year, on average. The significance of the MAR is discussed further in Section 6.4.

Natural streamflow patterns can be approximated for the majority of rainfall conditions (all rainfall in an average year) by providing enough storage capacity to capture the runoff from a MAR, and releasing the stored runoff at a rate that mimics the rate of interflow in a naturally vegetated watershed.

## Additional Performance Indicators

As discussed in Chapter 2, there are additional science-based indicators that could be used as performance targets for protecting watershed health, including:

- ❑ Maintain stream baseflow at a minimum of 10% of the Mean Annual Discharge (MAD).
- ❑ Maintain natural total suspended solids (TSS) loading rates.
- ❑ Maintain key indicators of aquatic ecosystem health (e.g. maintain Benthic Index of Biological Integrity (B-IBI) score above 30).
- ❑ Preserve a 30-metre wide intact riparian corridor along all streamside areas.
- ❑ Retain 65% forest cover across the watershed.

These indicators of watershed health can play an important role in comprehensive performance monitoring and adaptive management programs (as discussed in Section 6.5).

These indicators may also be used to help define a biophysically-based target condition for a healthy watershed. The GVRD's *Integrated Stormwater Management Planning Terms of Reference Template* (2002) provides an example of how some of these indicators have been applied to define a target condition.

This Guidebook presents a methodology for setting performance to achieve the runoff volume target (i.e. limiting runoff volume to 10% of total rainfall) and runoff rate target (i.e. maintaining natural MAF). The runoff volume and rate targets have been selected as the primary basis for defining a biophysically-based target condition to guide stormwater planning and design because:

- ❑ They are based on scientifically defensible research that correlates watershed imperviousness and changes in hydrology with stream health.
- ❑ They provide an easily understood starting point for the design of stormwater systems at the site level (as described in this chapter). These targets can be directly managed at the site level.
- ❑ Achieving the 10% volume target should also achieve management objectives for stream baseflows, water quality and aquatic ecosystem health. This is a reasonable assumption because:

- Infiltrating rainfall at the source is the most effective way to maintain stream baseflows.
- Infiltration and other stormwater source control strategies provide effective treatment for the first flush of pollutants that wash off from developed areas.
- Restoring the natural Water Balance eliminates the source of stream degradation and improves aquatic ecosystem health.

Monitoring the performance of demonstration projects will provide the opportunity to test how well alternative performance targets relating to baseflows, water quality and aquatic ecosystem health can be managed by achieving the runoff volume and rate targets (see Section 6.5).

## Achieving the Target Condition at the Site Level

Degradation of watershed health is the result of the cumulative impact of individual land development projects on runoff volume and rate (i.e. incremental changes in Water Balance and hydrology). Each development project contributes to increased runoff volume and rate in downstream watercourses.

In order to achieve the target condition for a healthy watershed as a whole, cumulative impacts must be managed at the site level. This means that stormwater systems at the site level must be designed to achieve the runoff volume and rate targets.

### The Role of Source Control

To achieve runoff volume and rate targets, development sites and their stormwater systems must be designed to replicate the functions of a naturally vegetated watershed (the most effective stormwater system). This requires stormwater source control strategies that 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 re-use it at the source. This creates hydraulic disconnects between impervious surfaces and watercourses (or storm drains), thus reducing the volume and rate of surface runoff.

Looking ahead, Chapter 7 presents a variety of source control solutions for maintaining or restoring natural runoff volume and rates, including:

- ❑ Preserving natural vegetation cover, natural stormwater management features (e.g. wetlands), and limiting the extent of impervious areas through low impact development practices
- ❑ Preserving or restoring natural infiltration capacity by infiltrating runoff from impervious surfaces and applying absorbent landscaping
- ❑ Preserving or restoring natural evapotranspiration capacity to the extent possible through conservation, landscaping and the application of green roofs
- ❑ Re-using rainwater for irrigation and for indoor uses

Chapter 7 provides guidance for selecting appropriate source control strategies for different land use types, soil conditions and rainfall characteristics.

## Other Objectives for Managing Stream Health

To maintain or restore stream health, this Guidebook recommends focusing limited resources on managing runoff volume and rate. Scientific research on the subject recommends a broad range of strategies including:

- ❑ Preserve or restore natural vegetation along riparian corridors.
- ❑ Preserve or restore natural features, such as wetlands, that play a key role in maintaining the hydrologic and water quality characteristics of healthy streams.
- ❑ Preserve or restore instream features that are key to the health of aquatic ecosystems, such as channel complexity and adequate spawning gravel.
- ❑ Control sources of water pollution (point and non-point sources).

Integrated Stormwater Management Plans (ISMPs) should address these objectives, in addition to the runoff volume and rate targets.

### Desired Outcomes for ISMPs

Integrated stormwater management plans (ISMPs) for individual watersheds should therefore:

- ❑ establish objectives for maintaining and/or restoring stream health
- ❑ develop comprehensive strategies to achieve these objectives, which not only deal with runoff volume and rate, but also address issues relating to water quality and preservation/restoration of key natural features (e.g. riparian forests, wetlands, in-stream features)

The elements of ISMPs are discussed further in Chapter 10.

## A Widely Applicable Target Condition

The fact that performance targets are based on the characteristics of a healthy watershed is key. This means that the performance targets for any given watershed apply to:

- ❑ **new development *OR* retrofit scenarios** - Appropriate land development practices can prevent the degradation of a healthy watershed or restore an unhealthy watershed. The target condition remains the same.
- ❑ **protection of environment *OR* property** - Maintaining or restoring the ecological health of a watershed will also eliminate the source of flooding risk to property and public safety. Protecting aquatic resources and protecting property are complementary objectives. Even if property impacts are the driver for action, biophysically-based performance targets are still appropriate.

## The Range of Case Study Experience

The methodology presented in this chapter for setting performance targets and design criteria evolved through recent integrated stormwater management experiences in British Columbia. Preliminary performance targets and site design criteria were developed using this methodology in three different catchments, all with different initial conditions, development types and drivers for action. The three case studies included the following development scenarios:

- ❑ **Urban** - High-density urban development at the top of a mountain, where protection of downstream aquatic habitat was the primary driver for action.
- ❑ **Suburban** - Fully developed suburban watershed, where the need for immediate flood relief was the driver for action.
- ❑ **Suburban/Rural** - A municipality comprising rural and suburban land uses, where future development areas (currently forested) drains to agricultural lowlands. Aquatic habitat protection was also a driver.

The methodology has been tested and accepted by the local governments in all three cases. The suburban/rural example (City of Chilliwack) is used as a case study for the remainder of this chapter to illustrate the methodology.

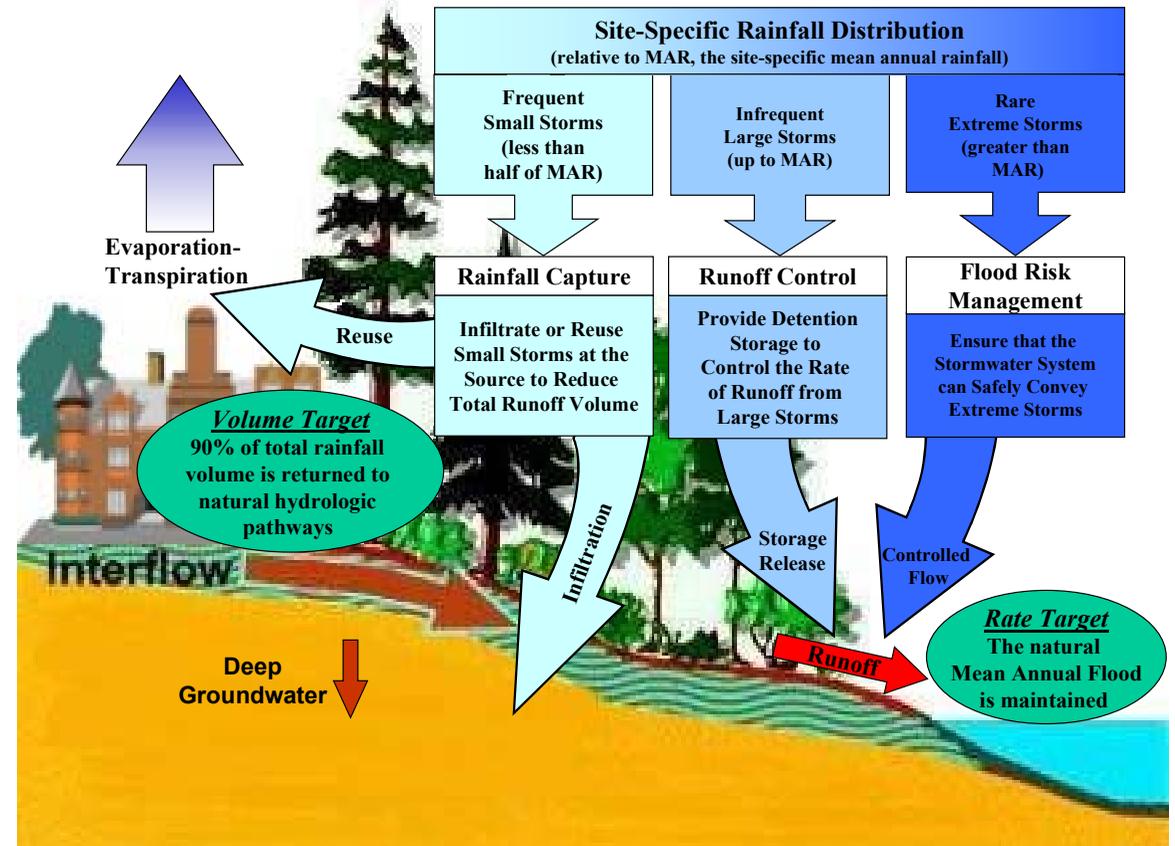
### 6.3 Moving from Science to Site Design

As shown below, the biophysically-based target condition provides a basis for a comprehensive stormwater management strategy (see Figure 6-3). Performance targets and site design criteria are needed to translate this strategy into action at the site level.

**Biophysically-Based Target Condition**

The target condition is based on the characteristics of a healthy watershed, and incorporates targets for maintaining the natural Water Balance (restore 90% of rainfall volume to natural hydrologic pathways) and hydrology (maintain natural MAF). Other characteristics of a healthy watershed (e.g. water quality, baseflow, riparian integrity) may also help define a target condition.

Leads to:



**Science-Based Performance Targets and Site Design Criteria**

Translating the above strategy into an action plan requires performance targets and design criteria to guide stormwater management and development practices at the site level.

Performance targets and design criteria can be evaluated and optimized to reduce costs over time by monitoring the performance of demonstration projects.

Implementing this strategy requires:

**Science Based Strategy for Managing the Complete Spectrum of Rainfall Events**

Stormwater impacts occur when land use change alters the water balance, thus increasing the volume and rate of surface runoff from *every rainfall event*. In order to maintain or move towards the target condition, the complete spectrum of rainfall events must be managed in a manner that approximates a naturally vegetated watershed.

Figure 6-2

## The Need for Flexibility in Setting Performance Targets

Establishing performance targets provides a quantifiable way of measuring success in protecting or restoring a watershed, and for identifying what needs to be done to achieve a certain level of protection for a given watershed.

The runoff volume and rate targets presented in presented in Section 6.2 provide a reference point that is based on the Water Balance and hydrology of a healthy watershed. To determine whether these targets are realistic or achievable for a given watershed, an ISMP must answer the following questions:

- ❑ What is the existing level of annual runoff volume? What percentage of total annual rainfall volume does it represent? What is the existing Mean Annual Flood (MAF)?
- ❑ What are acceptable levels of runoff volume and rate in terms of flood risk and environmental risk? What are the consequences of increased or decreased flows related to land development? Are these consequences acceptable?
- ❑ What actions are needed to avoid flooding or environmental consequences?
- ❑ How can necessary actions be staged over time?
- ❑ Are the targets to maintain 10% runoff volume and maintain the natural MAF necessary or achievable over time? If not, what levels are?

Performance targets that are based on the characteristics of a healthy watershed, including targets for runoff volume, runoff rate, and any other indicators that may be used to define a target condition, should be used as a starting point. Performance targets should be customized for individual watersheds and catchments, based on what is effective and affordable in the context of watershed-specific conditions.

For example, the 10% runoff volume target may not be appropriate for a watershed with limited fisheries value. In this case it may be more appropriate to establish targets for reducing the volume and rate of runoff based on judgements regarding acceptable levels of flooding.

Continuous Water Balance modeling can be applied to determine what is effective and affordable. Further discussion of Water Balance modeling is found in Chapter 7.

## 6.4 Managing the Complete Rainfall Spectrum

A guiding principle of integrated stormwater management is to design for the complete spectrum of rainfall events (as shown in Figure 6-2). Designing for the complete spectrum of rainfall events provides the foundation for protecting both property and stream health.

### Understanding the Rainfall Spectrum

A key parameter for describing the rainfall spectrum is the size of the Mean Annual Rainfall (MAR), the rainfall event that occurs once per year, on average. The distribution of rainfall events relative to the MAR is fairly constant throughout British Columbia.

The following rainfall tiers are the building blocks of an integrated strategy for managing the complete spectrum of rainfall events:

- ❑ **Tier A Events\*** – The small rainfall events that are less than half the size of a MAR. About 90% of all rainfall events are Tier A events.
- ❑ **Tier B Events\*** – The large rainfall events that are greater than half the size of a MAR, but smaller than a MAR. About 10% of all rainfall events are Tier B events.
- ❑ **Tier C Events\*** – The extreme rainfall events exceeding a MAR. An extreme event may or may not occur in any given year.

\* For the purpose of setting performance targets, a rainfall event is defined as total daily rainfall (i.e. mm of rainfall accumulated over 24 hours). This assumption results in conservative site design criteria, which can be optimized over time through continuous simulation modeling, and by monitoring the performance of demonstration projects (as discussed in Section 6.5).

These three rainfall tiers correspond to three components of an integrated strategy for managing the complete spectrum of rainfall events (see Figure 6-2); rainfall capture (source control), runoff control (detention), and flood risk management (contain and convey). These three components are discussed further in this section.

### The Importance of Rainfall Tiers

Defining tiers is the key to the rainfall analysis. It enables a systematic approach to data processing and identification of rainfall patterns, distributions and frequencies. Establishing the MAR as a reference point provides a convenient way to divide the rainfall database into three groupings.

Table 6-1 below shows how the rainfall tiers vary across the regions of BC where the most development is occurring. In the Georgia Basin the MAR ranges from about 40 mm on the East Coast of Vancouver Island, to about 60 mm in the Fraser Valley (also representative of much of the Lower Mainland), to about 80 mm on the North Shore of Vancouver. For the Okanagan Region, the MAR is closer to 20 mm.

**Table 6-1 – Rainfall Spectrum for Various Locations in BC**

Location	Tier A Events (less than 50% of MAR)	Tier B Events (between 50% of MAR and MAR)	Tier C Events (Greater than MAR)
<b>Vancouver (North Shore)</b>	< 40 mm	40 to 80 mm	> 80 mm
<b>Chilliwack</b>	< 30 mm	30 to 60 mm	> 60 mm
<b>Nanaimo</b>	< 20 mm	20 to 40 mm	> 40 mm
<b>Kelowna</b>	< 10 mm	10 to 20 mm	> 20 mm

\* approximate values based on statistical analyses using of 30+ years of rainfall data

One of these examples (Chilliwack) is used throughout this chapter to illustrate how to:

- ❑ use rainfall data to define MAR and the rainfall tiers
- ❑ apply the rainfall tiers to establish performance targets and site design guidelines

### Managing Rainfall Volume at the Source

Tier A events make up the bulk of total annual rainfall events and rainfall volume (see Figures 6-3 and 6-4). Capturing these small events at the source is the key to reducing runoff volume and managing the Water Balance (i.e. rainfall capture).

Figures 6-3 and 6-4 illustrate both coastal and interior conditions. Regardless of location, the majority of rainfall events are small (less than 50% of MAR). This is a key observation with respect to the feasibility of approximating the natural Water Balance through infiltration and and/or rainfall re-use.

### Consistency with Current Stormwater Practice

Referencing the rainfall tiers to the Mean Annual Rainfall (MAR) provides consistency with criteria that became accepted practice in the 1990s.

In British Columbia, the *Land Development Guidelines for the Protection of Aquatic Habitat* (1992) focus on managing runoff from storms with a 2-year return period, which is approximately equal to the MAR.

Also, 50% of the MAR corresponds to what is called a ‘6-month storm’ in Washington State. The concept of the ‘6-month storm’ was introduced in Washington to provide context for managing the six to ten runoff events per year that have the most potential to cause watercourse erosion (i.e. Tier B events). At the time, this approach represented a major departure from traditional drainage practice.

Prior to the late 1990s, the focus of drainage planning was on the extreme events that rarely occurred (Tier C events).

The tiered approach marks a further shift in drainage practice, from managing 25% of the rainfall volume (Tier B and C) to managing 100% of the rainfall (i.e. the complete spectrum).

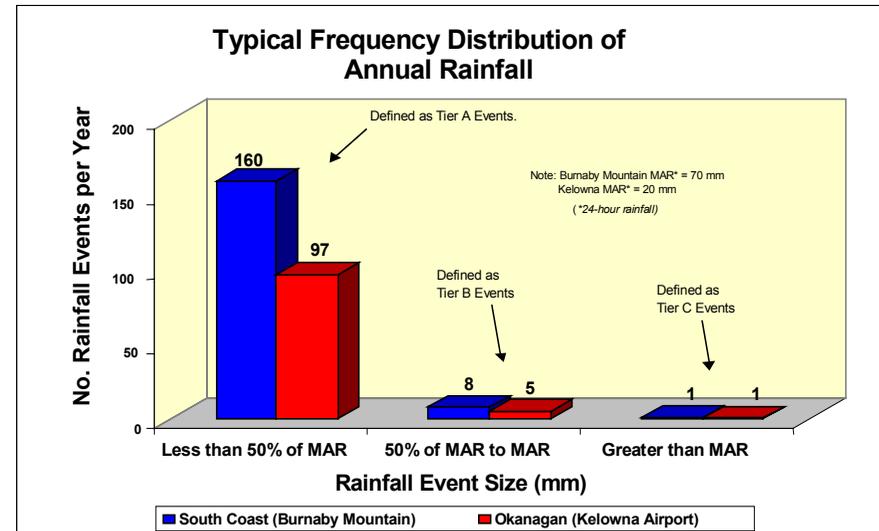


Figure 6-3

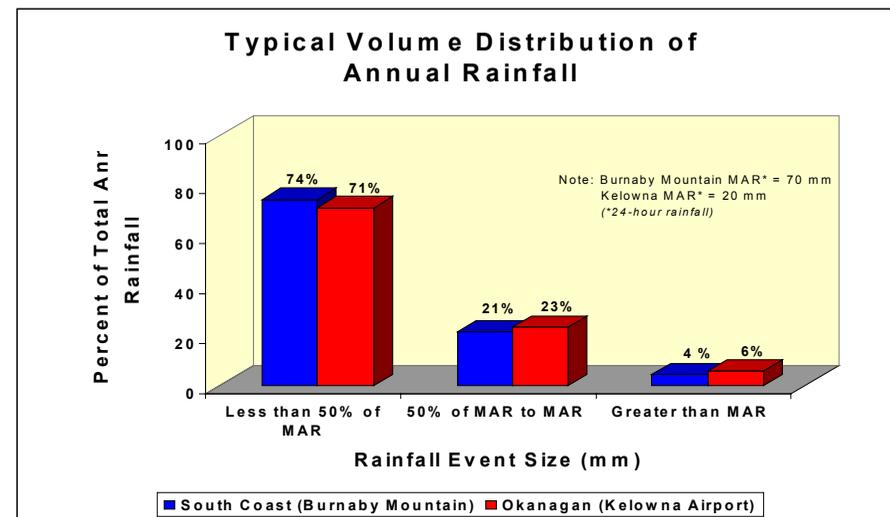


Figure 6-4

## Components of an Integrated Strategy for Managing the Complete Spectrum of Rainfall

Each of the three rainfall tiers corresponds to a component of an integrated strategy:

### 1. *Rainfall Capture (Source Control) to Manage the Small Tier A Rainfall Events*

The key to runoff volume reduction and water quality improvement is capturing the small storm runoff (Tier A rainfall events) from rooftops and paved surfaces. This captured rainfall should be infiltrated, evapotranspired, and/or re-used at the source. Rainfall capture can be provided at the source with:

- **On-lot stormwater source control facilities** to capture runoff from rooftops, driveways, parking and other impervious areas for infiltration, evapo-transpiration and/or reuse.
- **On-street source control facilities** to capture and infiltrate runoff from paved roadways. These facilities must also be designed to convey extreme storms, similar to conventional storm sewers.

Chapter 7 describes specific source control options available for development parcels and roads, including specific examples.

### 2. *Runoff Control (Detention) to Manage the Large Tier B Rainfall Events*

The runoff resulting from the large Tier B events causes the most significant peak flows in downstream watercourses. Therefore, the key to runoff rate control is storing the runoff from impervious surfaces resulting from the large Tier B rainfall events and releasing it at a controlled rate. This controlled release will eliminate the ‘spikes’ that characterize the rapid response of runoff from impervious surfaces. Storage capacity for large Tier B storms can be provided:

- By increasing the storage capacity of on-parcel and on-street source control facilities (above the capacity required to achieve rainfall capture targets).
- In community detention facilities that serve sub-catchments of a watershed (can provide runoff control but not rainfall capture).

### 3. *Flood Risk Management (Contain and Convey) for the Extreme Tier C Rainfall Events*

Development sites must have adequate escape routes for runoff from extreme storms (combination of overland flow and flow collection and conveyance systems). Stream channels and stream crossing (e.g. culverts and bridges) must have sufficient capacity to contain and convey flood flows resulting from very large storms (e.g. the 100-year storm), without resulting in threats to public safety or property damage. A framework for flood risk management is presented in Section 6.5.

## The Role of Continuous Simulation Modeling

Performance targets (i.e. a starting point) can be established based on simple rainfall analysis (see Section 6.5). The level of effort required to apply continuous simulation modeling is not appropriate for setting performance targets, but is appropriate for optimizing design solutions to achieve the performance targets.

As explained in Chapter 7, continuous simulation modeling is also appropriate for evaluating stormwater source control options and optimizing the design of stormwater system components.

## Understanding Why Rainfall Capture is the Key

Runoff control without rainfall capture is the conventional detention-based approach to stormwater management. It is only a partial solution. It is now recognized that this approach does not protect downstream fish habitat because it does not maintain natural levels of erosion or support baseflows in watercourses.

The water released from conventional detention storage typically goes directly to downstream watercourses. This slows down the water and reduces peak runoff rates, but does not reduce the total runoff volume. Therefore, the total runoff volume is spread out over a longer period of time, which can result in erosive streamflows for longer periods of time.

Rainfall capture requires storage at the source, where runoff from impervious surfaces can be infiltrated into the ground, evapotranspired, or re-used rather than released directly to surface drainage systems. Infiltration not only reduces runoff volume, but also supports stream baseflow by partially restoring the natural Water Balance.

Detention facilities that serve sub-catchments of a watershed do not provide the opportunity for infiltration, evapotranspiration or re-use at the source. However, there may be opportunities to implement community source control facilities through neighbourhood planning (e.g. infiltration facilities that serve multiple dwelling units).

The objective of emphasizing rainfall capture is to place the stormwater management focus clearly on volume. Traditional drainage practice concentrated on peak flow rates and overlooked the importance of volume management.

## The Importance of Rainfall Capture for Water Quality

Rainfall capture is important for improving water quality as well as for reducing runoff volume. The objective of rainfall capture is to infiltrate small storms and the first portion of large storms at the source. This means that the ‘first flush’ of pollutants that get washed off impervious surfaces at the beginning of rainfall events will be filtered and receive some treatment as they infiltrate into the ground.

Rainfall that is captured at the source for re-use may require a certain amount of treatment, depending on its intended use. Indoor uses, such as toilet flush water, would likely require some form of treatment to satisfy regulatory requirements for public health protection.

## 6.5 Methodology for Setting Performance Targets and Site Design Guidelines

### Case Study Example: City of Chilliwack

The City of Chilliwack is used as a case study in this section to demonstrate how to set performance targets and translate these targets into site design criteria. Chilliwack has applied a 6-step process for setting performance targets and developing site design criteria (see Figure 6-5). These steps are described in this section.

Chapter 4 showed how Chilliwack has integrated performance targets with stormwater management policies. This is a first step towards integrating targets with the Official Community Plan.

Chapter 7 elaborates on how Chilliwack has translated performance targets into a series of *Design Guidelines for Stormwater Systems* that developers can apply at the site level.

Chilliwack started applying the Guidebook methodology in the spring of 2001. Over the year that followed, the Chilliwack case study provided an opportunity to test, validate and refine the Guidebook methodology. This process was undertaken in an inter-departmental and inter-agency environment, and used actual land development projects in the City to apply the methodology. The interaction with the development community was essential to making the methodology practical.

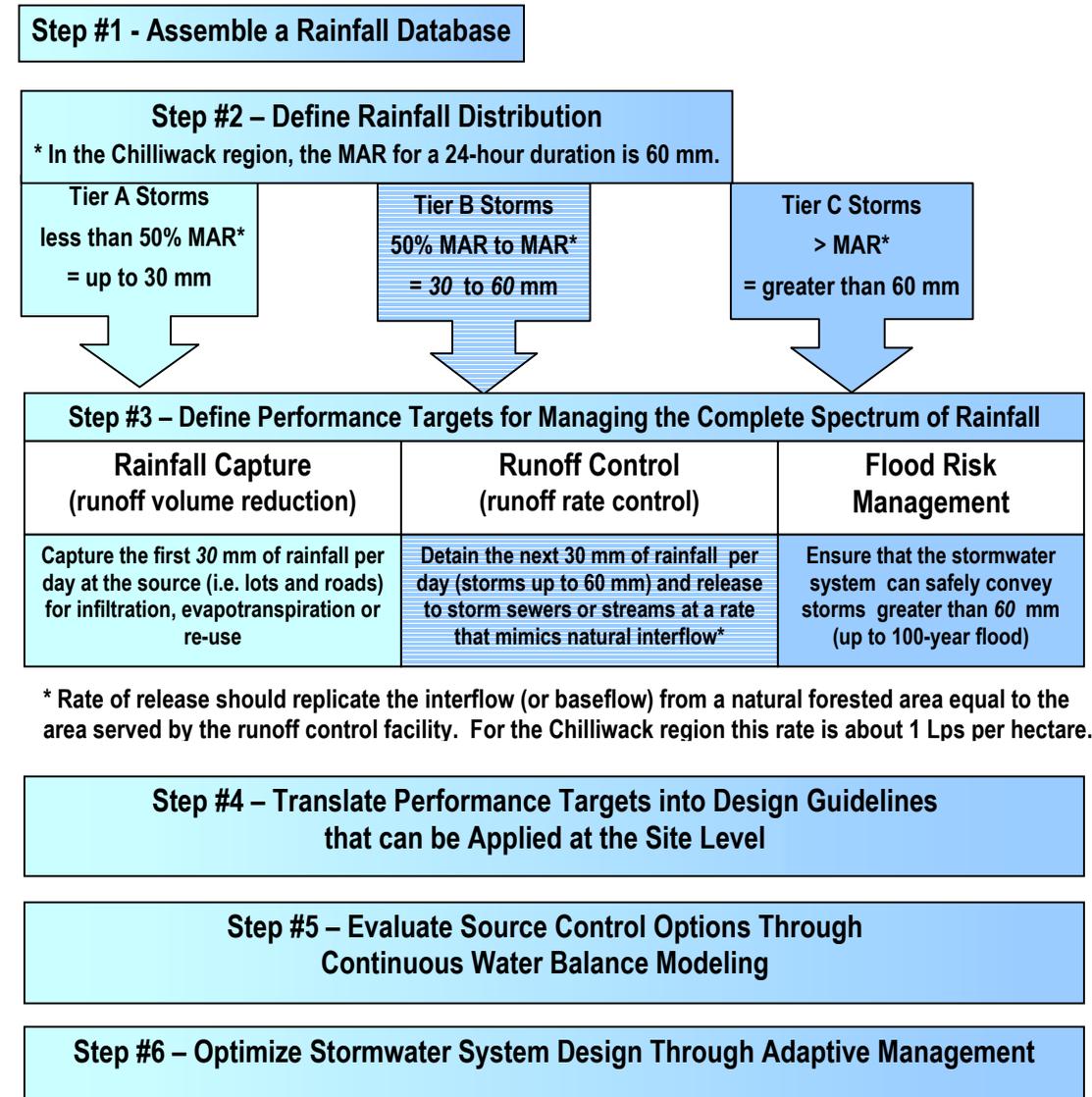


Figure 6-5

## Step #1 - Assemble a Rainfall Database

Rainfall data is readily available in most jurisdictions. Environment Canada operates an extensive network of rainfall gauging stations across the province. Many regional districts and municipalities are beginning to operate their own stations, and in some cases local government-operated networks are in place.

Rainfall data should be obtained from a gauging stations as close as possible to the watershed where performance targets are being set.

Obtaining rainfall data from several stations in a region can provide a good idea of rainfall variability and enable the establishment of regional performance targets (as shown in the Chilliwack example).

For establishing performance targets, a rainfall data set should have a period of record that is long enough to enable statistical analysis (longer is better). The rainfall data must be put into a spreadsheet format to enable the necessary analysis (described on the following page).

A key principle is to assemble the best rainfall data available (i.e. longest period of record, closest to watersheds of interest) and to use this data to establish performance targets.

Even in the absence of rainfall data, the example rainfall tiers shown in Table 6-1 (from the relevant region) can be used to develop performance targets that provide a reasonable starting point for action. The values in Table 6-1 can also provide a check on analyses performed using data from rain gauges with short periods of record.

### Daily versus Hourly Rainfall Data

Daily rainfall data is adequate for the basic analysis needed to set preliminary performance targets and site design criteria. However, hourly rainfall data provides a better description of local rainfall characteristics. Certain rainfall characteristics, such as rainfall intensity, can not be established based on daily data. Hourly data also enables more detailed monitoring and modeling (see Step #5 and #6).

### Climate Change Concerns

Climate change projections show that total winter rainfall is likely to increase over time (thus increasing total runoff volume), and that the frequency of short intense storms, or cloudbursts, is also likely to increase. Chapter 7 shows how the implementation of stormwater source control strategies can mitigate the impacts of climate change.

Performance targets provide a starting point for evaluating source control options. It does not matter that these targets are based on historic rainfall data.

### Case Study Example: Assembling Rainfall Data

Long-term rainfall data is available from three Environment Canada rainfall gauging stations in the greater Chilliwack area:

- ❑ **Agassiz** (on the north side of the Fraser River) – 109 years of record
- ❑ **Sardis** (near Vedder crossing) – 46 years of record
- ❑ **Chilliwack** (between Chilliwack City Center and Highway 1) – 90 years of record

Rainfall data from these three stations were used to establish general performance targets for the Chilliwack region. These targets can be customized for individual sub-catchments within the region by monitoring the performance of demonstration projects (see Step #6).

Since April 1999, the City has been operating two continuous rain gauges on a hillside area above the agricultural lowlands that is designated for future land development. These gauges are important for monitoring the change in rainfall-runoff response as land development progresses on the hillsides, and thus evaluating how well particular site design practices are mitigating the impacts of land development.

## Step #2 – Define Rainfall Distribution

The rainfall event categories (Tier A, Tier B, and Tier C) form the basis for setting performance targets and developing site design criteria to manage the complete spectrum of rainfall events. In order to define the thresholds for these categories, the Mean Annual Rainfall (MAR) must be determined.

### Methodology for Defining Mean Annual Rainfall (MAR)

The MAR for any watershed can be defined through the following process:

1. Calculate the peak daily rainfall (24-hr rainfall depth) for each year of record from the rainfall gauge. This can be done with a simple spreadsheet function.
2. Rank the rainfall maxima from highest to lowest and calculate a return period (T) for each using a standard plotting position formula (e.g. Weibull formula,  $T = [\text{total \# of rainfall maxima} + 1]/\text{rank}$ ).
3. Create a logarithmic plot of rainfall maxima vs. return period.
4. From this plot determine the rainfall maxima with a 2-year return period ( $R_2$ ). This is approximately equal to the MAR (the statistical definition of MAR is the rainfall with a 2.33 year return period).

Since the preceding methodology is a statistical analysis, a long period of record (30 years or more) will ensure confidence in the results.

### Defining Rainfall Tiers

Once the site-specific MAR is determined, rainfall event categories can be defined:

- ❑ Tier A = less than 50% of MAR
- ❑ Tier B = 50% MAR to MAR
- ❑ Tier C = greater than MAR

### Illustrating the Rainfall Distribution

The site-specific rainfall frequency distribution (see Figure 6-3) can be determined by applying a spreadsheet query to the rainfall database (count the total # of Tier A, Tier B, and Tier C events). This will validate that the majority of rainfall events are small.

The site-specific rainfall volume distribution (see Figure 6-4) can also be determined using spreadsheet functions (add up the total depth of Tier A, Tier B, and Tier C events). This will validate that the small Tier A events account for the majority of total annual rainfall volume.

### Case Study Example: Defining Rainfall Distribution

The MAR (24-hour duration) for Chilliwack was determined using data from the three long-term rainfall gauging stations. The points plotted on Figure 6-6 represent the peak annual rainfall event (24-hr rainfall depth) for each of the 90 years of record from the Chilliwack rainfall gauge. The same analysis was performed using the Sardis rainfall gauge and the Agassiz rainfall gauge.

Based on this analysis, the MAR at each of the three stations was determined to be:

- Chilliwack = 63 mm
- Agassiz = 60 mm
- Sardis = 55 mm

Therefore, the regional MAR for the Chilliwack area can be defined as 60 mm (over 24 hrs). This regional approximation provides the basis for specifying the following rainfall tiers:

- **Tier A** = less than 50% of MAR = less than 30 mm
- **Tier B** = 50% MAR to MAR = 30 mm to 60 mm
- **Tier C** = greater than MAR = greater than 60 mm

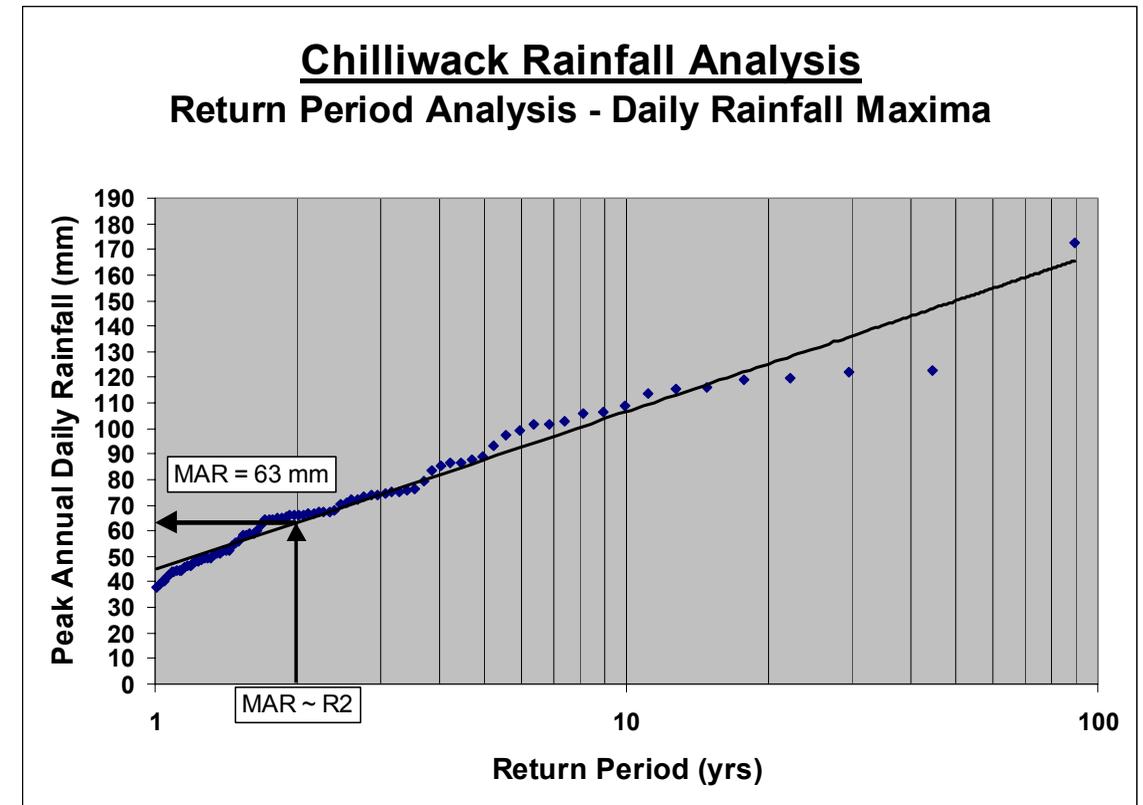


Figure 6-6

## Step #3 – Define Performance Targets for Managing the Complete Spectrum of Rainfall Events

The rainfall tiers, established in Step #2, must be translated into performance targets for rainfall capture, runoff control and flood risk management.

### Case Study Example: Translating Tiers into Targets

The City of Chilliwack’s performance targets are presented below to illustrate how rainfall tiers translate into performance targets.

#### Rainfall Capture Performance Targets (for Tier A Events)

***Capture the first 30 mm of rainfall per day (24 h) at the source (i.e. lots and roads) and restore to natural hydrologic pathways (infiltration and evapotranspiration) and/or re-use.***

This relates to the following specific rainfall capture targets:

- ❑ **For impervious areas** – Provide stormwater source control facilities\* on development lots, roads or neighbourhood sites that are designed to capture 30 mm of rainfall per day, and either infiltrate, evapotranspire, or re-use the captured rainfall.
- ❑ **For pervious areas** – Preserve as much undisturbed natural area as possible. For landscaped areas, provide an absorbent surface soil layer that has the capacity to store at least 60 mm of rainfall and infiltrate at the natural rate of local soils. This will ensure that pervious areas produce virtually no surface runoff (much like a naturally vegetated watershed).

\* the selection and design of source controls must be based on site-specific conditions (see Steps #4 and #5)

#### Runoff Control Performance Targets (for Tier B Events)

***Detain the next 30 mm per day (all rainfall events up to 60 mm over 24 h) and release to storm sewers or stream channels at a rate that approximates a natural forested watershed.***

This relates to the following specific runoff control target:

- ❑ **For impervious areas** – Provide enough storage volume to detain the runoff resulting from rainfall events up to 60 mm per day, either in rainfall capture facilities and/or community detention facilities. Release the stored rainfall at a rate that replicates the interflow from a natural forested area\* (equivalent to the area served by the runoff control facility).
- ❑ **For pervious areas** – Meeting the rainfall capture target also provides adequate runoff control (i.e. enough storage for 60 mm of rainfall).

\* natural interflow can be defined based on streamflow monitoring in undeveloped catchments (see Step #4)

#### Flood Risk Management Performance Target (for Tier C Events)

***Ensure the stormwater system is capable of safely conveying an extreme flood event that results from rainfall events greater than 60 mm (e.g. the 100-Year Flood, Q<sub>100</sub>).***

The runoff from extreme storms must be conveyed, through a combination of overland flow paths and flow collection and conveyance systems, without causing property damage, posing a threat to public safety, or causing unacceptable levels of flooding in agricultural areas.

### Validating Performance Targets

As discussed in Section 6.2, achieving the biophysically-based target condition (a healthy watershed) means that 90% of total rainfall volume must be captured at the source to reduce total runoff volume to 10% or less of total rainfall volume.

Figure 6-7 relates the performance targets for rainfall capture, runoff control and flood risk management to rainfall volume distribution (at the Sardis gauge).

The same analysis was performed using data from the other two long-term rainfall stations (Chilliwack and Agassiz). The volume distribution for all three stations is summarized below.

Rainfall Station	Rainfall Capture Volume	Runoff Control Volume	Flood Control Volume
<b>Chilliwack</b>	89%	7%	4%
<b>Agassiz</b>	91%	6%	3%
<b>Sardis</b>	93%	5%	2%

Capturing the first 30 mm of rainfall per day (i.e. meeting Chilliwack’s rainfall capture target) would result in capture of about 90% of the total volume of runoff from impervious areas. Also, implementing absorbent landscaping practices can virtually eliminate runoff from pervious areas (i.e. achieve close to 100% capture), as discussed in Chapter 7.

The key point is that meeting rainfall capture targets should achieve the biophysically-based target condition.

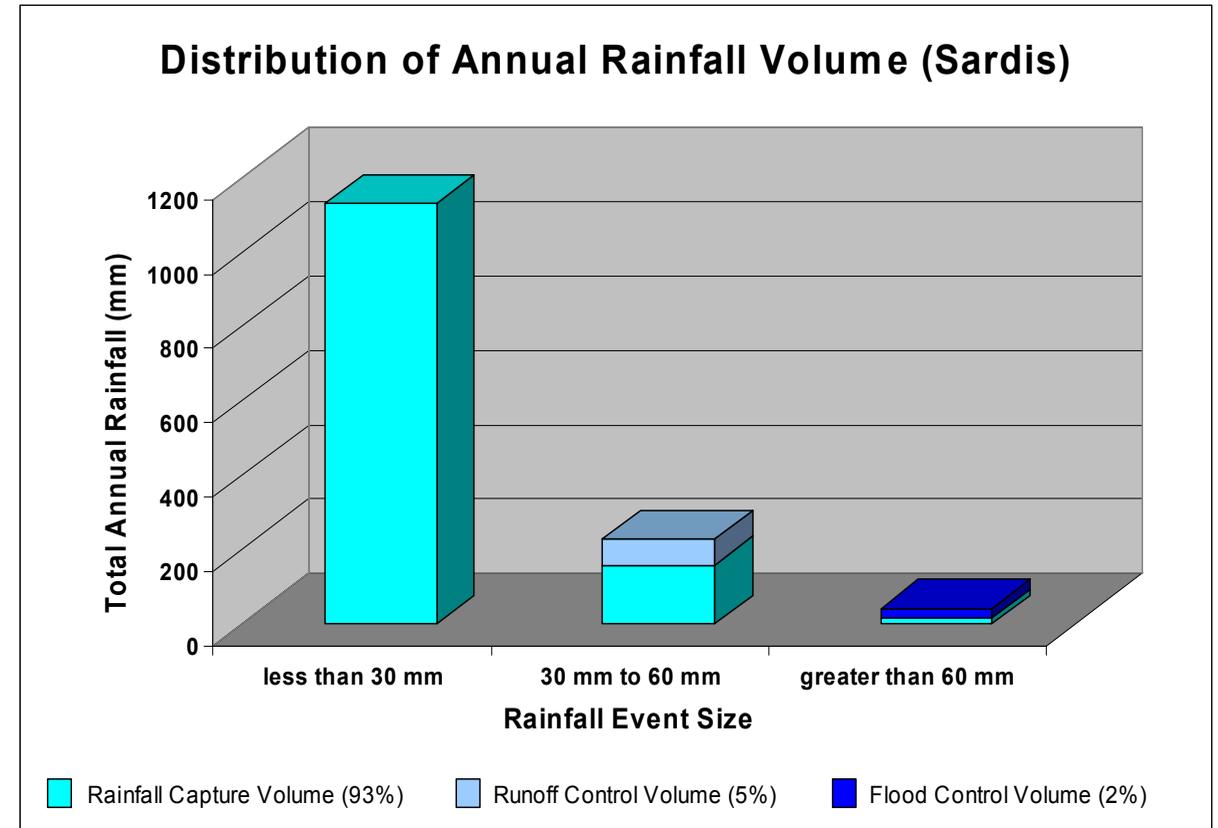


Figure 6-7

## Step #4 – Translate Performance Targets into Design Guidelines that can be Applied at the Site Level

In order to achieve performance targets for rainfall capture, runoff control and flood risk management, the targets must be translated into achievable design guidelines that developers and local government staff can understand and apply at the site level.

### Design Guidelines for Rainfall Capture (Managing Tier A Events)

Reducing runoff volume is the key to achieving performance targets for rainfall capture. The following volume reduction strategies should be applied:

- ❑ **Minimize the disturbance of natural soils and vegetation.** At the land use planning and site design levels, it is important to identify and preserve the natural areas that are most important to maintaining the natural Water Balance, such as wetlands, natural infiltration areas and riparian forests. Low impact site design practices that limit the creation of impervious area, the compaction of natural soils and the clearing of natural vegetation should also be applied.
- ❑ **Apply absorbent landscaping.** For landscaped areas, an absorbent surface soil layer should be provided. This absorbent soil layer should:
  - be deep enough to store the mean annual rainfall (24-h duration). Since most absorbent soils store about 20% of their volume in soil water, five times the MAR is an appropriate soil depth (e.g. for Chilliwack this would be  $60 \text{ mm} \times 5 = 300 \text{ mm}$ ).
  - meet the BC Landscape Standard for medium or better landscape, which will ensure the type of hydrologic characteristics required for rainfall capture.
- ❑ **Implement stormwater source control practices to capture runoff from impervious surfaces.** Source control options include:
  - **Infiltration Facilities** – Infiltration is likely the only way achieve the target condition of restoring 90% of total rainfall volume to natural hydrologic pathways, and is the most appropriate source control for single family land uses, which is the dominant land use in most developed watersheds in the province.

The level of reduction in the volume and rate of runoff that is achievable using infiltration depends on soil conditions, and therefore, soils information is key to the planning and design of infiltration facilities.

- **Green Roofs** – The volume and rate of rooftop runoff can be reduced by installing absorbent landscaping on rooftops of buildings or parkades. Green roofs will store and evapotranspire rainfall from small events, and will slow the rate of release of medium-sized events. Green roofs are most effective for land uses with high levels of rooftop coverage, such as multiple family and commercial land uses (especially with underground or structured parkades).
- **Rainwater Re-use** – Capturing and re-using rooftop runoff for greywater uses (e.g. toilets, laundry) or for irrigation can reduce runoff volume. The opportunities for volume reduction through re-use are most significant for high density residential and commercial land uses with high water use.

Chapter 7 provides quantitative information on the effectiveness of these stormwater source control options under various conditions (e.g. rainfall, land use, soil type), and also provides further guidance on low impact site design practices and absorbent landscaping.

## Determining What is Achievable

Establishing a rainfall capture target, as shown in Step #3, provides a starting point that is based on the characteristics of a healthy watershed. The next step is to determine what is achievable and affordable based on assessments of constraints and opportunities in individual catchments.

Based on these assessments, catchment-specific performance targets and design guidelines for achieving these targets can be established. These catchment-specific targets and guidelines will then provide direction for all land development projects within each catchment.

The following information is key to assessing opportunities and constraints in any given catchment:

- **Soils Information** - Soil conditions govern the feasibility and affordability of using infiltration facilities to meet rainfall capture targets. At the watershed planning level, coarse level soils mapping can provide local government staff with the information needed to determine where infiltration makes sense, and to evaluate the level of runoff volume reduction that could be achieved through infiltration in various catchments. This will enable the establishment of catchment-specific performance targets.

It is also important to evaluate soil conditions at the site level, in order to determine how much infiltration area is required to meet catchment-specific targets, and to identify the most suitable infiltration areas within a development site (see the case study example on the following page).

- **Land Use Information** – Land use information will provide local government staff with guidance regarding where source control options other than infiltration should be considered. In multiple family and commercial land uses, or where opportunities for infiltration are limited, there may be opportunities to achieve significant levels of runoff volume reduction by implementing green roofs or rainwater re-use.

### Case Study Example: Design Guidelines for Infiltration Facilities

Since the majority of new development in the City of Chilliwack are likely to be single family residential, the City’s guidelines for rainfall capture focus on infiltration.

The key design parameter for infiltration facilities is footprint area. Increasing the area of infiltration facilities improves their effectiveness at reducing runoff volume, but also increases their cost.

#### Determining What is Achievable Through Infiltration

Soil conditions govern the feasibility and affordability of using infiltration facilities to meet rainfall capture targets. Figure 6-8 shows that the amount of infiltration area required to meet Chilliwack’s rainfall capture target becomes very large where the hydraulic conductivity of soils is low.

The City’s rainfall capture target is not likely achievable through infiltration in areas where the hydraulic conductivity of local soils is less than about 5 mm/hr (typical of soils with high clay content). Also, infiltration is not likely feasible in areas where the regional water table is at or very near the ground surface. Where appropriate, alternative source control strategies (green roofs or rainwater re-use) should be considered in areas where the opportunities for infiltration are limited.

Chilliwack’s approach allows for flexibility in setting catchment-specific performance targets that reflect what is achievable and affordable.

#### Catchment-Specific Performance Targets

Chilliwack has adopted three levels of stormwater planning: watershed, sub-watershed and catchment. Catchment-specific performance targets will be established through the master planning process (at the sub-watershed level) based on a planning-level assessment of soil and groundwater conditions in individual catchments. Having catchment-specific targets will then provide direction for all land development projects within that catchment.

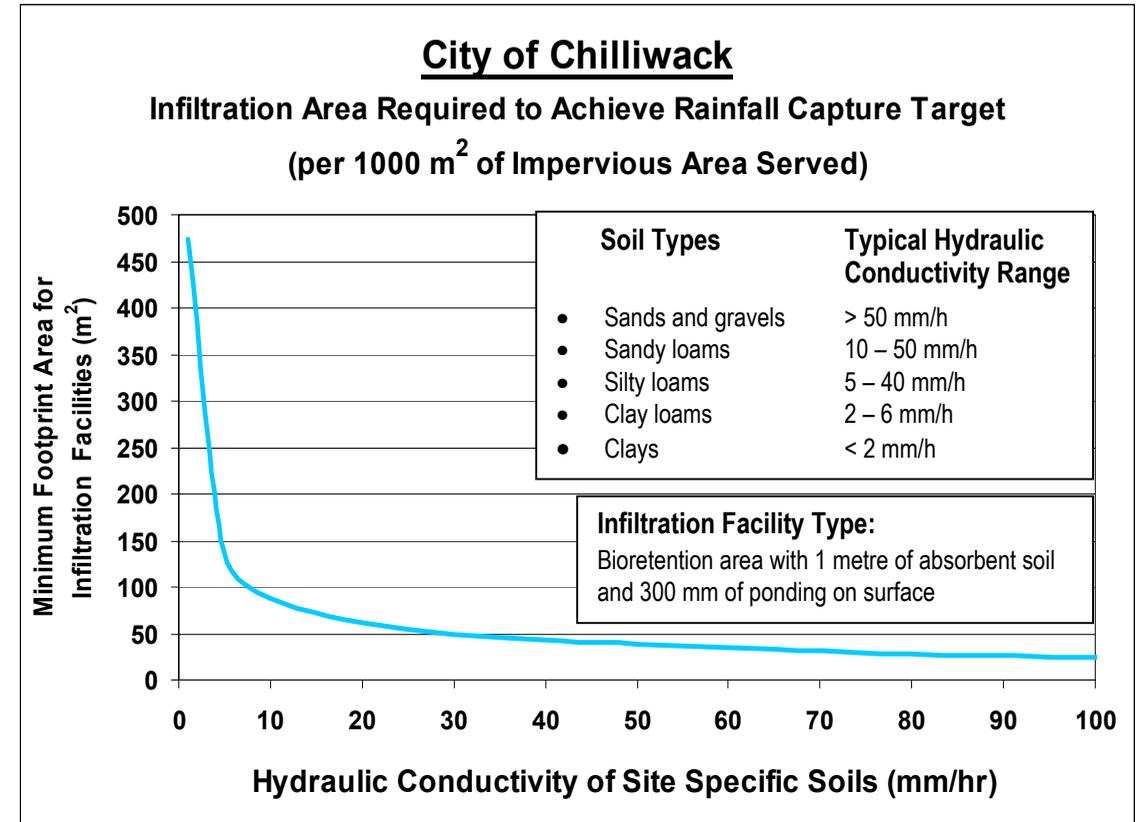


Figure 6-8

## Communicating Performance Targets to Developers

Chilliwack's *Design Guidelines for Stormwater Systems* (see Chapter 7) include a step-by-step procedure for land developers to follow in order to design infiltration facilities that meet the City's rainfall capture performance targets. These Guidelines apply to all land development projects in catchments where the rainfall capture target is considered achievable.

Figure 6-8 shows an example design curve for sizing a particular type of facility based on the hydraulic conductivity of site specific soils.

## Soils Information

Chilliwack has been building a database of the soils data submitted with development applications throughout the City. Using this information, coarse level soils mapping has been prepared to provide City staff and developers with guidance regarding where infiltration makes sense. This soils information will be used to develop catchment-specific performance targets.

At the site level, developers are required to perform soil investigations and percolation testing to identify the best infiltration areas and to design infiltration facilities.

Infiltration facilities should be sized based on site-specific estimates of saturated hydraulic conductivity. To obtain these estimates, on-site specific percolation tests should be performed at the location and depth of proposed infiltration facilities, and carried out under saturated soil conditions.

Developers may consider using areas with the best soil conditions to locate neighbourhood infiltration facilities serving multiple dwelling units.

## Estimating Hydraulic Conductivity of Soils

The hydraulic conductivity of soils can initially be estimated through on-site percolation testing. These estimates can be improved over time by monitoring infiltration facility water levels and overflows (see Step #6).

It is also possible to estimate hydraulic conductivity based on soil texture and composition. A good reference is Washington State University's on-line *Soil Texture Triangle* (<http://www.bsyse.wsu.edu/saxton/soilwater/>), which estimates hydraulic conductivity based on approximate sand and clay content. The typical conductivity ranges shown on Figure 6-8 were obtained from this source.

## The Importance of Protecting Infiltration Areas

Where infiltration facilities are to be located, it is critical to maintain soils in their natural, undisturbed state and to prevent sedimentation during construction. This requires:

- ❑ **sediment and erosion control** during construction to prevent clogging of rainfall capture facilities and their underlying soils
- ❑ **management of construction sites** to prevent disturbance and compaction of infiltration areas; infiltration areas should be identified by fencing or other means

Failure to adequately protect infiltration areas during construction will likely result in failure to achieve rainfall capture targets.

## Design Guidelines for Runoff Control (Managing Tier B Events)

In order to meet runoff control targets, the combination of source control facilities and community detention facilities should have the capacity to detain the MAR. Increasing the level of runoff reduction achieved through source control (i.e. rainfall capture) decreases the storage volume needed in community detention facilities.

For detention facilities, the operational objective is to replicate the hydrograph of an undeveloped drainage catchment as closely as possible. Therefore, the rate of release from detention facilities should approximate the natural streamflow rates that results from Tier B rainfall events (i.e. the target events for runoff control). Ideally, this release rate should be estimated based on streamflow monitoring from undeveloped catchments, as shown in the following case study example.

### Case Study Example: Design Criteria for Runoff Control Facilities

Chilliwack has established preliminary detention storage and release criteria to achieve the City's runoff control target (i.e. detain rainfall events up to 60 mm per day and release at the natural interflow rate).

#### Storage Volumes

For development sites that achieve the City's rainfall capture target (i.e. capture the first 30 mm per day), an additional 300 m<sup>3</sup> of detention storage (i.e. 30 mm x 10 m<sup>3</sup> per mm) should be provided in community detention facilities.

Developers can reduce the size of detention facilities by increasing the size of infiltration facilities. The City's *Design Guidelines for Stormwater Systems* (see Chapter 7) provide a step-by-step procedure for designing integrated infiltration and detention systems and allow developers to make trade-offs between storage at the source and community storage.

Similarly, in catchments where the City's rainfall capture target cannot be achieved due to physical constraints (high water table, poor soils), more detention storage is required.

Release rate is not subtracted from storage volume criteria, which builds in a safety factor to account for back-to-back rainfall events. Performance monitoring may demonstrate that the safety factor is not needed in future development phases (see Step #6).

## Release Rates

In 1999, the City of Chilliwack was proactive in setting up a network of streamflow monitoring stations, including two in natural forested catchments. This has enabled the City to establish the following detention release rate that approximates the natural forested condition.

**Preliminary Release Rate for Detention Facilities in the City of Chilliwack  
= 1 L/s per hectare (total area tributary to the detention facility)**

Continued operation of the streamflow monitoring stations in the forested catchments (prior to development occurring in these catchments) will enable validation and refinement of this release rate. Post-development streamflow monitoring will enable the operation of detention facilities to be optimized (see Step #6).

## Design Guidelines for Flood Risk Management (Managing Tier C Events)

Conveyance of peak flows from extreme storms and minimizing flood risk was the focus of traditional drainage engineering. While the focus has shifted to managing the complete spectrum of rainfall events (i.e. incorporating rainfall capture and runoff control), the flood risk management function is still an essential component of the overall strategy.

### Providing Escape Routes for Extreme Storms

Flood risk management at the site level requires a common sense approach to site drainage. The objective is to ensure that the runoff from extreme rainfall events, such as a 100-year storm event, can escape to downstream watercourses without posing a threat to property or public safety. To achieve this objective, three design conditions must be addressed:

- ❑ All rainfall capture and runoff control facilities must include overflow escape routes to allow extreme storms to be routed to downstream watercourses, either as overland flow or via a storm drainage system (swales, ditches or pipes).
- ❑ Sites must be graded to ensure that any overland flow resulting from extreme storms is dispersed away from areas where flooding problems could otherwise result (e.g. residential properties in low-lying areas).
- ❑ The downstream storm drainage system must meet assessment criteria for both hydraulic and physical adequacy to handle the runoff from upstream development areas (refer to adjacent discussion).

Note that managing volume at the site through rainfall capture and runoff control will also reduce peak rates of stormwater runoff resulting from extreme storms.

### Ensuring that Drainage Installations in Watercourses are Adequately Designed

Drainage system requirements for adequate containment and conveyance of stormwater runoff via watercourses are highly site-specific. However, the risk and acceptability of any drainage facility should be assessed in the context of two basic criteria:

- ❑ **Hydraulic Adequacy** – A comparison of rated capacity versus design flow
- ❑ **Physical Adequacy** – A qualitative judgement regarding physical constraints (e.g. culvert blockage) that could adversely impact hydraulic adequacy

Based on long-term experience, the governing criterion is almost always physical adequacy, with hydraulic adequacy generally being a secondary concern. Assessment of physical adequacy is a key input for any flood risk analysis.

Drainage problems often occur in small tributaries where stream crossings, such as culvert installations, are vulnerable to blockage (i.e. physically inadequate). Flooding may be a common occurrence at tributary stream crossings even though conventional analysis indicates that the conveyance capacity (i.e. hydraulic adequacy) is adequate.

### Guiding Design Principle for Stream Crossings: Maintain Waterway Opening

A guiding principle for the design of stream crossings is to preserve or improve the cross-sectional area and gradient of the natural waterway. Clear span bridges are typically better than culverts.

A smooth flow condition should be maintained through culvert installations to minimize the degree of interference with creek processes. If this principle is followed, then the need for peak flow estimates to design culverts is diminished because it is of incidental interest. Physical acceptability governs.

### Physical Acceptability of Culvert Installations in Watercourses

The high-risk locations for stormwater system failure are most often at culvert installations that are vulnerable to blockage (often on the smaller watercourses). Assessment of physical adequacy for culvert installations involves a 3-step process:

- **Conformance with Design Guidelines (Step #1):** Assess the overall conformance with the nine guidelines for effective culvert design presented below.

#### Nine Guidelines for Effective Culvert Design

1	Maintain line and grade of creek channel
2	Maintain the waterway opening by 'bridging' the creek channel
3	Construct inlet structure to provide direct entry and accelerated velocity
4	Ensure that culvert can pass trash, small debris and bedload material
5	Install debris interceptor upstream to provide protection from large debris
6	Provide scour protection to prevent undermining of the outlet structure
7	Incorporate provision for an overflow route in the event of a worst-case scenario
8	Provide equipment access for ease of maintenance (debris removal)
9	Consider environmental issues, such as fish passage

- **Vulnerability to Blockage (Step #2):** Assess culvert vulnerability and probability of culvert failure due to blockage. The potential for blockage reflects the bedload and debris characteristics of a creek.
- **Consequences of Failure (Step #3):** Assess the consequences of culvert failure due to blockage (e.g. road failure, damage to downstream properties)

The nine guidelines can be used to qualitatively assess the adequacy of existing facilities as either poor, fair, good or excellent. The outcome of Step #1 is an overall rating.

The results of Step #2 and Step #3 then determine the acceptability of the overall rating and whether or not to replace an existing facility.

The level of risk associated with the status quo then determines the need for and timing of replacement.

### The Importance of Erosion Control for Flood Management

The culvert blockages that are often the cause of flooding problems on tributary streams can usually be traced back to two sources:

- erosion and deposition of bedload material
- transport of floatable debris such as branches and brush

Deposition of bedload material also results in the progressive reduction of drainage channel capacity, which increases flooding risk and can create an ongoing channel maintenance problem.

As discussed in Chapter 2, these physical processes are the result of increases in volume and rate of surface runoff. Therefore, providing rainfall capture and runoff control to reduce the volume and rate of runoff is an important part of flood risk management.

## Flood Management Guidelines for Agricultural Areas

A primary flood management objective for agricultural areas is to provide adequate drainage to ensure that the frequency and duration of flooding in agricultural areas does not inhibit productivity. Meeting the following drainage criteria from the *Agri-Food Regional Development Subsidiary Agreement* (ARDSA) will ensure that flood management is adequate for agriculture:

- ❑ Flooding should be limited to a maximum of five days for the 10-year, 5-day winter storm (November to February).
- ❑ Flooding should be limited to a maximum of two days for the 10-year, 2-day growing season storm (March to October).
- ❑ Between storm events, the baseflow in ditches should be maintained at 1.2 m below the average ground level to provide free outlet for drains.

Note that these criteria are based on winter storms with a 10-year return period, which are significantly larger than a MAR (corresponds roughly to a 2-year return period).

The stormwater management practices required to achieve flood management criteria for agricultural areas will be highly watershed-specific, and should be evaluated as part of Integrated Stormwater Management Plans (ISMPs).

It is important to consider agricultural drainage objectives in the context of other objectives. For example, there may be a need to achieve a balance between the third ARDSA criterion defined above, and a fisheries objective of maintaining adequate low flows in channels to allow for fish passage, since agricultural drainage channels are often used as fish migration corridors.

## Impacts from Upstream Areas

A key stormwater planning consideration is the potential impact that development could have on downstream agricultural areas (and vice versa). A common stormwater-related problem is the increase in frequency of flooding of agricultural areas as a result of increased runoff from upstream development areas. Implementing site design practices that meet rainfall capture and runoff control targets will mitigate this problem to a large extent.

## Impacts on Downstream Areas

Agricultural areas can also have an impact on downstream urban and suburban land uses. This is often related to water quality impacts associated with agricultural land uses. Specific practices for managing water quality in agricultural areas (e.g. proper storage of manure) are beyond the scope of this Guidebook.

## Step #5 – Evaluate Source Control Options Through Continuous Simulation Water Balance Modeling

### The Importance of Continuous Simulation for Site Design

The most appropriate site design solutions for achieving rainfall capture targets on any given development site will depend on site-specific conditions such as soil type, land use type, rainfall and groundwater characteristics.

Continuous simulation modeling provides a tool to evaluate site design options under a full range of operating conditions (i.e. the complete rainfall spectrum).

While single event modeling provides an expedient way of establishing capacities and sizes for the design of conveyance facilities, it does not account for seasonal variation in hydrologic parameters such as antecedent soil moisture and evapotranspiration capacity. Nor does it account for the frequently occurring small rainfall events (the focus of rainfall capture). Chapter 7 provides a more detailed discussion on continuous simulation modeling for stormwater source controls.

Chapter 10 provides a more detailed discussion on the applications of single event and continuous simulation modeling in the context of integrated stormwater management plans (ISMPs).

### Water Balance Modeling

Water Balance modeling using spreadsheets is a cost-effective method to ensure that the design of rainfall capture and runoff control facilities:

- meets performance targets for reducing runoff volume and rate
- is practical and achievable in the context of local conditions

Water Balance modeling for rainfall capture and runoff control facilities serves several purposes:

- **Validates preliminary design criteria** – Model outputs will provide confidence that preliminary design criteria meet (or exceed) performance targets for rainfall capture and runoff control.
- **Provides a benchmark for future evaluation** – Model outputs will guide the periodic evaluation of stormwater system performance and facilitate the process of optimizing design criteria (see Step #6).
- **Provides further design guidance for source control facilities** - The performance of source control options will depend on site-specific conditions such as soil conditions, land use and rainfall characteristics. Water Balance modeling helps with the selection of appropriate design options.

### Case Study Example: Applying Water Balance Modeling to Evaluate the Effectiveness of Stormwater Source Control Options

The Water Balance Model (WBM) is a continuous simulation model that has been developed to simulate the hydrologic performance of stormwater source control options (i.e. how well they reduce the volume and rate of runoff). This model has evolved through case study applications of the Water Balance design approach presented in this Guidebook, including:

- developing design criteria for infiltration facilities in the City of Chilliwack (discussed in Step #4)
- evaluating the potential effectiveness of a broader range of stormwater source control options in the Greater Vancouver Regional District (GVRD), including:
  - absorbent landscaping
  - infiltration facilities (on lots and along roads)
  - green roofs
  - rainwater re-use

Key findings from the GVRD source control evaluation are presented in Chapter 7.

## Step #6 - Optimize Stormwater System Design Through Adaptive Management

The performance targets and site design criteria presented in Steps #1 through #5 provide a starting point for the design of stormwater systems.

Stormwater system design criteria should be reviewed periodically (e.g. every 3 years), and optimized based on a detailed performance evaluation. The primary objective of this evaluation is to reduce stormwater-related costs while still achieving the defined goals and objectives for protecting downstream property, aquatic habitat and receiving water quality.

### Performance Evaluation at the Site Level

Monitoring and evaluating the performance of demonstration projects at the site level is the primary basis for optimizing the design of stormwater systems. Figure 6-9 shows the indicators that should be monitored to enable a thorough evaluation of stormwater system performance.

Monitoring water level and flow in rainfall capture and runoff control facilities provides the basis for performance evaluation. A continuous record of water level and flow in rainfall capture and runoff control facilities (including road drainage flows) over an extended time period, combined with continuous rainfall data over the same time period, provides an accurate picture of how water moves through a stormwater system.

This continuous record will provide answers to key questions related to stormwater system performance, such as those shown in the adjacent table.

### Framework for Performance Evaluation

For Rainfall Capture Facilities:	For Runoff Control Facilities:	For Road Infiltration/Drainage:
<ul style="list-style-type: none"> <li>▪ What is the frequency and volume of overflow?</li> <li>▪ Are targets for runoff volume reduction being achieved?</li> <li>▪ How often does water accumulate?</li> <li>▪ How fast does water level drop (i.e. infiltrate) under saturated soil conditions?</li> <li>▪ What would be the effect of increasing/ or decreasing infiltration area?</li> <li>▪ What would be the effect of decreasing storage volume?</li> </ul>	<ul style="list-style-type: none"> <li>▪ What is the frequency and volume of overflow?</li> <li>▪ Are targets for runoff rate control being achieved?</li> <li>▪ Do detention facilities empty prior to large rainfall events?</li> <li>▪ What would be the effect of decreasing storage volume?</li> <li>▪ Does the outflow hydrograph from detention facilities resemble the hydrographs observed at the streamflow monitoring stations in adjacent undeveloped catchments?</li> </ul>	<ul style="list-style-type: none"> <li>▪ Where does road runoff go?</li> <li>▪ How much runoff discharges to detention ponds? storm sewers? directly to watercourses?</li> <li>▪ How much infiltrates?</li> <li>▪ How fast does road runoff and overflow from rainfall capture facilities enter the road drainage system?</li> <li>▪ are the targets for runoff volume reduction and rate control being achieved?*</li> </ul>

\* These targets will depend on the road design objectives. Roads may be designed to provide rainfall capture or to be 'self-mitigating' (i.e. provide rainfall capture *and* runoff control).

### Case Study Example: Communicating Performance Monitoring Requirements to Developers

The City of Chilliwack's *Design Guidelines for Stormwater Systems* (refer to Chapter 7) include requirements for performance monitoring, which correspond to Figure 6-9.

## Performance Monitoring Requirements

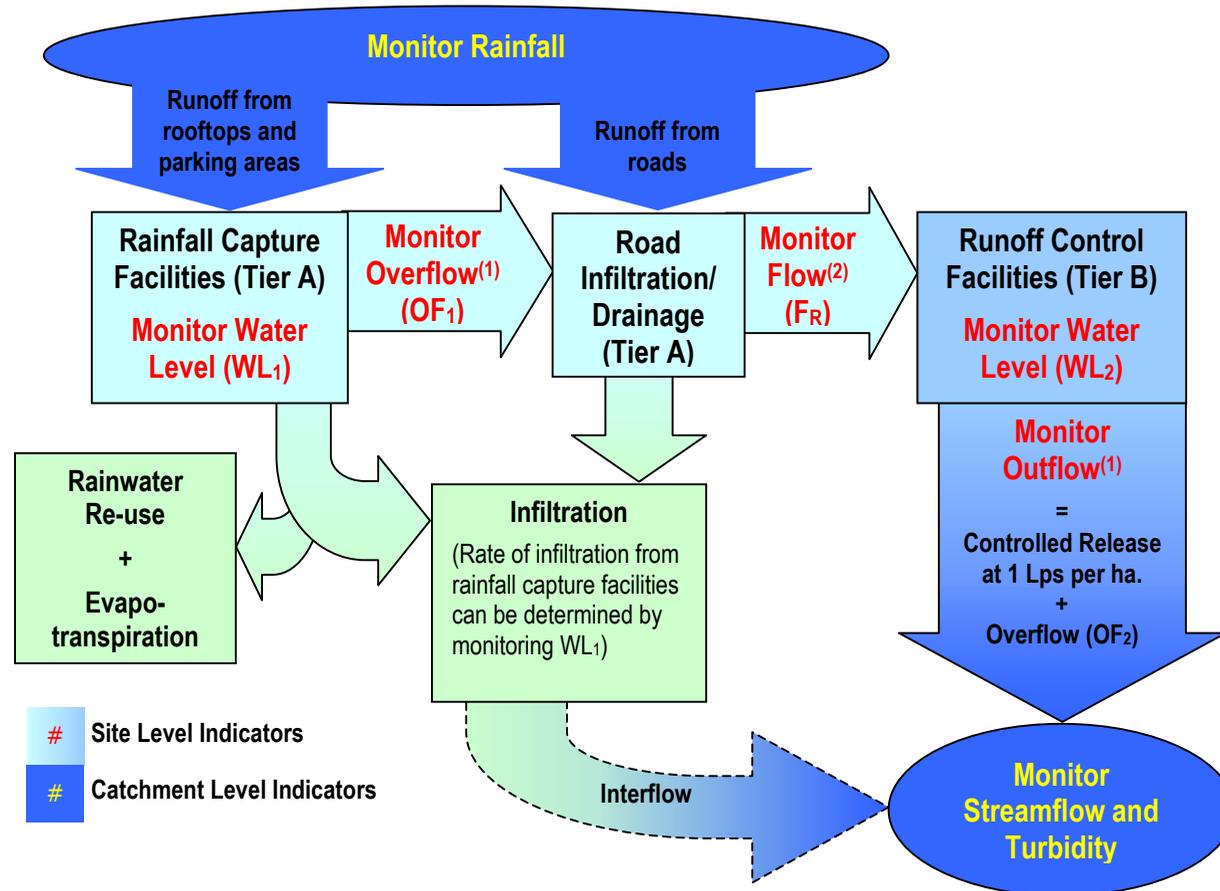


Figure 6-9

Indicator	OF <sub>1</sub>	OF <sub>2</sub>	Road Drainage	Streamflow
Performance Targets	<ul style="list-style-type: none"> <li>➤ Total overflow volume should be about 10% of total runoff volume.</li> <li>➤ The frequency of overflows should be about 6 to 8 times per year, on average.</li> </ul>	<ul style="list-style-type: none"> <li>➤ Total overflow volume should be about 3% of the total runoff volume.</li> <li>➤ The frequency of overflows should be about once per year, on average.</li> </ul>	<ul style="list-style-type: none"> <li>➤ total flow in the road drainage system should meet the volume and frequency targets<sup>(3)</sup> for OF<sub>1</sub> or OF<sub>2</sub></li> </ul>	<ul style="list-style-type: none"> <li>➤ The pre-development hydrograph should be maintained in downstream watercourses.</li> </ul>

Note: These overflow targets relate to the typical volume and frequency distribution of Tier A and Tier B rainfall events.

<sup>(1)</sup> Compound weir outlet structures will enable overflow from rainfall capture facilities and outflow from runoff control facilities to be correlated with water levels (WL<sub>1</sub> and WL<sub>2</sub>, respectively). Overflow from runoff control facilities (OF<sub>2</sub>) can be determined by subtracting controlled release (a known parameter) from total outflow.

<sup>(2)</sup> The amount of road runoff that infiltrates can be determined by subtracting F<sub>R</sub> from total road runoff (and accounting for OF<sub>1</sub>).

<sup>(3)</sup> If the design objective for roads is to provide rainfall capture, then the targets for OF<sub>1</sub> would apply. If the design objective is to make roads 'self-mitigating' (i.e. provide rainfall capture *and* runoff control), then the targets for OF<sub>2</sub> would apply. Note that storage does not need to be provided in runoff control facilities for self-mitigating roads.

## Deciding Which Facilities to Monitor

To properly evaluate the performance of a demonstration stormwater management system, a comprehensive monitoring program should define the Water Balance of the development site served by that system. This means that the monitoring information must answer the following question:

- ❑ Where does the rain that falls on the site end up?

Not every rainfall and runoff control facility needs to be monitored, however, it is important to monitor a representative sample from each component of the stormwater system. For example, a comprehensive monitoring program for a residential subdivision may include:

- ❑ **On-lot rainfall capture monitoring (Tier A)** – Monitor water level and overflow from at least one on-lot rainfall capture facility.
- ❑ **Road infiltration/drainage monitoring (Tier A)** – Monitor the drainage from at least one section of road, which may include more than one drainage path (e.g. french drains and catch basins).
- ❑ **Community detention pond monitoring (Tier B)** – Monitor water level and outflow from a detention pond serving the entire subdivision.

The monitoring information from a stormwater system should enable the performance of each stormwater system component and the performance of the overall system to be evaluated separately based on the appropriate performance targets and design objectives.

## Testing Conservative Assumptions

To deal with uncertainty, the preliminary stormwater system design criteria presented in Steps #1 through #5 are based on conservative assumptions:

- ❑ Detention storage volumes are conservative because they are based on long-duration rainfall events (24 hr) and do not account for release rate.
- ❑ Infiltration facility design criteria are based on conservative modeling assumptions.

Performance monitoring would be expected to confirm that initial assumptions are conservative and provide the certainty needed to reduce the size of facilities installed in subsequent developments. This should translate into cost savings over time.

## Customizing Infiltration Criteria for Different Zones

The rate of infiltration from on-lot or on-road infiltration facilities, and from unlined detention ponds, depends on soil conditions.

Monitoring the water level in rainfall capture or runoff control facilities will demonstrate how much water actually infiltrates and how the infiltration rate varies throughout the year.

This site-specific information can be used to develop customized design criteria for zones that have similar soil types.

## Performance Evaluation at the Catchment Level

Performance evaluation at the site level is the primary basis for optimizing the design of stormwater systems. Performance evaluation at the catchment level is also important to ensure that overall objectives for protecting aquatic habitat and receiving water quality are being achieved over time, and to improve stormwater management practices. Performance evaluation at the catchment level may require monitoring of:

- ❑ **Hydrologic Indicators** (e.g. change in rainfall-runoff response). Monitoring rainfall and runoff patterns provides an understanding of the effectiveness of source control strategies at maintaining or restoring the catchment's natural Water Balance and hydrology.
- ❑ **Water Quality Indicators** (e.g. change in total suspended solids (TSS)). Monitoring changes in TSS provides an indicator of improvements or declines in water quality. TSS acts as a 'carrier' for other pollutants such as heavy metals, and provides a direct measure of stream erosion and sedimentation rates.
- ❑ **Ecological Indicators** (e.g. abundance of benthic invertebrate community). Monitoring the characteristics of benthic invertebrate communities can provide a direct measure of changes in stream health over time.

### Hydrologic Performance Evaluation

A key performance objective is to maintain, as closely as possible, the characteristics of the natural hydrograph (i.e. hydrograph of the catchment in its undeveloped state), including:

- ❑ total flow volume
- ❑ peak flow rates
- ❑ baseflow rates (i.e. interflow)
- ❑ hydrograph shape

Note that when natural forest cover is removed a certain amount of natural evapotranspiration capacity is lost. Therefore, an increase in total flow volume is almost always expected from developed catchments (unless rainwater re-use is implemented). This underscores the importance of land development practices that preserve and/or restore as much natural forest cover as possible. The use of green roofs can also limit, though not replace, the loss of natural evapotranspiration capacity.

Continued streamflow monitoring at the catchment level will answer the following key performance evaluation question:

- ❑ How well are stormwater management practices at the site level maintaining the characteristics of a natural hydrograph as development proceeds within a catchment?

### Water Quality Performance Evaluation

Another performance objective is to maintain pre-development water quality. Turbidity and total suspended solids (TSS) are key water quality indicators that can be monitored at the catchment level. Because turbidity can be correlated with TSS, turbidity monitoring could be effectively integrated with streamflow monitoring.

A water quality baseline should be established by measuring turbidity and TSS prior to development proceeding in a catchment. This will enable future water quality monitoring to answer the following performance evaluation question:

- ❑ How well are stormwater management practices at the site level maintaining the pre-development water quality?

### Benthic Monitoring as an Early Warning Indicator

The Benthic Index of Biological Integrity (B-IBI) is a direct indicator of stream health. For streams that are seen as highly valuable (by citizens or environmental agencies), establishing a B-IBI baseline and implementing an ongoing monitoring program would provide an 'early warning' of stream degradation, and signal the need for action.

### A Look Ahead

Chapter 10 elaborates on environmental monitoring techniques that can be used to measure success at the catchment scale. This includes a discussion of the suite of tools that comprise a comprehensive approach, and an overview of the appropriate scale on which to use them.

The key message is that this suite of indicators accurately represents the environmental state of both the surface drainage function and the ecological function of receiving waters and can therefore be used to evaluate and optimize stormwater management strategies over time.