the partnership for water sustainability in bc

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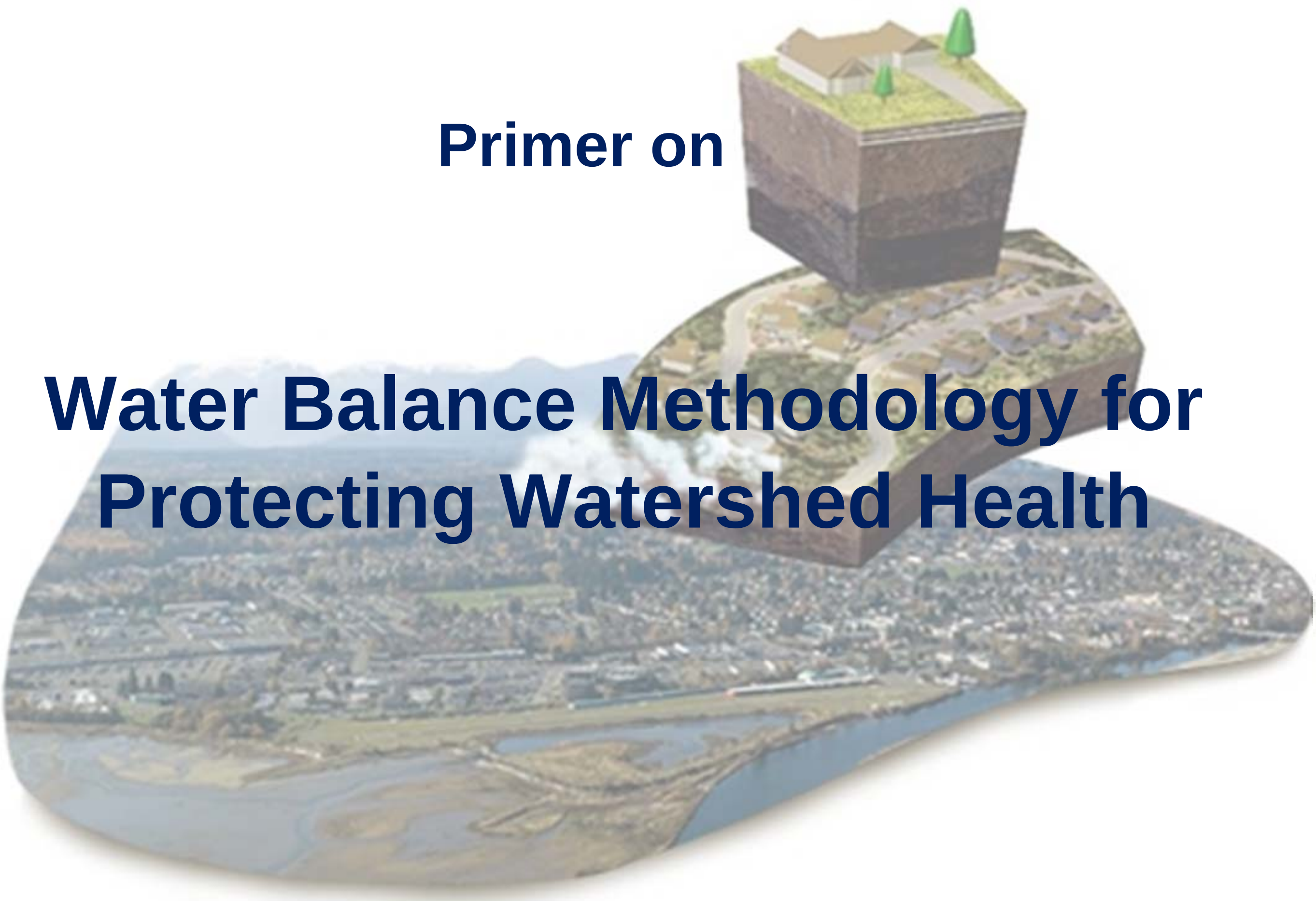


Primer on

Water Balance Methodology for Protecting Watershed Health

Integrating the Site with the Watershed, Stream and Aquifer

February 2014

About This Primer

This Primer supports implementation of targets and actions listed in **"Living Water Smart: British Columbia's Water Plan"***. The targets and actions establish expectations as to how land will be (re)developed so that stream and watershed health are protected and/or restored.*

Rainwater management and watershed health must be key considerations in urban development and redevelopment.

This is the fifth in a series of guidance documents that form the basis for knowledge-transfer via the Georgia Basin Inter-Regional Education Initiative (IREI). The foundation document for the series is **"Stormwater Planning: A Guidebook for British Columbia"**, *released in 2002.*

The goal in producing the "Beyond the Guidebook Primer Series" is to facilitate inter-regional collaboration, such that sharing and cross-fertilization of experience and understanding helps all local governments go farther, more efficiently and effectively.

The Primer storyline is structured in five parts. Table 1 (opposite) presents a synopsis for each part and is written for the busy reader

We take this opportunity to recognize the contributions of Jim Dumont, as principal author, and others who have reviewed and provided insightful suggestions.

Jim Dumont, in his role as Engineering Application Authority for the Partnership, is passionate and tireless in his efforts to evolve and advance a science-based approach to rainwater management, and that results in effective and affordable standards of practice.

Reviewers include Erik Karlsen and Peter Law who provide relevant perspectives from their decades of contributions to water sustainability approaches in BC.

Kim A. Stephens, MEng, PEng,
Executive Director
Partnership for Water Sustainability in BC
February 2014

Incorporated in 2010 as a not-for-profit society, the Partnership embraces shared responsibility and is the hub for a "convening for action" network in the local government setting. The Partnership plays a bridging role between Province, local government and community; and is the steward for the Stormwater Guidebook.

Table 1 – Synopsis for the Busy Reader

ABSTRACT: This Primer is the fifth in a series of guidance documents. These add depth to *Stormwater Planning: A Guidebook for British Columbia*. This Primer describes the science-based Water Balance Methodology that integrates engineering and biophysical understanding so that communities can implement Watershed-based Targets that "mimic the Natural Water Balance" and thereby restore and/or protect Watershed Health after the Natural Environment is altered by human activities.

Target Audiences: The methodology and science behind it are presented in a layered fashion to accommodate the interests of a continuum of audiences, ranging from those who are generalists and desire a basic understanding of core concepts, to those who are drainage modellers and wish to delve into supporting details.

Part	Title	Content Highlights
A	**Watershed-Based Approach to Rainwater Management**	Presents an overview of the regulatory and historical context for the Watershed Health Goal that drives the performance target approach to capturing rain where it falls, and then maintaining the natural proportion of rainwater entering streams via three pathways: surface flow, interflow (shallow sub-surface flow), and groundwater flow.
B	**Water Balance Methodology Explained**	Elaborates on watershed processes and the three pathways introduced in Part A; explains HOW the Water Balance Methodology examines both the flow path of water in a watershed and the flow in a stream; and introduces the three performance criteria for balancing volumes and measuring success in protecting stream health.
C	**Science Behind the Methodology**	Provides an overview of computer modelling practice for context; and then elaborates on WHY and HOW the Water Balance Methodology is innovative because it integrates and applies standard scientific and engineering principles which are not typically employed in standard engineering design of municipal infrastructure.
D	**How to Establish Watershed Targets**	Draws on case study experience to lead the reader through the 'how-to' steps when applying the Water Balance Methodology to complete statistical analyses, verify a computer model for baseline conditions, and establish performance targets that would mitigate the impacts on stream health that would otherwise result from land development.
E	**References**	Provides a starting point for interested readers to learn more about the regulatory context for the *Beyond the Guidebook Primer Series*; describes the scope of each Primer and includes links so that copies can be downloaded from the waterbucket.ca website.

A. Watershed-Based Approach to Rainwater Management

Since the 1990s, and largely due to heightened awareness as an outcome of the impact of the "salmon crisis" in the southwest region of BC, governments have recognized the need to restore and protect watershed and stream health.

By 2002, looking at rainfall differently led the Province to adopt the Water Balance Methodology, initiate a performance target approach to capturing rain where it falls, and initiate changes in the ways rainwater runoff is returned to streams.

Restoration and protection of watershed health is a priority for local governments in BC, especially in the Lower Mainland and along the east coast of Vancouver Island. Hence, the purpose of this Primer is to support implementation of standards of practice that are affordable and effective in achieving the Watershed Health Goal.

The Goal: Mimic Natural Water Balance and Protect Water Quality

When the natural environment is altered by human activities, the slow-release and sponge-like functions of vegetation and soil are lost, such that the balance and flow of water are severely upset.

Protection of watershed and stream health ultimately involves maintaining the natural proportion of rainwater entering streams via three pathways: surface flow, interflow (shallow sub-surface flow), and groundwater flow.

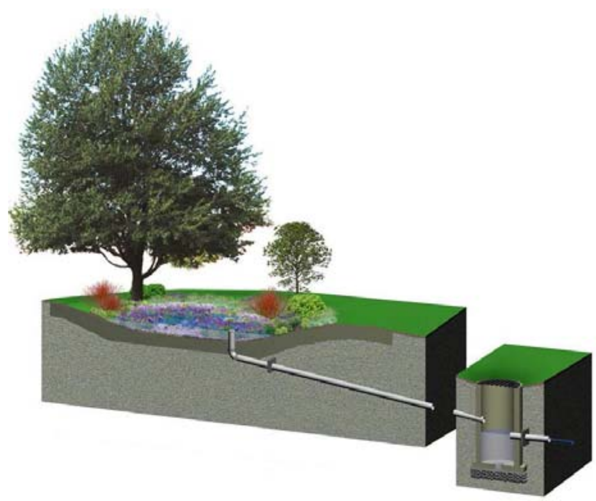
This desired outcome is described as "mimicking the natural Water Balance". Performance targets define how to "slow, sink and spread" rainwater and thereby replicate natural processes.

This Primer provides guidance on how to apply the ***Water Balance Methodology*** *and quantify three performance targets, namely:* storage volume, infiltration area *and* flow release rate.

Implementation: Landscape-based solutions would allow each property in a neighbourhood to capture, store and slowly release the right proportion of rainwater into the ground to replenish aquifers and streams. Illustrated below is a rain garden, which is a typical application.

A rain garden is a dished and landscaped area that is made up of two layers – a top layer of garden soil that acts like a sponge, and a base layer of porous granular material (e.g. drain rock, sand) where water is stored in void spaces. Stored water then both infiltrates into the native soil below and discharges horizontally through a controlled outlet and ultimately to a stream as baseflow.

Figure 1 is a rain garden in cross-section view. It shows the application of performance targets.



More than Surface Runoff: "Defining how much water can be retained, infiltrated, and detained on a lot is a completely different way of looking at the drainage problem and solutions. Surface runoff is a small component of natural watershed function. The key to replicating watershed function and mitigating impacts is understanding ALL flow paths through the landscape. Then, Watershed-based Targets can be distilled into a set of design values that are easily applied at a lot level," explains Jim Dumont, the Partnership's Engineering Applications Authority.

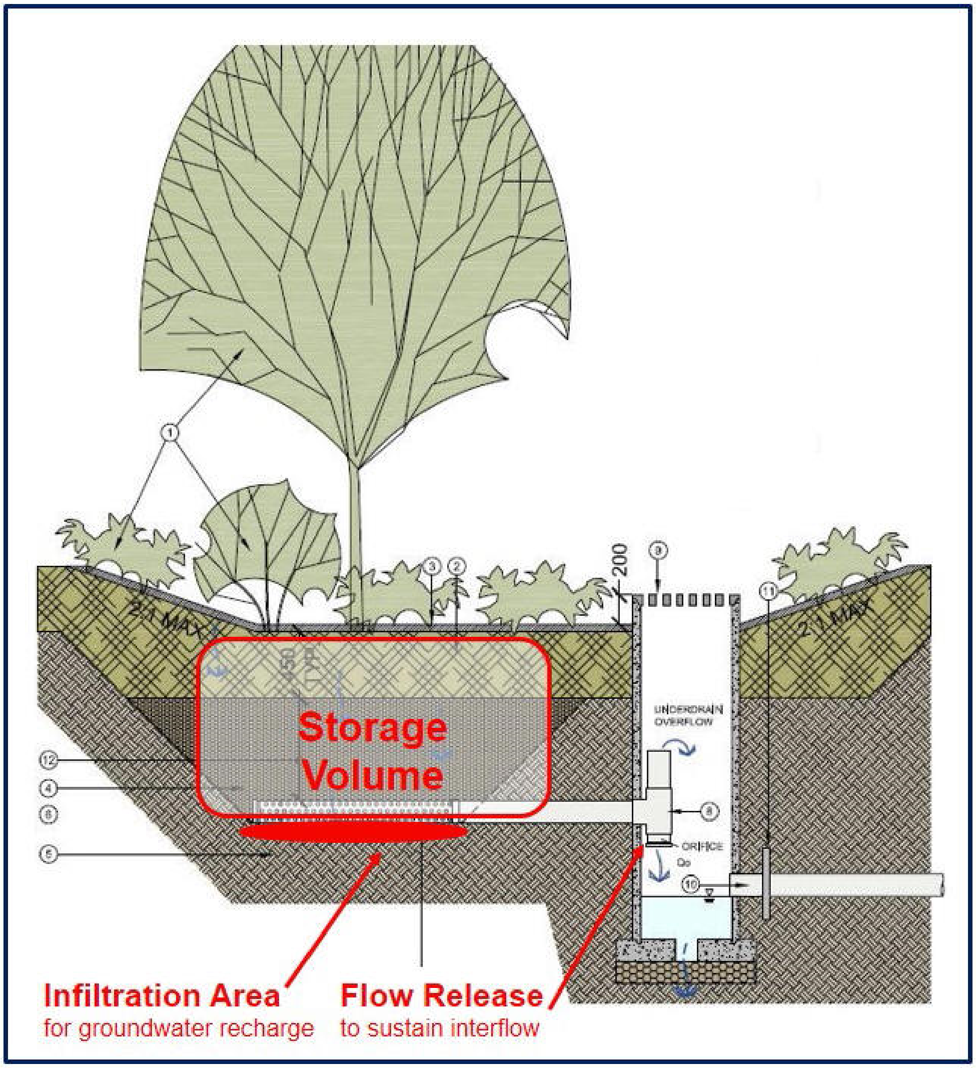


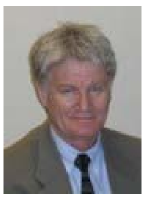
Image Source: *Stormwater Source Control Design Guidelines 2012 (Final Report), Metro Vancouver*

Figure 1 – How Performance Targets for Storage, Infiltration and Flow Release are incorporated in a Rain Garden Design

Evolution of Watershed-Based Approach to Community Planning

It is helpful to take a step back and view the Water Balance Methodology in an historical context. The methodology is a pragmatic outcome of a 'design with nature' guiding philosophy that had its genesis more than two decades ago when British Columbia and Canada co-published the Stewardship Series.

Building on the Stream Stewardship Guide: "Released circa 1993, *Stream Stewardship: A Guide for Planners and Developers* document was an early, and in some respects the first, local government focussed design with nature guide," recalls Erik Karlsen, formerly an Executive Director in the BC Ministry of Municipal Affairs.



Erik Karlsen co-authored a guidance document titled *A Watershed / Landscape-Based Approach to Community Planning*, released in 2002. Produced by a Metro Vancouver interdisciplinary working group, the underpinning premise is that resource, land use and community design decisions will be made with an eye towards their potential impact on the watershed.

"Not surprisingly, the Stream Stewardship Series was led by a group of landscape architects. Prior to this, although local government legislation empowered local governments to address the topics in this guide, until its publication there was limited guidance available to help planners, developers and biologists to work to together."

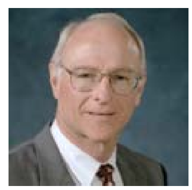
"Looking back over the past 20-plus years, if the Stewardship Series was the first wave, the work of UBC's James Taylor Chair on Sustainable Urban Landscapes was the second, and the Water Balance Approach is the third."

"Each of these 'waves' was initiated by different 'groups' focussing on different aspects of stream stewardship issues; but over time they shared members, and merged from one to the other."

Application of Science-Based Understanding: Breakthroughs in science-based understanding occurred in the mid-1990s. Yet engineering practice generally did not incorporate this understanding. The Water Balance Methodology addresses this historical oversight because…integrating the site with the watershed, stream and aquifer requires …synthesis of hydrology, aquatic ecology, geomorphology and hydrogeology principles.

In hindsight, what did not happen in the 1990s was a comprehensive bringing together or synthesis of engineering and biophysical understanding. At the time, neither discipline had a clear understanding of the processes involved nor of the wide ranging impacts that they were trying to mitigate.

Yet the way forward is foreshadowed in this quote from Larry Roesner (of Colorado State University), proceedings editor for a 1996 ASCE conference: "What is required is the development of soft engineering that simultaneously achieves the scientists' criteria for ecosystem protection or restoration, and looks and acts like a natural environment".



> *The Province of BC's decision to embed the Water Balance Methodology in* **Stormwater Planning: A Guidebook for British Columbia***, released in 2002, defined a turning point in the regulatory vision for drainage planning, from reactive to proactive and science-based.*

The Guidebook presents a framework for implementing an 'adaptive management approach' to watershed-based actions. This means learn by doing; also, change direction when science-based understanding leads to a better way.

Beyond the Guidebook Primer Series: The purpose of the Primer Series is to inform and educate infrastructure, environmental and land use professionals about how to implement actions at the site scale that achieve desired outcomes at the watershed scale. Refer to Part E for details.

B. Water Balance Methodology Explained

British Columbia was the first province or state in North America to adopt the Water Balance Methodology. In 2002, the Guidebook translated science-based understanding so that local governments could establish achievable and affordable performance targets for rainfall capture and runoff control.

The Water Balance Methodology accounts for all the rainfall-days in a year and is founded on the concept known as the *Rainfall Spectrum*. This is a universal relationship. In other words, the number of rainfall-days and the total rainfall volume per year may vary by region, but the distribution of that volume has a consistent pattern.

> *The Water Balance Methodology provides a logical and straightforward way to assess potential impacts resulting from urban development; and analytically **demonstrate** the effectiveness of the methods proposed for preventing and/or mitigating those impacts.*

Development & Evolution of the Water Balance Methodology

The Water Balance Methodology was developed to address the need to (avoid, prevent, reduce or mitigate) the impacts of land development while at the same time providing a scientifically defensible approach to assessment, analysis, and design.

The Water Balance Methodology is dynamic; and it is being enhanced over time to incorporate fresh insights resulting from applications of science-based understanding.

The Water Balance Methodology is superior to, and would therefore take precedence over, a prescriptive approach that cannot demonstrate effectiveness in protecting watershed function.

Evolution of the Methodology: A key goal is to improve the technical basis for local government decisions. Three milestones in the evolutionary process are introduced below:

- ☐ First, in 2002, the Guidebook integrated hydrology and aquatic ecology. This built on Washington State research findings about the four factors limiting stream health. These are introduced in Part C.
- ☐ Then, in 2007, the 'Beyond the Guidebook' initiative added geomorphology to the mix. This addressed the relationship between volume control and resulting flow rates in streams; and correlated stream health with stream erosion.
- ☐ More recently, in 2012, watershed research completed on Vancouver Island has added a groundwater dimension to stream health.

Assess Impacts and Evaluate Effectiveness: The primary impact of land development results from the alteration of the watershed hydrology. The Water Balance Methodology provides a framework that allows the alteration to be analyzed and defined.

Impacts which have been identified can then be mitigated and the effectiveness of the mitigation measures can be quantified using an assessment of calculated stream discharges as the primary method to measure success.

> *If the stream flows and durations of flow can be maintained without increasing the magnitude and duration of above average stream discharges, then success can be demonstrated.*

In 2002, the science-based understanding that underpinned development and application of the Water Balance Methodology set the stage for defining **water sustainability** and **watershed sustainability** as an outcome of 'designing with nature' and implementing **green infrastructure** policies and practices. This "next step" followed four years later in 2006.

Comparison with Prescriptive Approaches: The following discussion is included to address concerns related to the use of a prescriptive approach which only calls for rainwater capture. Examples include requirements such as:

- Retain 90% of rainfall on site; or
- Capture 50% of Mean Annual Rainfall.

Rainwater management based on a prescriptive approach typically makes several assumptions, which may or may not be explicitly stated. Some of these assumptions are listed as follows:

- All watersheds are similar and the prescribed capture volume is the same for each watershed and each site;
- Amounts of infiltrated water would be the same and would follow the same flow paths under developed conditions as under undeveloped conditions;
- There is no risk arising from infiltration of the captured rainfall; and
- The rate of infiltration is sufficient for disposal of captured rainwater.

The variability of watersheds includes factors such as aspect, underlying geology, and vegetation which all contribute to variations in the relationship between precipitation and stream flow. While there would be similarities in watersheds situated in close geographic proximity, the concept of a universal prescription is open to challenge.

A simple examination of watershed variability leads to the conclusion that prescriptive approaches are not appropriate, and a better foundation is necessary to make decisions on how to mitigate the impacts of urban development.

> *The Water Balance Methodology provides a much greater degree of certainty than a prescriptive approach which only calls for capture of rainwater.*

Rainwater in Watersheds

The hydrologic cycle describes the path of water as it circulates through the environment. When rainwater falls from the sky, it follows a number of possible paths as shown on Figure 2 (on page 6). Only a portion naturally enters the stream as surface runoff.

> *The Water Balance Methodology examines the flow paths of water in the watershed, and the flow in streams.*

Development Increases Runoff Volume: Urban development almost universally results in a greater area of imperviousness, a greater area of less perviousness, and a corresponding reduction in vegetation. This combination will increase the volume of surface runoff; and will decrease the moisture which is captured on the surface and which evaporates directly back into the atmosphere.

Figure 3 (also on page 6) compares the water balance across a range of impervious values for a typical watershed over a 17-year period and with a precipitation total of approximately 24,000 mm (or 2.4 metres). As the total impervious proportion of the watershed increases from a low of 5% to a maximum of 95%, the following alterations to the water balance would occur:

- Total rainfall remains constant at 24,000 mm;
- Total surface runoff increases 6-fold from 3,000 mm to 19,000 mm;
- Total surface infiltration decreases to one-fourth - from 12,000 mm to 3,000 mm; and
- Total surface evaporation decreases 60% - from 10,000 mm to 4,000 mm.

In this example watershed, the amount of rainwater returned to the atmosphere could equal the amount infiltrated into the soil. A mitigation strategy that focuses only on surface runoff would ignore the need to double the soil infiltration that occurs naturally, as well as the actual impacts upon the watershed and stream.

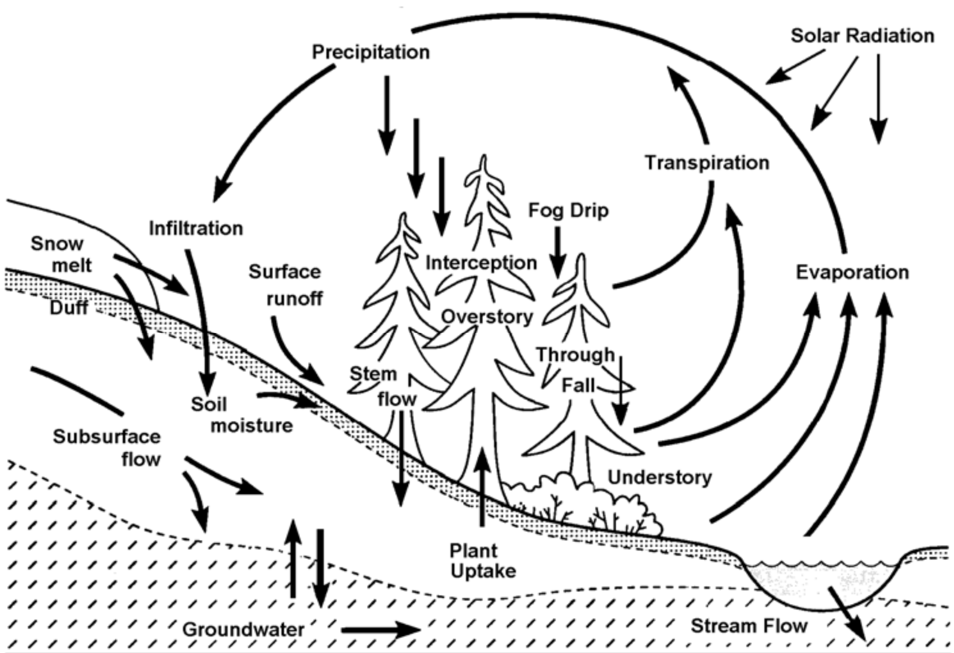


Figure 2 – Hydrologic Cycle

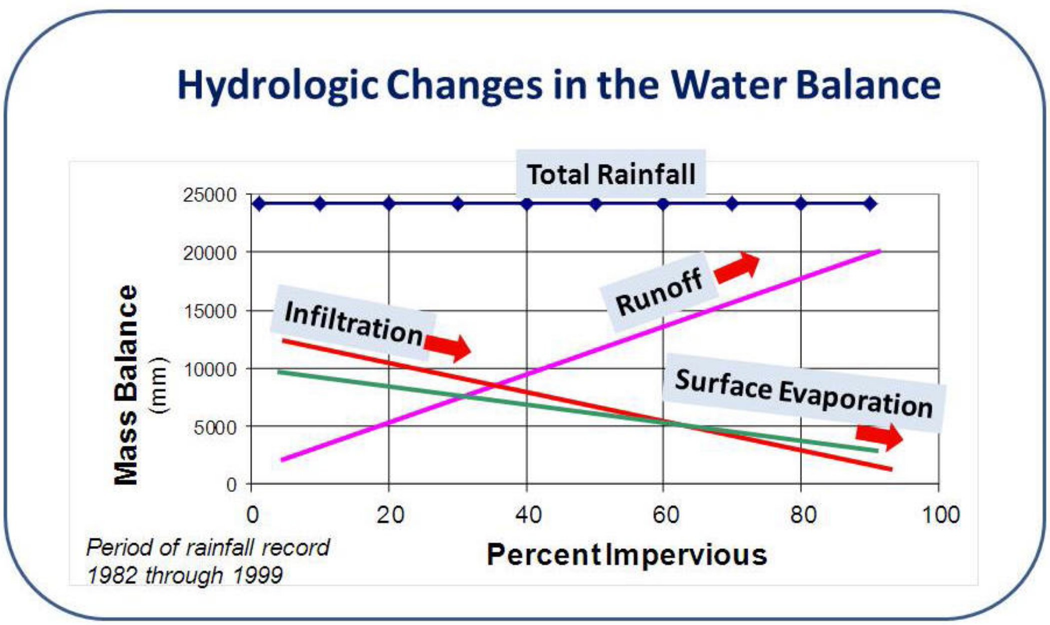


Figure 3 – Water Balance Impacts from Development

Three Pathways to Streams: Figure 4, which is presented on page 8, shows the three flow paths that rainwater will follow from the point where it reaches the ground until it finally enters the stream. These flow paths are:

1. **Surface Runoff** – The period of time water spends on this path is typically in the order of minutes to hours. Where lakes and ponds are a part of the flow path, the time could be extended to days.
2. **Interflow** – This system is seasonal. Water that enters shallow soils typically flows into the stream within a year.
3. **Deep Groundwater** - Flow duration can be from years to decades depending upon the flow path and porosity of the aquifer.

At the heart of the Water Balance Methodology is recognition of the integrated significance of these three flow paths, the period of time required for rainwater to reach the stream via each flow path, and the need to protect and maintain the natural distribution of rainwater via each flow path.

Mimic the Natural Water Balance: Protection of watershed and stream health ultimately involves maintaining the natural proportion of rainwater entering the stream via each pathway shown on Figure 4. This desired outcome is described as "mimicking the Natural Water Balance".

The Water Balance Methodology addresses the flow path differences, and provides solutions that would maintain stream health within a developed watershed.

The Water Balance Methodology also recognizes the potential changes in the paths followed by rainwater in the hydrologic cycle, and formalizes the science-based understanding of the methodologies necessary to protect the stream, the watershed and the aquifer.

Impacts and Mitigation

As urban development proceeds, and as illustrated on Figure 4, there is drastic disruption to the shallow soils as building foundations and underground infrastructure are constructed.

Such disruptions result in large alteration of the shallow surficial soils and the interflow system. The fact that post-development flow paths for shallow groundwater are disrupted invalidates the assumption that prescriptive approaches are applicable in all locations.

The combined impact of interflow disruption and alterations to the landscape (i.e. more impervious area, less pervious area, and less vegetative cover), would increase the volume of surface runoff.

If the runoff volume is to be maintained, then a larger volume would need to be infiltrated into the ground to account for the loss of surface evaporation. Where the terrain is steep risks loss of life or property damage may be increased as a result of land-slides.

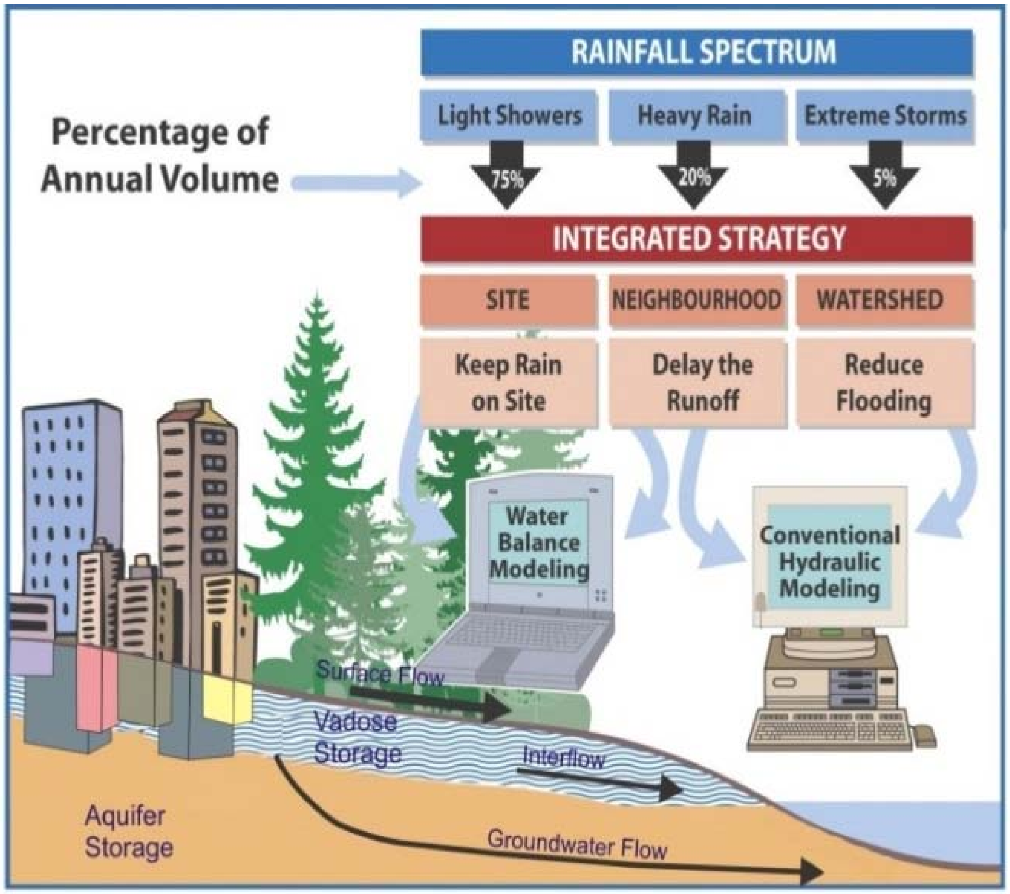
In areas located on clays, bedrock, or high groundwater levels, infiltration rates may not be sufficient to allow large rates of infiltration, resulting in flooding of previously dry areas.

Mitigation of adverse impacts can be divided into two separate approaches, depending on whether the surface type is pervious or impervious.

Pervious Surfaces: The alteration of the hydrologic response of a watershed can affect even the pervious surfaces - for example, when vegetation and trees are cleared to provide grassy surfaces and the top soil is removed and not replaced.

If the pervious surfaces are protected, and no harmful alteration occurs, then they would respond in a hydrologically similar manner following development. This would mean that the soil and its rainwater holding capacity are preserved through careful topsoil and vegetation management.

If preservation of pervious area conditions is achieved, then the focus of the assessment can be on the effect of the impervious areas.



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

Figure 4 – Watershed Flow Paths

Explanatory Notes – Key Messages:

Definitions: *'Aquifer Storage' refers to the saturated zone below the groundwater table where all pore spaces in the soil are filled with groundwater. 'Vadose Storage' refers to the unsaturated zone above the groundwater table where pore spaces are filled with air AND water.*

Urban development reduces the 'vadose storage' and interflow. Therefore, to mimic the natural water balance of the site, development projects should strive to retain or restore these processes by means of green infrastructure solutions.

Basements and underground structures will lower groundwater levels to the footing level. The ground above this then becomes part of the vadose zone and can be used for vadose storage. When designed properly, this zone can form part of the green infrastructure solution.

How Does Water Reach a Stream?

Surface Runoff -
from minutes to hours

Interflow (Shallow Groundwater) -
from days to years

Deep Groundwater -
from years to decades or more

Impervious Surfaces: Conversion of pervious areas to impervious prevents rainwater infiltration and results in almost all of the rainwater being converted into surface runoff. A similar loss of surface area for flow to deep groundwater is lost. There are some evaporation losses but those are relatively minor.

> *The mitigation of this hydrologic change is the main challenge. Municipal infrastructure must be designed to replace the lost natural retention systems and flow paths.*

The infrastructure that mitigates the impacts would receive the surface runoff from the impervious areas and then operate in a manner which would replicate the interflow system while limiting the infiltration to deep groundwater to naturally occurring rates.

Mitigation System Criteria

Construction of urban infrastructure and site development causes a disruption to interflow through the shallow surface soils.

The storage capacity of the shallow surface soils is considerably reduced, resulting in the loss of the storage reservoir capacity of the watershed.

In the built environment, the interflow system is typically replaced by urban conveyance systems which are very rapid and contain far less storage capacity than the surface soils.

In summary, the loss of the interflow system due to urban development represents a very significant impact to the natural environment. Thus, mitigation of this impact is essential in a developed urban setting.

> *This means **replicate the shallow soil storage and interflow conveyance system** in order to mimic the natural watershed.*

Protect Recharge of Deep Groundwater: The deep groundwater flow path cannot be the only one that remains following land development. The reason is that the time scale over which it occurs is significantly greater that the response of the lost interflow system.

The implication of the foregoing statement is that the proportion of infiltration to deep groundwater must be maintained and not significantly increased or decreased.

How to Mimic the Natural Watershed: A 'design with nature' approach that mimics the hydrologic function of a natural watershed would incorporate these features and considerations:

1. The interflow system would allow stored water to enter the stream from the shallow systems, rather than relying entirely upon groundwater discharge.
2. The overflow rates would be controlled to prevent increased risks for flooding of properties downstream of any specific development.
3. The flow to ground would be assessed using a sensitivity analysis combined with the storage size, area available for infiltration to groundwater, and controlled discharge rates.

> *By applying a 'design with nature' approach that is watershed-based and achieves integration of the foregoing, the resulting Rainwater Management System can be optimized to maintain both the volumes and the rates of discharge to the stream.*

Benefits of Integrated Rainwater Management: The desired outcome when implementing an integrated Rainwater Management System is to provide interflow connectivity to the stream and to maintain or decrease potential flood risks, and to mimic the proportion of rainwater that would be infiltrated to deep groundwater under natural watershed conditions.

A watershed-based approach to system design that integrates the site, watershed, stream and aquifer would provide a level of assurance that:

1. Excess water would not be directed to the ground and would avoid potentially adverse impacts of excessive groundwater levels and discharges in areas lower in the watershed.
2. Low summer flows would be maintained with an operating interflow system.
3. Downstream properties would not suffer an increased risk of flooding or flood damages.

In summary, land development and watershed protection can be compatible when the Water Balance Methodology is applied in order to design an integrated Rainwater Management system that mimics the Natural Water Balance.

Mitigation System Analysis

The hydrologic performance of a watershed and areas undergoing development or redevelopment can be simulated by applying a standard computer modeling approach and using continuous climate data for the period of record.

The schematic diagram presented as Figure 5 on page 11 identifies the processes for simulation of the watershed, plus retention and infiltration discharge control systems. For purposes of analysis, note that surface evaporation is assumed to be negligible to allow rainwater control systems to be constructed below ground.

If portions of a developed watershed are serviced with surface facilities, then the process of surface evaporation can be turned on in the computer simulation model so that potential implications for system operation and sizing can be assessed.

How to Measure Success: The benefits of an integrated Rainwater Management System that mimics the Natural Water Balance were introduced on page 9. These were framed in terms of "level of assurance" vis-à-vis low flow, infiltration and flood risks. The criteria used to measure success would be:

- No increase in magnitude of flood events,
- No increase in the duration of the 2-year (Q_2) and 5-year (Q_5) discharge rates (i.e. to prevent increased stream erosion), and
- No increase in the infiltration to deep groundwater.

Examination of the process flow chart shown as Figure 5 leads to the conclusion that there are three physical characteristics of retention / infiltration systems that can be varied to influence the hydrologic operation of rainwater control systems. The three physical characteristics are described as follows:

1. **Volume of Retention** which stores rainwater for controlled release to deep groundwater or to the stream through the municipal drainage system;
2. **Infiltration System Area** which is in contact with the subsurface and would allow retained water volumes to infiltrate to deep groundwater to mitigate loss of groundwater recharge caused by impermeable surfaces; and
3. The **Base Flow Release Rate** which can be used to augment small stream discharges through release of retained rainwater.

The analysis embodied in the Water Balance Methodology seeks to minimize the volume of retention and the infiltration system area while sustaining the selected base flow release rate.

The objective of a sensitivity analysis is to determine the minimum retention / infiltration system size that achieves the stated objectives. This would lead to the least-cost system to mitigate the impacts of urban development.

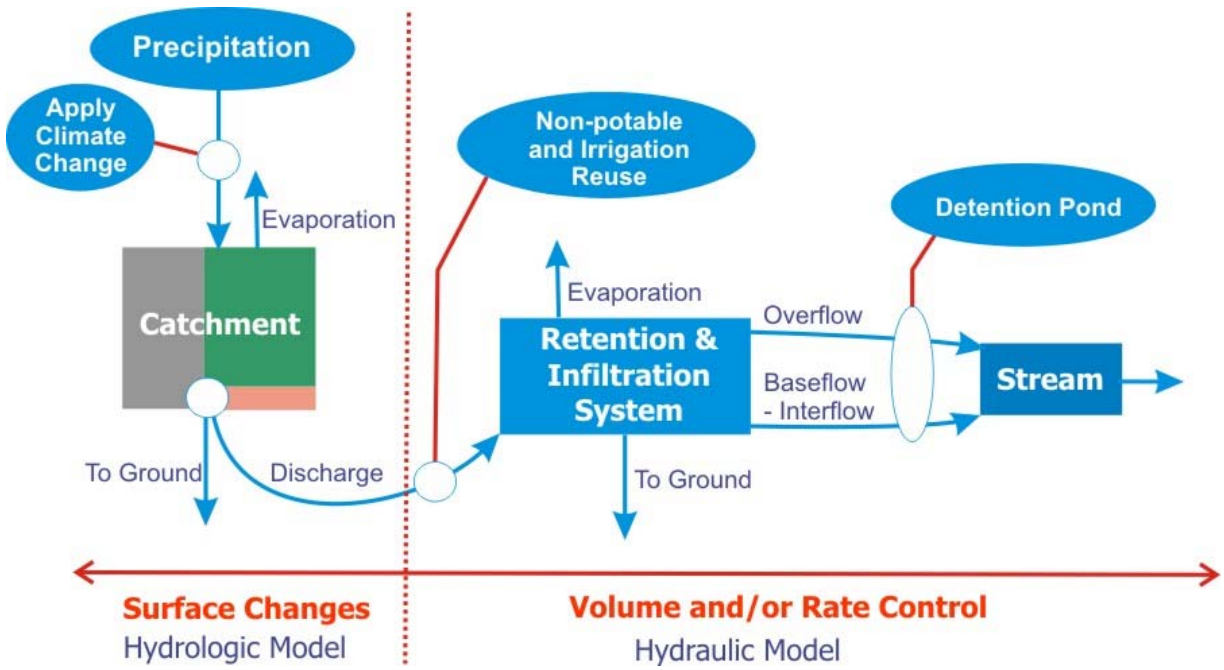


Figure 5 – Watershed and Rainwater Control System Operation

Rainwater Management Targets

The results of the rainwater analysis would yield three performance targets necessary to achieve the objectives, these targets being:

1. **Retention Volume** expressed in terms of cubic metres per hectare (m^3 per ha) of development area,
2. **Base Flow Release Rate** from retention expressed in terms of litres per second per hectare (Lps per ha), and
3. **Infiltration Area** for the retention facilities expressed in terms of square metres per (m^2 per ha) of development area.

Figure 6 below is included in order to illustrate the application of the Water Balance Methodology.

A Guiding Objective is to Balance Volumes: The table presents the three Performance Targets that in combination mimic the natural Water Balance.

Performance targets are watershed-specific and are most reliably established through application of continuous hydrologic simulation. In the absence of local data, interim targets may reasonably be derived from a regional hydrologic analysis.

An integrated design for land development, rainwater management and groundwater recharge would balance the annual volume necessary for interflow storage with the annual volumes necessary to sustain the duration of interflow and allow infiltration to groundwater.

Watershed-Specific Performance Targets

Target Parameter	Water Balance Function	Units of Measurement	Example Target Values*
Base Flow Release Rate	Interflow Replicator Rate	litres per second per hectare of drainage area	0.5
Storage Volume	Interflow Storage Replicator	cubic metres per hectare of hardened land surface	300
Infiltration Area	Groundwater Storage Recharge	percentage of project site area in contact with native ground	3%

*represents expected order-of-magnitude of target value

Figure 6

An Illustration of How the Water Balance Methodology Can Be Applied to Establish Targets for Design of Rainwater Capture & Flow Release Systems

C. Science Behind the Methodology

A minimum amount of information is necessary to undertake a watershed assessment and then formulate a mitigation plan that is based on application of the Water Balance Methodology. This Part C provides a summary of the science-based understanding. Part D then presents an example of its application.

Scope of Rainwater Management

The multiple risks to a watershed that result from urban development include:

1. Increased flood risks in downstream reaches;
2. Aquatic habitat damage and the loss of fisheries resources.
3. Increased erosion and property damage; and
4. Costs associated with flood damage and repairs to eroded streams.

The goal of rainwater management in an urban area is to prevent and/or mitigate adverse impacts which would otherwise result from urban development. Each of the above risks is described on pages 15 through 17. First, however, relevant context on engineering standards of practice and choice of modelling tools is provided.

Overview of Modelling Practice: Preventing and/or mitigating adverse impacts involves the application of **standard engineering analysis and methodologies** combined with **typical design techniques** in an **innovative manner**.

> *The Water Balance Methodology is founded on standard scientific and engineering principles which are not typically used in standard engineering design of municipal infrastructure. The innovation is in the integration and application of these principles.*

The practice of municipal engineering, and the specific applications in drainage design, places a special emphasis on building infrastructure that has the sole purpose of reducing surface flooding due to inconvenient, infrequent large storm events (such as a 1-in-5 or 1-in-25 year return period event). As a result, many currently available urban runoff computer models have their roots in traditional design where the focus is on large and rare rainstorm events.

In contrast, the focus of rainwater management and stream health is mostly on the common and relatively small rainfalls that would occur on an average daily basis (less than a 1-in-1 year return period event).

Thus, the assumptions and simplifications that are reasonably used with drainage design models are not appropriate for models used to assess stream impacts and rainwater management systems.

Figure 7 includes two images in order to contrast the simplifications associated with **drainage system modelling** when compared side-by-side with **rainwater modelling for watersheds and urban impact mitigation**.

The left image is extracted from the US EPA SWMM User Manual. Surface runoff is calculated by subtracting evaporation, surface storage and infiltration. The path the infiltration takes is not assessed. Rather, the rainwater infiltrated into the ground is simply considered to be a loss.

While SWMM is capable of continuous simulation, there is a problem in the current version of SWMM 5.0.022 for long-term snowmelt modeling related to double accounting of snowmelt and infiltration in pervious areas. Until this is resolved, there will be issues in using SWMM for continuous simulation.

The right image on Figure 7 is from the QUALHYMO User Manual. With this tool, the surface soils and interflow system are an integral part of the analysis.

> *When the goal is to assess watershed hydrologic responses to climate as well as mitigation of urban impacts, the QUALHYMO calculation engine yields results that are more appropriate than those generated using SWMM.*

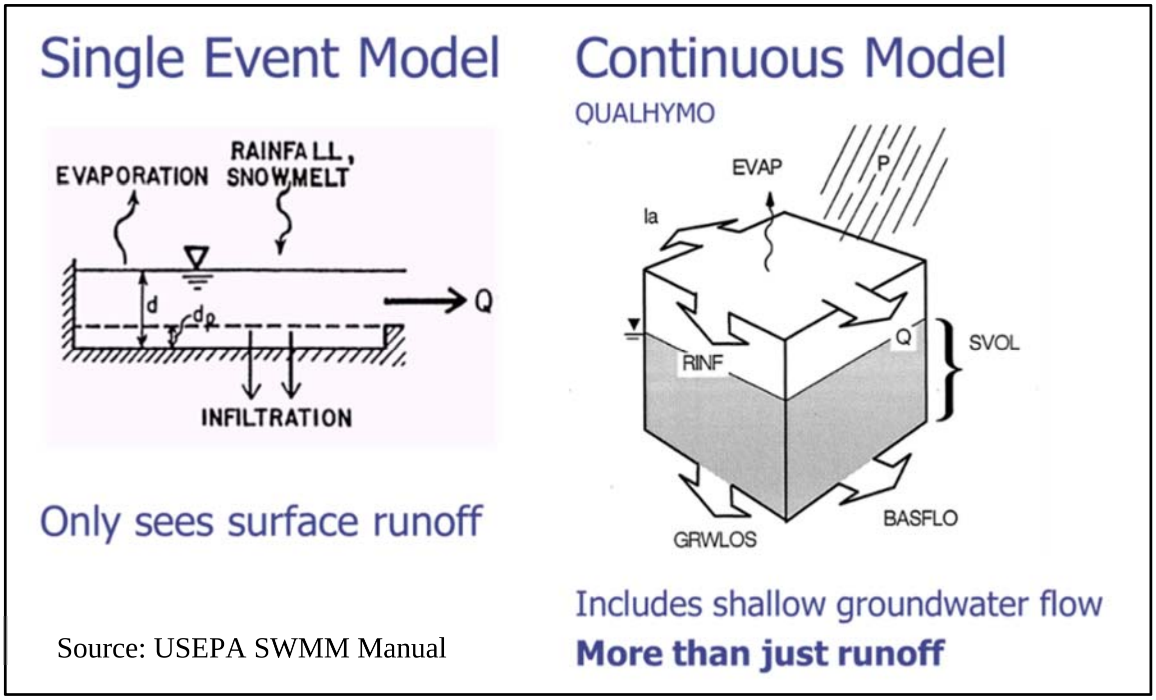


Figure 7– Single Event versus Continuous Model

Increased Downstream Flooding (#1): As rural land undergoes urban development there is an increase in impervious areas such as driveways, sidewalks, etc., and in the number of directly connected methods of drainage, such as sewers and roadways. These factors combine to yield higher volumes of runoff and flow rates as compared to pre-development conditions.

In a conventional drainage system, either the downstream system is enlarged to receive the increased flow; or new outlets for rainwater and stormwater runoff are constructed to accommodate development. Or, sometimes the risk of increased flooding in downstream areas may be ignored until flooding occurs.

As an alternative, storage, in the form of stormwater detention facilities, is frequently utilized to control the stormwater runoff so that the peak flows discharging from the development do not exceed acceptable pre-development flow rates in the downstream receiving drainage system for a given return period event.

If the post-development discharge rates are not restricted, then there is a real increase in the risk of flooding and its associated damages to properties in a downstream direction from the development.

This increased risk is to both property damage and loss of life in the affected areas. Hence, it is critical that the pre-development rates of discharge be maintained, or even reduced, to prevent such adverse impacts.

Flood Protection Criteria: The criteria generally accepted for flood protection in British Columbia are the 1-in-200 year return period event (Q_{200}) along natural flood plains, or Q_{100} in other areas. However, standard design practice in municipal infrastructure design in British Columbia utilizes a somewhat different standard for drainage system design.

The primary intent is to prevent post-development discharges from exceeding pre-development peak flow rates over a wider range of return periods, that is: from the 2- to 100-year events (Q_2 to Q_{100}).

Damage to Aquatic Habitat (#2): In 1996, Horner et al published landmark findings in their seminal paper titled "*Watershed Determinants in Ecosystem Functioning*". They demonstrated that the impacts from urban development fell into four different categories, with the effects (and hence the limiting factors for aquatic productivity and fish survival) ranking from highest to lowest as follows:

1. Changes in Hydrology
2. Disturbance to Riparian Corridor
3. Degradation of In-Stream Habitat
4. Deterioration of Water Quality

Figure 8 identifies the importance of the total imperviousness of a watershed. This indicates that stream health will be impacted with as little as 10% impervious area. The impact increases significantly beyond that value, with an identified critical value of 30% being the upper limit to support a population of cold water fish species.

Figure 9 presents the correlation of water quality with impervious area. The acute and chronic toxicity levels of pollutants in the stream becomes a factor for cold water fish species only after an imperviousness of 60% is reached. Therefore, water quality would only be an issue long after the other effects of development had eliminated the cold water fish species (i.e. salmonids).

The conclusion flowing from this information is that the impacts of development must be mitigated in order to support healthy populations of cold water fish species.

> *The four limiting factors and order-of-priority identified by Horner et al has provided a 'road map' for integrated watershed management.*

In BC, these findings provided a springboard from which to reinvent urban hydrology and develop the Water Balance Methodology as the centrepiece of *Stormwater Planning: A Guidebook for British Columbia*, released in 2002.

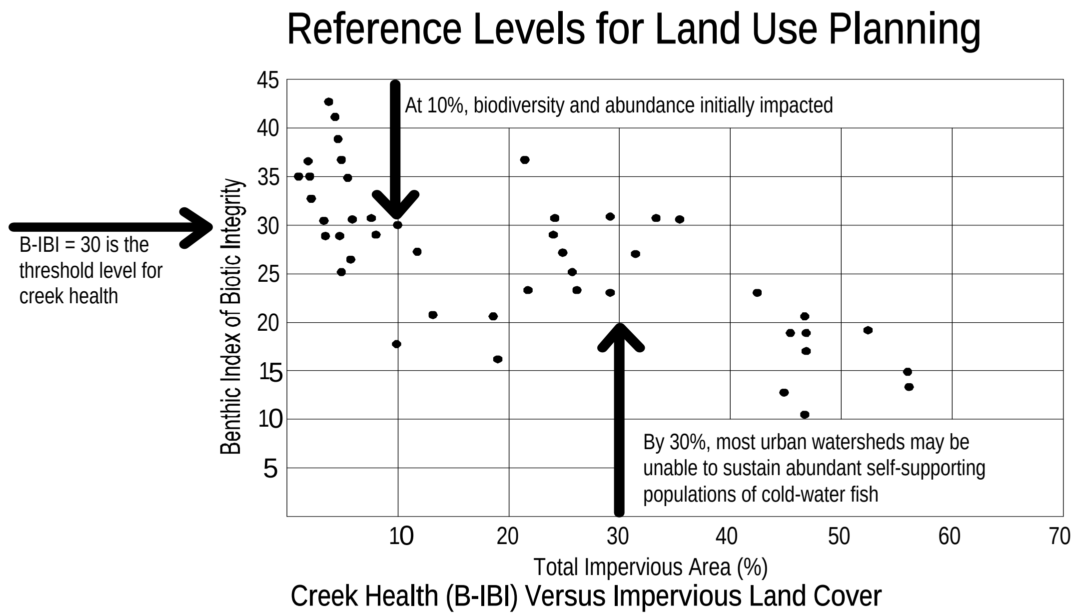


Figure 8

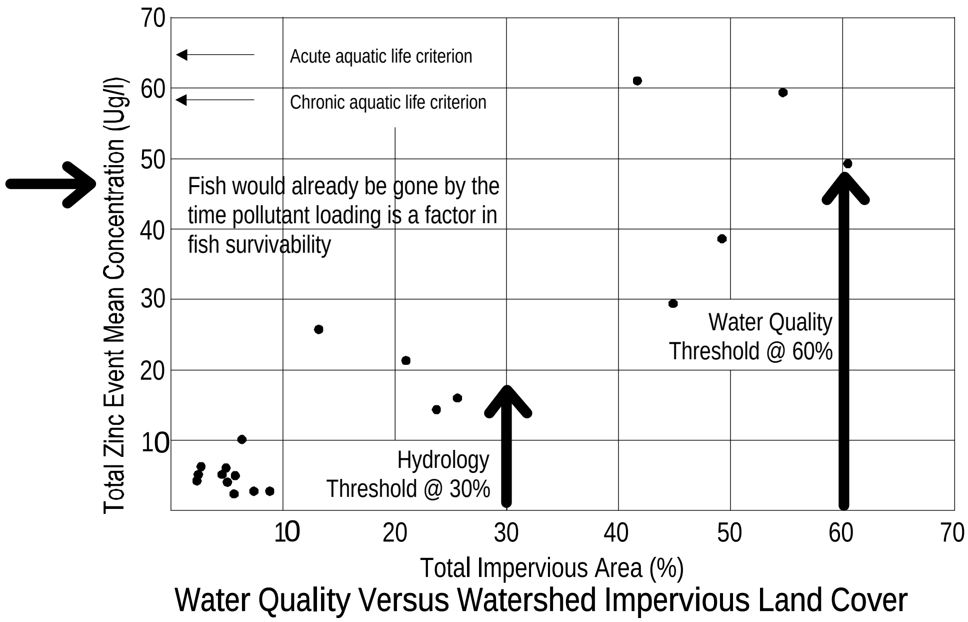


Figure 9

Increased Erosion (#3): The increased erosion in streams is an impact of development that relates to the changes in hydrology, which include greater rates and volumes of discharge in the stream.

A traditional engineering approach to prevent increased stream erosion is to limit post-development discharge rates to those occurring from pre-development conditions. That approach also generally assumes that a 2 or 5-year return period event (Q_2 or a Q_5) rate of discharge would not result in stream erosion.

Both of these assumptions can be shown to be incorrect. Both the discharge rates and the flow durations when combined are the critical factors in stream erosion. Two excellent references include:

- *"Experience from Morphological Research on Canadian Streams"* MacRae, American Society of Civil Engineers, 1997"
- *"Vulnerability of Natural Watercourses to Erosion Due to Different Flow Rates",* Lorent, Ministry of Natural Resources of Ontario, 1982

The erosion in streams has been found to be a related to the duration of discharge above critical threshold values rather than simply the discharge rate. Further, the threshold discharges are smaller than the commonly accepted Q_2 or Q_5 events.

> *An increase in erosion can be avoided if both the duration of flow and the rates of discharge are maintained following urban development.*

Increased Costs (#4): Stream erosion costs resulting from urban development are generally well-documented by local governments.

Typically, the eroded material accumulates in the lower reaches of the stream. This reduces stream capacity and increases flood levels.

An extensive and very expensive rehabilitation program is often necessary to protect properties from eroding stream banks and flood overflows

Computer Models and Continuous Simulation of Watershed Performance

This section builds on the overview of modelling practice that was presented on page 13. A key message is that the assumptions and simplifications that are reasonably used with drainage design models are not appropriate for models used to assess stream impacts and rainwater management systems.

Why Need for Extended Durations of Analysis: The seasonal time frame associated with the flow of rainwater through the interflow system on its way to a stream means that the computer models that would be used to simulate watershed processes must be capable of performing extended durations of analysis.

> *A single design storm would not adequately provide sufficient information to allow a description of the impacts of urban infrastructure on the watershed, nor would it allow the creation of a mitigation strategy to eliminate adverse impacts resulting from development.*

This leads to the selection of continuous simulation modelling tool that utilizes many years of recorded climate and stream discharge data for establishing the framework for the Water Balance Methodology, which in turn is used to establish watershed targets for implementation.

Why Select QUALHYMO Calculation Engine: A number of modelling tools are available for simulation purposes. The QUALHYMO computer model is preferable, in part because it is the calculation engine for the web-based and public domain Water Balance Model (WBM). It is also preferable due to the ease of extracting calculation results from the model output.

Using the QUALHYMO model outside of the WBM framework allows access to the full capabilities of the model. Continuous simulation can be extended over the period of available data records.

Why Simulate Water Balance Processes: The QUALHYMO model also allows variation of select input parameters to fully calibrate results to recorded events during a period of record.

Of relevance when applying the Water Balance Methodology to assess watershed performance, the QUALHYMO engine incorporates hydrologic process descriptions to more accurately predict the range of stream flows from a range of storm sizes which are of most interest in rainwater management and related analyses.

Figure 5 on page 11 identifies the processes, namely: evaporation, surface infiltration, soil moisture content, interflow (baseflow) and flow into deep groundwater.

Why Use One Model for a Range of Analyses: QUALHYMO can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of rainwater controls on drainage design.

QUALHYMO can be used to continuously simulate the water balance and to estimate rainwater retention performance.

> *Selection of the QHALHYMO continuous simulation model allows a single model to undertake all of the required analyses.*

Why QUALHYMO History is Relevant: The original QUALHYMO model was developed in 1983 in conjunction with development of a methodology for analysis of stormwater detention ponds for water quality control, and was funded by a grant from the Ontario Ministry of Environment.

QUALHYMO is most suited to analyses in basins where the land surface is developing from a rural or undeveloped state to an urban land use.

Long term continuous precipitation, temperature, and evaporation records are used to simulate the response of the watershed and its components.

Through such studies, it is possible to have an enhanced understanding of the watershed's response to extended wet weather conditions (multiple events). The climate records also include temperature which allows simulation of snow accumulation and melting in addition to evaporation. The latter allows simulation of extended dry periods.

Why Continuous Simulation is Necessary: A primary benefit of continuous simulation is that the frequency of various conditions and system operations can be estimated more easily than when alternate approaches are used.

> *The hydrologic responses of watersheds depend not only on the rainfall volume and temporal distribution, but also on antecedent conditions such as soil moisture and the volumes of existing water retained from previous storms.*

All of these factors overlie the physical characteristics of a watershed in terms of vegetative cover, imperviousness, connectivity, slope, and the many defining parameters describing the condition of the soils.

Simulations utilizing relatively short duration (from several hours to a few days) single event storms, or even the ‘quasi continuous’ technique of using a number of selected single storms, cannot match the capability of the truly continuous model.

Why Single-Event Design Storms are Arbitrary: The frequency of an individual rainstorm’s average intensity, duration, volume and maximum intensity can be found to form the Intensity-Duration-Frequency relationship (i.e. known as “IDF curve”).

The rainfall distribution and antecedent conditions, however, are usually chosen according to some arbitrary design rule, if they are considered at all.

> *The frequency of occurrence of the design condition therefore represents some unknown combined probability of rainfall and antecedent conditions.*

Hence, the frequency of the resulting condition of interest (e.g. retention volume, runoff, infiltration, evaporation, etc.) is also unknown.

Therefore, analyses depending upon a single event, or even a limited number of single events, cannot describe the operational characteristics of the source controls, nor their anticipated impact in restoring a natural pre-development hydrologic response to an urbanized watershed.

Why Rainfall and Runoff Differ Statistically: An often unstated assumption that occurs with the use of design storms is that the return period of the peak runoff or the retention volume is the same as that of the design storm.

For any 1-in-100 year return period storm there are numerous different design storms that can be applied with variations of duration and volume along with intensity distribution and the number of time steps within the design storm.

This results in a near infinite number of different 1-in-100 year return period design storms.

On the other hand there is only one value for the 1-in-100 year return period discharge. This simple comparison of the number of possible design storms versus the single flood discharge value leads to the conclusion that the return period of the design storm is seldom the return period of the discharge event, and by extension the return period of the retention volume for a storm.

Why Account for Effects of Joint Probabilities: Continuous simulation allows a direct observation of the frequency of the condition of interest from the modelling results, and therefore accounts for the effect of joint probabilities of intensity, volume, duration, antecedent rainfall and other hydrologic factors which would affect discharge rates and volumes.

Why Antecedent Conditions Matter in BC: Any system that utilizes storage and by default a restricted discharge capacity is extremely sensitive to conditions prior to any actual rainfall event.

A period of relatively low intensity of rainfall, but with a considerable volume of rainfall, may fill, or at least partially fill, any system storage available.

The system would then react quite differently to a significant rainfall event than had the system storage been empty.

This meteorological series of events is common in British Columbia. Hence, source controls are subject to operating conditions that are not normally given consideration in other geographic locals or in typical municipal drainage system design.

It is important to note that continuous simulation accounts for the effect of sequential rainfall events and extended durations of rainfall.

If an on-site system utilized retention and is designed with a low effective outflow rate, then it is possible that a sequence of small storms will successively raise the water level by increasing the system storage. This would leave the system effectively unable to contain and control subsequent relatively minor storms.

Statistical Analysis

Continuous simulation allows a probabilistic analysis of runoff in a study area. The probabilities attached to various events, or put another way, their return periods, are determined so as to properly carry out any associated risk analysis.

The probabilities are determined by frequency analyses of the simulation results, in exactly the same way as if there were recorded stream flow data available.

Statistical analysis of both watershed discharge and retention volumes is fundamental to the continuous hydrologic and hydraulic simulation process.

Methodology for Establishing Return Periods: The standard method of determining the return period of frequency associated with any given discharge or retention volume begins with acquiring the annual maximum value for each series of events to be analyzed.

From the continuous simulation record, the greatest discharge and/or retention volume which occurs in every year is extracted from the results of the simulation.

The assumptions inherent in the statistical analysis are that the values represent a series of independent events. The values are ranked from highest to lowest and are plotted against probability.

A curve is extended through the points of the plot to establish a relationship of magnitude with probability, or return period of the event. The standard Weibull plotting position defines:

Probability = (1 / Return Period)
Return Period = (N+1)/R; where
N = Number of Events
R = Rank (largest event to smallest)

A specific distribution curve is then fitted to the plotted data. The Log Pearson Type III curve fitting methodology is almost universally accepted as the standard for statistical analysis of stream flood discharge. Other curve fitting methods may be applicable.

Stream Flow Records

The first step in understanding the hydrologic operation of a watershed is to evaluate recorded stream flow data.

Where recorded data is not available for a given watershed, standard of engineering practice is to undertake a Regional Analysis of streams with flow records. This would yield a reasonable estimate of expected values for a given watershed.

To identify a potential list of streams suitable for a Regional Analysis, apply selection criteria such as those listed as follows:

- Located in geographically nearby area with similar aspect and characteristics;
- Minimum of 15 years of continuous records, and which include annual maxima for mean daily and peak daily discharges;
- Unregulated discharges; and
- Watersheds do not contain large lakes which could attenuate recorded peak discharges. Note that where lakes occur special considerations must be provided in the analyses.

Climate Records

Simulation of stream flow and watershed discharges is required for a watershed assessment. Climate data is an essential part of the information that is required for continuous simulation.

Much like the situation with stream flow, there is often a lack of specific local climate data that can be used directly. This results in the need to utilize a representative data set from a nearby climate recording station. A short list of acceptable climate stations can be established using these selection criteria:

- Located in a geographically nearby area with similar geographic aspect, and physical characteristics,
- Included in the Environment Canada Climate Normals summaries,
- A minimum of 15 years of Environment Canada archived hourly records for rainfall and temperature, daily precipitation used to derive snowfall contribution, and evaporation.

Climate Change

At any point in the modelling, projections into the future can include the effects of climate change which are applied as factors to the recorded climate data. While QUALHYMO and the Water Balance Model have this feature built into the code of the models, manipulation of the raw climate data can be undertaken for use in any other computer model.

Surficial Soils

Examination of surficial soils is critical to understanding the hydrology of an area. The shallow (less than 1 m in depth) soils are most affected and altered by the interaction of both rainwater and biological activity are commonly referred to as "top soil".

> *This section is included in order to provide the reader with a basic understanding of the soil formation processes; and can therefore be considered a primer on soil formation.*

Why Understand the Nature of Shallow Soils: The surficial soils are modified over time by these factors and their physical and chemical characteristics will be altered from those of the original geological materials.

The surficial soils develop as a result of combined physical characteristics of the geological materials, topography, biological activity and climate.

Our past experience leads us to believe that these processes and the resulting soil properties are not well understood by many practitioners in the area of water resources.

> *Understanding the nature of the shallow soils allows us to view how they interact with rainwater and determine how they alter the flow path to the stream.*

About Soil Properties & Hydrologic Response: A brief description of the soil formation processes and the soil types that are typically present within British Columbia follows.

Surface soils are the product of the environmental factors under which they have developed and are developing. These factors include the mineral parent materials plus topographic, climatic and biological influences.

The climatic and biological factors are the normal forces of change acting in soil development.

One very important aspect in understanding the hydrology within a watershed lies in the descriptions of the shallow surficial soils and their formation.

> *The shallow surface soils form the interflow media and directly interact with any rainfall. The physical properties of these shallow soils determine hydrologic response of the watersheds, specifically: how the rainfall interacts with the landscape; where the rainwater goes; and how the rainwater gets there.*

Descriptions of the shallow surface soils can be found in reports published by Agriculture Canada and the Ministry of Environment of British Columbia.

The formation of soils is a complex interaction of the geologic material that remained after the most recent glaciation plus climate and biota of plants and animals that use or disturb the soil.

These processes are described by a branch of soil science that focuses on the formation, morphology, and classification of soils as bodies within the natural landscape.

The science of pedology seeks to understand how the properties and distribution patterns of soils have developed along with broader landforms, biogeochemical environments, and habitats of living organisms.

Accordingly, pedology embraces several sub-disciplines, namely, soil chemistry, soil physics, and soil microbiology.

Additional information or interpretation of information provided in soils reports can be provided by a soil scientist or a Professional Agrologist with expertise in soil science.

Soil Properties: An understanding of the physical characteristics of the shallow surficial soils will aid in developing an understanding of the existing watershed hydrology and how one can mitigate alterations to the surface that would result from a development process.

Soil is composed of two different components: organic matter; and the mineral soil which is made up of a mixture of nonorganic particles.

Sand is coarse and the particles can be seen with the naked eye, while silt and clay particles require a microscope to be seen.

Both silt and clay feel smooth to touch, but clay will become sticky when wet.

The proportion of nonorganic particles of clay, silt, and sand determines the textural classification of the soil.

The Textural Soil Triangle as shown on Figure 10 on page 23 provides a graphical presentation of the soil textural classification system used in Canada.

The Soil Texture Triangle provides the relative proportion of the soil content of the mixture of clay, silt, and sand. This classification is critical in determining the interaction of soil and water.

The relative proportion of sand, silt, and clay will have a great effect upon the properties of the soil that include its capability to hold moisture and the ease that it can be cultivated.

For example, a soil that is primarily clay is considered “heavy” because it is difficult to cultivate. However, it has the potential to hold the greatest proportion of water.

Pure sand, on the other hand is “light” because it is easy to cultivate but it will retain the least amount of water.

The soil composed of equal parts of sand, silt, and clay will exhibit the best combination of properties of moisture retention and ease of cultivation or use in rainwater management and growing plants.

The **water retaining capacity** of a soil relates to its and the difference between the Wilting Point and Saturation as shown on Figure 11 on page 23. The terms can be defined as:

- **Saturated** is when every possible free space within the soil is filled with water. Saturated soils drain quickly to the Field Capacity.
- **Field Capacity** is the moisture content when air displaces some of the water volume as it drains away. At this moisture content the water is adhering to soil particle and will not freely flow away. Continued water losses are limited to evaporation, plant uptake and a small amount of gravity flow.
- **Wilting Point** is the moisture content when plans can no longer access the water in the soil and even evaporation of soil moisture ceases.

The water capacity of the soil is dependent upon the proportions of sand, silt and clay.

A soil will only retain the amount of water equal to the Field Capacity. Only the water above the Wilting Point is available for plant uptake.

The greater the field capacity the greater the retained moisture. This view must be tempered with the knowledge that moisture less than the wilting point is not available to plants.

The best soil for retaining plant useable moisture has the greatest difference between the Field Capacity and the Wilting Point.

A soil composed entirely of sand has a large drainable moisture content yet will not retain much moisture for plants.

A clay soil will retain a large amount of water but it will not be available to plants.

The best soil for retaining plant available water is one that contains a sand, silt, and clay in nearly equal amounts.

The best soils are identified on Figure 11 and their texture (content of sand, silt, and clay) can be seen on Figure 10.

Figure 11 confirms the common knowledge that sandy soils retain very little water and that they dry out quickly following a storm.

Figure 11 also confirms that the best soil types for retaining soil moisture for use by plants are soils with a mixture of silts, clays, and sand.

The soils which retain the most plant available moisture fall within the textural classifications of Loam, Silty Loam, Clay Loam, and Silty Clay.

These soils retain moisture for plant use while allowing the excess to drain quickly thus avoiding excessive durations where the root zone is saturated and plant damage can occur.

These soils are best for landscaping and growing vegetation with a minimal need for supplemental irrigation to make up for periods without rainfall.

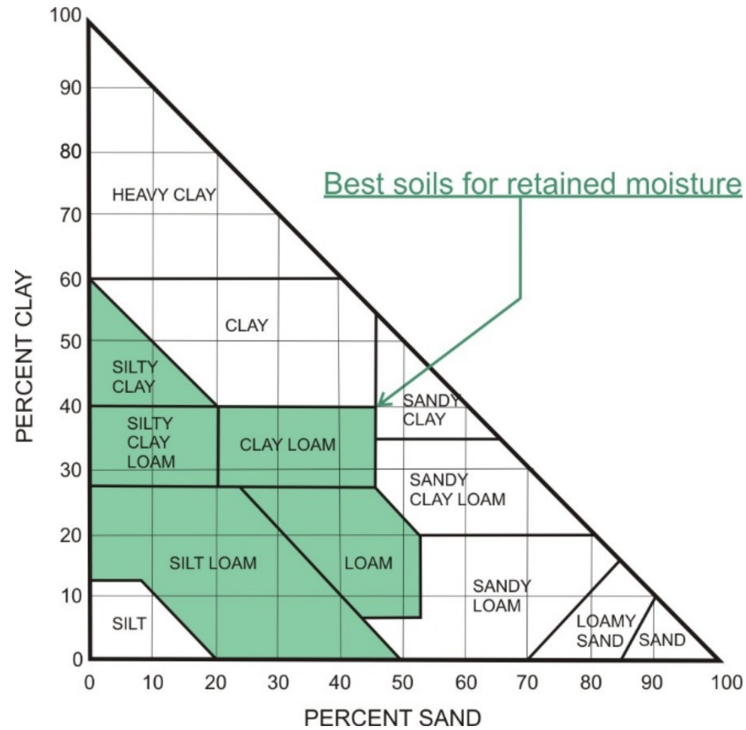


Figure 10 – Soil Texture

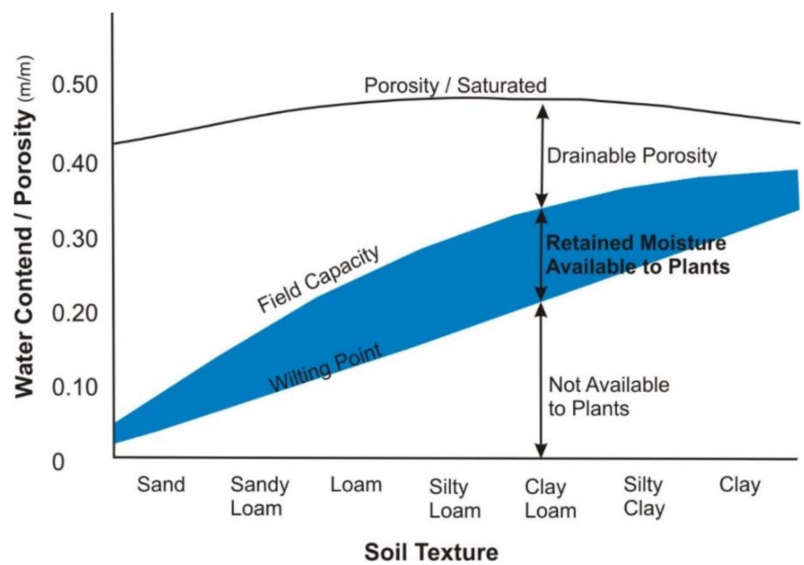


Figure 11 – Soil Porosity

Soil and Water Transmission: Important hydrological differences relate to how rapidly water flows through the soil and how much water can be retained by the soils which is a function of the soil texture (the blend of sand silt and clay).

This information is important in establishing the hydrology of the area and ultimately in sizing mitigation measures to manage environmental impacts of urban development.

It is important to identify here the difference between the rate of infiltration, water transmission, and permeability. These terms are often, and mistakenly, used incorrectly.

Infiltration is a measure of downward rate of water movement through a saturated soil.

Permeability on the other hand is defined using Darcy's Law where

V = K (Δ h/ L), velocity (m/s), where

K = hydraulic permeability, (m/s)

L = flow path length, (m)

Δ h = change in hydraulic head (hin – hout) over the distance L, (m)

and Q = VA, discharge rate of a measured volume over a time (m3/s)

A = flow area perpendicular to flow path L, (m2)

Permeability can be determined through laboratory testing as shown in Figure 12 opposite where flow rate and distances are measured.

> *It is clear that **permeability cannot be a measure of infiltration** in spite of the similar units of measure used to describe its properties.*

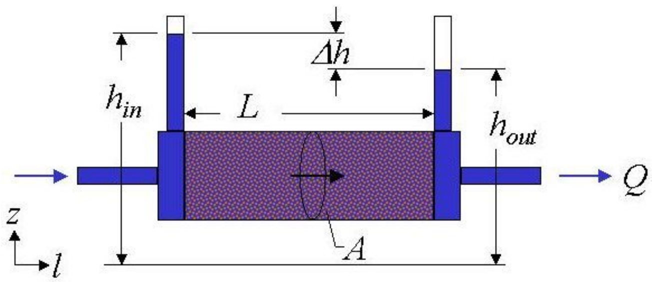


Figure 12 – Permeability Test

D. How to Establish Watershed Targets

Part C summarized the science behind the Water Balance Methodology. Next, this Part D draws on case study experience to lead the reader through the 'how-to' steps when applying the Water Balance Methodology to complete statistical analyses, verify a computer model for baseline conditions, and establish performance targets that would mitigate the impacts on stream health that would otherwise result from land development.

The objective herein is to provide a window into the thinking behind the analytical process.

Model Verification for Pre-Development

Verification of the computer model is essential to the process of accurately developing the watershed target values for a watershed.

The calculated flows from the model require a record of stream flow for comparison purposes during the model verification process.

Calibration of the computer model used for watershed simulation generally would involve matching the calculated watershed discharges with the recorded discharge values when applying the recorded climate data for the watershed.

When the climate station used for modelling purposes is not located within the watershed, there is the potential for differences in the specific events recorded at the climate gauge when compared to the recording gauge measuring stream discharge.

While the climate records from the selected climate recording station would be representative of the climate experienced within the watershed, there would be instances when recorded discharge events do not correspond perfectly with the recorded climate events.

This would occur, for example, if a localized storm were to be recorded at the climate gauge while no storm were to occur in the watershed as a whole. Alternatively, a storm in the watershed may not always be experienced at the climate gauge.

Another consideration is that there may not be a one-for-one correlation between recorded precipitation events and recorded stream flow events. However, the number and magnitude of the recorded events should be representative of annual and long-term hydrology.

When there are potential differences in precisely matching each event, a more pragmatic process would be necessary to demonstrate that the continuous simulation model is providing an accurate representation of the hydrologic response to the climate data.

The objective when verifying a hydrologic model would be to demonstrate that the predicted flood frequency is achieved along with the volumes of discharge measured by the stream gauge.

At a watershed scale the micro-differences in soils, vegetation and geography would not be identifiable. Rather, the watershed-based approach assumes an averaging of these across the watershed.

Some "watershed averaging" would be required in the absence of extensive climate data, stream flow records and detailed soils investigations. This approach has positive attributes as well as some potential drawbacks.

On the positive side, targets and standards would be developed and could be uniformly applied within the watershed.

A drawback is that some variations in local site conditions may not be recognized by the modeller. However, this would not have an impact upon the watershed analysis as the variability would be offset by a variation in the opposite direction on a different site within the watershed.

Therefore, using watershed average values would result in impact mitigation which would normally be appropriate when viewed in the context of the entire watershed.

Flood Discharge Verification: When climate records are not available for a watershed, a verification process would be necessary. This would involve matching the flood peaks as represented by a flood frequency analysis and the discharge volume as measured an annual basis.

Table 2 shows the flood frequency based upon a unit area discharge for a typical watershed and the calculated values as produced by the QUALHYMO computer model for a natural area.

Table 2 – Flood Frequency Comparison		
Return Period (years)	Model Discharge (L/s/ha)	Recorded Streamflow Discharge (L/s/ha)
200	17.0	17.1
100	16.0	16.3
50	15.0	15.4
25	14.0	14.3
10	12.0	12.4
5	10.0	10.7
3	9.0	9.0
2	7.0	7.4

For the example watershed, the estimation of flood discharges by the model was very close to the recorded values for watershed and replicates the discharges estimated from recorded stream flow.

Figure 13 presents a graphical presentation of this comparison. This very close correlation was a demonstration that the computer model had been verified and that it would provide an accurate representation of the stream flow and watershed discharge.

Stream Discharge & Watershed Precipitation: A critical factor for stream health is the quantity of water that enters a stream and discharges along it.

As the only source of water in the watershed is precipitation, the ratio of the precipitation to the total stream discharge is an important measure of the hydrology of the stream.

Table 3 on page 27 compares the recorded precipitation to the total stream discharge. The results of the Water Balance analysis for the example watershed are then summarized in Table 4 on page 27.

Discussion: The model verification process shows that an average of nearly 80% of the total precipitation that falls within the example watershed enters the stream.

Approximately 10% of precipitation would be captured by the vegetation and would evaporate from the surface of the plants or ground without infiltrating into the soil.

Of the rainfall that actually impacts the ground and infiltrates, only about 5% would enter deep groundwater with about 5% being transpired by the vegetation.

The remainder of the infiltrated water would discharge to the stream through interflow of very shallow groundwater from the soil moisture reservoir.

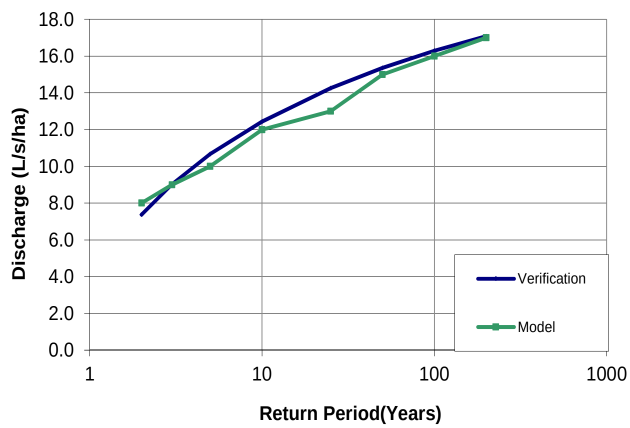


Figure 13 Model Verification Comparison

Figure 14 on page 28 presents a graphical view of the discharge when compared to precipitation. This shows that for years with smaller precipitation the corresponding rates of discharge are increasingly small.

Extension of the trend line beyond the limits of the data may lead to incorrect conclusions that no stream discharge would occur unless a precipitation threshold of approximately 6,000,000 m^3 were achieved.

Figure 15 on page 28 presents a second view of the information. It shows the discharge coefficient in relation to the precipitation total.

The information contained on this chart indicates that, in some years, there is more actual stream discharge than precipitation.

This is an indication that storage and release from groundwater occurs over a time period that is greater than a single year.

And furthermore, it indicates that the groundwater reservoir for this example watershed would be an important source of water for its tributary streams.

Table 4 - Water Balance of Watershed

Water Balance Components	Annual Volume
Precipitation	100%
Streamflow	80%
Surface Capture & Evaporation	10%
Flow to Deep Groundwater	5%
Plant Transpiration	5%

Table 3 – Precipitation and Stream Discharge

Year	Total Precipitation (m^3)	Watershed Total Stream Discharge (m^3)	Discharge Coefficient (Discharge / Precipitation)
1985	13,407,500	7,253,280	0.54
1986	19,827,600	14,916,528	0.75
1987	14,291,000	11,573,712	0.81
1988	15,128,000	9,965,376	0.66
1989	13,080,450	10,091,520	0.77
1990	20,376,300	16,051,824	0.79
1991	18,646,500	14,569,632	0.78
1992	16,222,300	14,601,168	0.90
1993	14,019,750	10,186,128	0.73
1994	16,595,850	14,506,560	0.87
1995	22,227,000	17,754,768	0.80
1996	20,683,200	15,137,280	0.73
1997	20,715,750	19,836,144	0.96
1998	20,311,200	20,939,904	1.03
1999	23,494,900	21,255,264	0.90
2000	15,097,000	8,293,968	0.55
2001	15,241,150	10,879,920	0.71
2002	15,921,600	N/A	N/A
2003	17,586,300	17,912,448	1.02
2004	17,505,700	12,362,112	0.71
2005	18,108,650	14,065,056	0.78
Ave.	17,547,033	14,107,630	0.80

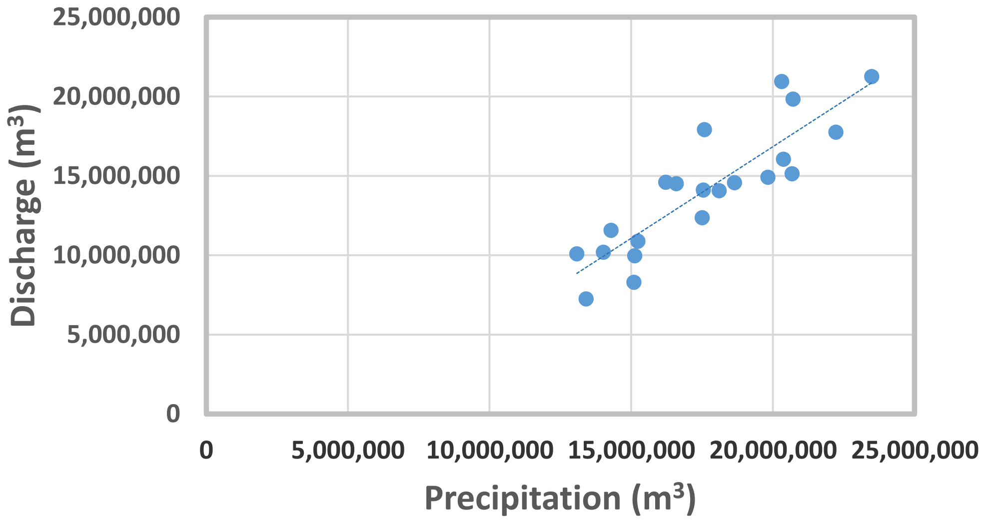


Figure 14 – Volume of Annual Precipitation versus Annual Stream Discharge

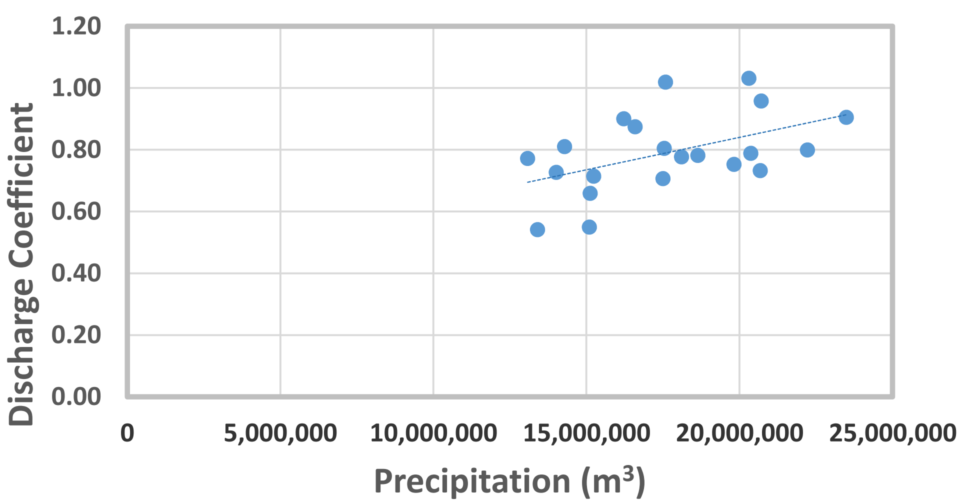


Figure 15 – Discharge Coefficient versus Precipitation

Application of Water Balance Methodology to Post-Development Watershed Condition

Describing the hydrologic operation of a watershed under post-development conditions is the starting point when creating a Rainwater Management Plan that would mitigate impacts caused by land development and infrastructure servicing.

The primary impacts that result in changes in the hydrology of a watershed result from the total imperviousness of the watershed.

Framework for Analysis: The goal when applying the Water Balance Methodology is to answer this question: *"How can the developments within the subject watershed mimic a natural watershed?"*

The natural watershed would have the flood frequency and total volumes of stream discharge. Hence, the objective of a watershed analysis would be to identify the necessary infrastructure components and systems in new and redeveloping areas that would mimic the natural watershed hydrologic conditions.

As discussed in Part B, the objective of Rainwater Management is to mimic the amount of water infiltrated to groundwater under natural watershed conditions, ensure interflow connectivity to the stream, and maintain or decrease potential flood risks. This approach would provide a level of assurance that:

- Excess water would not be directed to the ground, and would avoid potentially adverse impacts of excessive groundwater levels and discharges in downstream areas of the watershed.
- Low summer flows would be maintained with an operating interflow system.
- Downstream properties would not suffer an increased risk of flooding or flood damages.

Measures of Success: The criteria that are used to measure success are repeated as follows:

- No increase in magnitude of flood events,
- No increase in the duration of Q_2 and Q_5 discharge rates to prevent increased stream erosion, and
- No increase in the losses to deep groundwater.

For this case study application, the focus of the analysis was on maintaining the flood frequency and the water balance within the watershed for a range of development defined by the amount of impervious surface.

Given the travel time of rainwater to the stream, the very short duration of time within a pipe system was neither a critical nor important factor in the assessment. Rather, it is the processes that occur over a period of days and seasons that were more critical. Hence, a model that focusses upon those longer term processes was more appropriate.

The Water Balance Methodology was applied in the example watershed by examining the stream discharges to determine what was happening and to identify the methods required to protect stream health.

The assumed infiltration rate from the rainwater retention systems of 2.5 cm per hour at a depth of approximately 1.5 m was based upon a published soils report. The flow to ground was assessed using a sensitivity analysis which combined the retention volume, infiltration area and the base flow release rate to minimize the retention / infiltration system size. This allowed the least cost system to mitigate the impacts of urban development.

The Underflow, or Base Flow Release Rate, was set at the mean annual stream discharge value to allow any stored volume to augment the low summer flows in the stream. This rate of 0.5 L/s/ha provided a direct connection and an assurance that the volumes would be controlled and released in a manner that would mimic the interflow in the natural watershed.

The overflow rates were controlled to provide a post development flood frequency equivalent to the natural watershed. The 2, 5, and 100 year return period discharge rates were used for the storage release as is typical in a number of local municipalities. Controlling discharges to these rates would eliminate the risk of increased flooding in downstream reaches of the watershed streams.

One of the watershed targets, the Base Flow Release Rate was established at 0.5 L/s per ha and the remaining two target values were established using an iterative process. The other two target values were:

- The **Retention Volumes** required to limit the flood frequency of discharges, to allow time for infiltration to ground, and to provide a volume to augment low stream discharges.
- The surface contact area of the infiltration systems, **Infiltration Area**, required to achieve the desired volumes of infiltration to deep groundwater so as to mimic predevelopment conditions and achieve the water balance of discharges to the stream, surface evaporation and losses to deep groundwater.

  In this example, the area should not be overly large to prevent excess discharge to deep groundwater. Also, this area should not be so small that it would reduce the volumes discharging to deep groundwater.

A statistical analysis of both the annual maximum discharges and the annual maximum retention volumes yielded the values associated with a range of return periods and probabilities of occurrence.

A number of alternative retention / infiltration system sizes were assessed to establish the minimum size that would achieve the performance criteria. The minimum size met the stated criteria and objectives with a minimum of installed infrastructure. Hence, this approach would provide a system that would meet the goals and objectives at a minimum cost.

Development Areas: The assessment of high imperviousness areas was completed and the results are summarized below in Table 5.

Table 5 – Impacts to Flood Frequency

Return Period (years)	Natural Discharge (L/s/ha)	Uncontrolled Discharge (L/s/ha)	Controlled Discharge (L/s/ha)
200	17.1	45.0	17.0
100	16.3	41.0	17.0
50	15.4	37.0	16.0
25	14.3	33.0	15.0
10	12.4	29.0	14.0
5	10.7	25.0	13.0
3	9.0	23.0	12.0
2	7.4	21.0	11.0

The results of the storage / infiltration system optimization to determine the minimum system size established that the target release discharge rates and Water Balance could be achieved.

The systems would provide downstream flood protection and would eliminate the increase in flood risk to the watershed and property that would otherwise result from land development.

The flood frequencies of a natural watershed are compared in Table 5 with the flood frequency of a developed watershed without mitigation and a developed watershed with mitigation.

Figure 16 on page 31 presents a graphical depiction of this information.

Figure 17 on page 31 then shows how the optimized storage and infiltration system for the developed areas can be demonstrated in the discharge exceedance relationship.

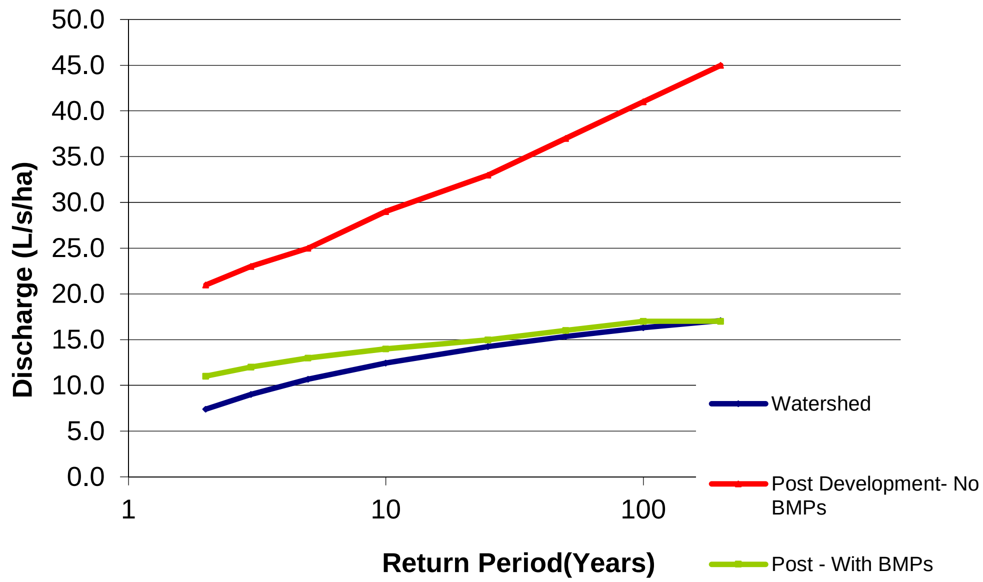


Figure 16 – Flood Discharge Estimate

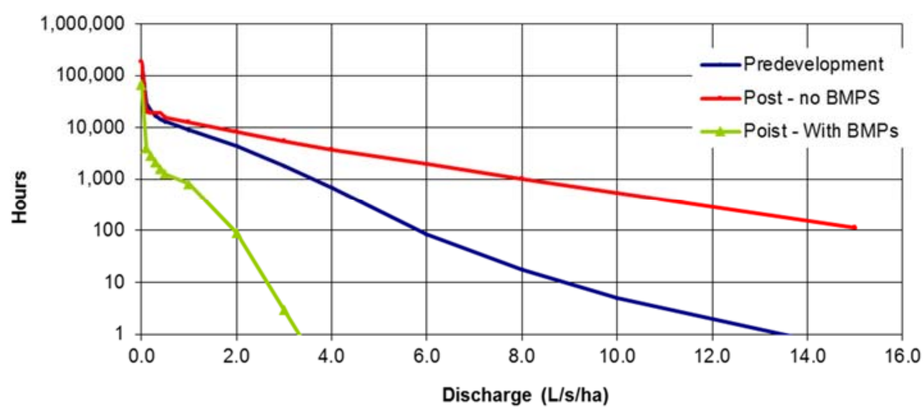


Figure 17 – Discharge Exceedance

For the example watershed and case study application described herein, the optimized system would have the following target characteristics:

1. Retention Volume = 365 m^3 per ha of development,
2. Base Flow Release Rate = 0.5 L/s per ha, and
3. Infiltration Area = 100 m^2 per ha of development area.

The results and their significance for this example watershed are described as summarized below.

The "post development with BMPs" plot on Figure 17 (on page 32) indicates the number of hours during the simulation that the specific discharge rates were exceeded.

The "post development with no BMPs" plot shows a very great increase in the number of hours for large discharge rates.

Also, Figure 16 shows that the addition of the BMPs (i.e. source controls) reduced the magnitude of the very large discharges, while maintaining the anticipated frequency of flood discharges.

Due to the scale of the chart axis on Figure 17, there is some compression of the low discharge and high duration values.

The small and almost continuous discharges account for most of the total volume of discharge.

The total volume of discharge to the stream was maintained and slightly increased while decreasing the duration of the larger magnitude discharge events.

This would reduce the potential for stream erosion in addition to providing increases to the valuable low flows that are critical to aquatic health.

Watershed Targets

In summary, the results of the rainwater analysis using the Water Balance Methodology provided the basis for establishing the three targets necessary to achieve the watershed health objectives for the example watershed, as defined by the percentage of total imperviousness.

For emphasis, as well as for purposes of highlighting the order-of-magnitude of the numbers used for system sizing, the three watershed-based targets are repeated below:

1. Retention Volume = 365 m^3 per ha of development,
2. Base Flow Release Rate = 0.5 L/s per ha, and
3. Infiltration Area = 100 m^2 per ha of development area.

This combination would allow the infiltration to deep groundwater, which is important in the watershed, and would also maintain the Interflow System of shallow groundwater storage and release which is critical to the hydrologic cycle on a seasonal basis.

The volumes of storage were estimated with the continuous simulation model to account for longer storage times and multiple storm events.

The combination of storage infiltration and baseflow release would replicate the natural watershed flood frequency and water balance in the watershed.

These values are an accurate representation of the retention volumes required to achieve the goals and objectives of the watershed to achieve the Water Balance and to mimic the pre-development flood risks.

E. References

Part E provides a starting point for interested readers to learn more about the regulatory context for the *Beyond the Guidebook Primer Series.* The scope of each Primer is described and links are provided so that copies can be downloaded from the waterbucket.ca website. Launched in 2007, "Beyond the Guidebook" is an ongoing initiative.

Beyond the Guidebook Primer Series

To date, the Partnership for Water Sustainability has released four guidance documents in the Beyond the Guidebook Primer Series. They are listed below:

- **Primer on Rainwater Management in an Urban Watershed Context:** Provides engineers and non-engineers with a common understanding of how a science-based approach to rainwater management has evolved since the mid-1990s. *Released in November 2011.*
- **Primer on Urban Watershed Modelling to Inform Local Government Decision Processes:** Provides engineers and non-engineers with guidance in three areas: setting performance targets, defining levels-of-service, and application of screening / scenario tools. *Released in November 2011.*
- **Primer on Integrated Rainwater and Groundwater Management for Lands on Vancouver Island and Beyond:** Provides engineers and non-engineers with a common understanding of the links between rainfall, groundwater movement and surface flows in sustaining aquatic life. *Released in May 2012.*
- **Primer on Land Development Process in British Columbia:** Illustrates how to seamlessly integrate the legal and administrative parts of the Land Development Process through the designing with nature and rainwater management lens. *Released in September 2013.*

Historical Perspective: "A decade ago, looking at rainfall differently led the Province to initiate a change in the way rainwater is managed. In 2002, introduction of the Water Balance Methodology was a catalyst to trigger actions on the ground that would maintain or restore the natural Water Balance. The initial priority was to reduce surface runoff volume," states Peter Law, Chair of the Guidebook Steering Committee. Formerly with the Ministry of Environment, he is a founding Director of the Partnership.

"Then, in 2007, the Beyond the Guidebook initiative enhanced the Water Balance Methodology to address the relationships between volume of rainwater captured and held on site, release to interflow, and resulting flow rates in streams."

"Now, Beyond the Guidebook has addressed the relationship between volume of rainwater captured and groundwater recharge. Application of the Water Balance Methodology enables local governments to establish a set of watershed-specific and integrated Performance Targets."

Integration with Land Development Process: An integrated design for land development, rainwater management and groundwater recharge would balance the annual volume necessary for interflow storage with the annual volumes necessary to: sustain the duration of interflow; and allow infiltration to groundwater.

Achieving this Water Balance outcome depends on a clear delineation and common understanding of expectations, roles and responsibilities of those involved to ensure a seamless progression from Watershed Planning through to Rezoning, Land Subdivision and Building Construction.

Links

Core concepts presented in the *Beyond the Guidebook Primer Series* provide an educational foundation for rainwater management in a watershed context. Copies of the Primers as well as other related guidance documents may be downloaded by following the links below:

A Watershed / Landscape-Based Approach to Community Planning (2002)
http://www.waterbucket.ca/rm/sites/wbcrm/documents/media/26.PDF

Stormwater Planning: A Guidebook for British Columbia (2002)
http://www.env.gov.bc.ca/epd/mun-waste/waste-liquid/stormwater/index.htm

Beyond the Guidebook: Context for Rainwater Management and Green Infrastructure in British Columbia (2007)
http://www.waterbucket.ca/rm/sites/wbcrm/documents/media/37.pdf

Beyond the Guidebook 2010: Implementing a New Culture for Urban Watershed Protection and Restoration in British Columbia (2010)
http://www.waterbucket.ca/cfa/sites/wbccfa/documents/media/403.pdf

Primer on Rainwater Management in an Urban Watershed Context (2011)
http://www.waterbucket.ca/rm/sites/wbcrm/documents/media/239.pdf

Primer on Urban Watershed Modelling to Inform Local Government Decision Processes (2011)
http://www.waterbucket.ca/rm/sites/wbcrm/documents/media/243.pdf

Primer on Integrated Rainwater and Groundwater Management for Lands on Vancouver Island and Beyond (2012),
http://waterbucket.ca/wp-content/uploads/2012/05/3_Primer-on-Integrated-Rainwater-Groundwater-Management-for-Lands-on-Vancouver-Island_April-2012.pdf

The Genesis of Water-Centric Planning in British Columbia

Published in March 2002 by Metro Vancouver, *A Watershed / Landscape-Based Approach to Community Planning* was developed by an interdisciplinary working group under the aegis of Metro Vancouver's Technical Advisory Committee. In its simplest expression a watershed / landscape-based approach is aimed at the:

- Protection of people and property from natural hazards.
- Protection and conservation of self-sustaining ecosystems.
- Continuation and growth of resource-based economic activity.
- Provision of an affordable, sustainable and maintainable infrastructure.

The underpinning premise is that resource, land use and community design decisions will be made with an eye towards their potential impact on the watershed. Hence, the *Watershed/Landscape-based Approach* was incorporated as an original element of the **Water Sustainability Action Plan for British Columbia**. This element subsequently morphed into *Water-Centric Planning*. By definition, this means planning with a view to water – whether for a single site or the entire province. At the core of water-centric planning is a water balance way-of-thinking and acting.

Stormwater Planning: A Guidebook for British Columbia is a prime application of the watershed / landscape-based approach. In the Guidebook context, what happens at the scale of the individual parcel and street affects what happens at the watershed scale. Released in 2002, the Guidebook was the catalyst that resulted in BC being recognized internationally as a leader in implementing a natural systems approach to rainwater management. The Guidebook's premise that land development and watershed protection can be compatible represented a radical shift in thinking in 2002.