RE-INVENTING URBAN HYDROLOGY IN BRITISH COLUMBIA: RUNOFF VOLUME MANAGEMENT FOR WATERSHED PROTECTION

Kim A Stephens, PEng, KSA Consultants Ltd[1], West Vancouver, British Columbia
Ted van der Gulik, PEng, BC Ministry of Agriculture, Food and Fisheries[2], Abbotsford , British Columbia
Laura Maclean, Environment Canada[3], North Vancouver, British Columbia
Ed von Euw, PEng, Greater Vancouver Regional District[4], Burnaby, British Columbia

ABSTRACT

There is a logical link between changes in hydrology and impacts on watershed health, whether those impacts are in the form of flooding or aquatic habitat degradation. The link is the volume of surface runoff that is created by human activities as the result of alteration of the natural landscape (i.e., through removal of soils, vegetation and trees). When trees, vegetation and soils are replaced by roads and buildings, less rainfall infiltrates into the ground or is taken up by vegetation, which results in more rainfall becoming surface runoff. The key to protecting urban watershed health is to maintain the water balance as close to the natural condition as is achievable and feasible by preserving and/or restoring soils, vegetation and trees. But accomplishing this requires major changes in the way we approach urban drainage and in the way we develop land. Drainage engineers have traditionally thought of reconciling pre- and post-development runoff in terms of flow rates, not volumes. At the site level, however, we need to focus on how much rainfall volume has fallen, how to capture the excess, and what to do with it. The Province of British Columbia in the Pacific Northwest is leading the way in North America in developing and implementing innovative criteria and methodologies for reducing excess runoff volumes at the source, where rain falls. Science-based performance objectives and targets have been established to mimic the hydrology of a natural forest. Performance targets are being implemented through demonstration projects, notably at two large-scale 'sustainable communities':

- **UniverCity** - A high-density urban community that is being developed by Simon Fraser University to house 10,000 people at the top of Burnaby Mountain in the heart of the Greater Vancouver urban region

- **Headwaters** - A medium-density residential community that is being developed to house 14,000 people in the East Clayton area of the City of Surrey, a suburban municipality in the Greater Vancouver region that is the Province's second largest city (with a population 300,000).

Through an Inter-Governmental Partnership, a decision support tool called the ***Water Balance Model for British Columbia*** is being enhanced to help local governments integrate land use planning with volume-based analysis of stormwater management strategies. The WBM is used to evaluate the potential for developing or redeveloping communities that function hydrologically like naturally forested or vegetated systems. The tool creates an understanding of *how*, and *how well*, stormwater source control strategies for runoff reduction would be expected to achieve watershed protection and/or restoration objectives.

What Can be Done at the Site Level to Protect Watershed Health

The Logical Link

There is a logical link between changes in hydrology and impacts on watershed health, whether those impacts are in the form of flooding or aquatic habitat degradation. The link is the volume of surface runoff that is created by human activities as the result of alteration of the natural landscape. The key to protecting urban watershed health is to maintain the water balance as close to the natural condition as is achievable and feasible by preserving and restoring soils, vegetation and trees. Accomplishing this requires major changes in the way we approach urban drainage and in the way we develop land. In the future, there will be more runoff volume to manage in the urban regions of British Columbia due to the combination of:

- **Population Growth** – resulting in more land development plus re-development and densification of existing urbanized areas
- **Climate/Weather Change** – likely resulting in both increased seasonal rainfall and more frequent 'cloudbursts'

The financial and staff resources of local government are limited. Therefore, those resources must be invested wisely to maximize the return-on-effort. Common sense says that the best return will be at the site level where local government exerts the most influence, and can therefore make a cumulative difference at the watershed scale. The term 'source control' is used in this context to describe the suite of strategies available to capture and retain rainfall volume at the development site.

Water Balance Model for British Columbia

The practice of low impact development often involves efforts to reduce the impacts of stormwater runoff using various types of source controls designed to minimize runoff volumes. The effectiveness of these source controls varies with their design, with precipitation patterns, and with soil type, among other factors. The overall performance of these source controls is obviously of great interest to developers, homeowners and local governments alike.

In June 2002, the British Columbia Ministry of Water, Land and Air Protection published the document *Stormwater Planning: A Guidebook for British Columbia*[5] The Guidebook lays out targets for reducing runoff volume to achieve watershed protection objectives. The Greater Vancouver Regional District (GVRD) recently completed a study to evaluate the effectiveness of a suite of such stormwater source controls with these targets in mind. The results of the GVRD study are incorporated in the Guidebook.

In order to answer questions about the effectiveness of source controls, the GVRD's consultant developed and applied a water balance model, an interactive tool that can simulate the performance of impervious controls, absorbent landscaping, infiltration facilities, green roofs and rainwater harvesting under various development scenarios. After exploring the capabilities of the model, a group of municipal, regional, provincial and federal government representatives saw the potential to use it to integrate volume-based analysis of stormwater management strategies into land use planning throughout British Columbia.

An Inter-Governmental Partnership was struck in the summer of 2002 to secure access to the model and develop a more user-friendly version, to be called the *Water Balance Model for British Columbia*. The Inter-Governmental Partnership is chaired by the BC Ministry of Agriculture, Food and Fisheries, and co-chaired by Environment Canada. The GVRD is the host organization, providing logistical support as required. A number of municipalities are currently engaged in the project, and others who share an interest are invited to join as the project evolves. The end result will be a user-friendly model that can be used to inform and evaluate land use planning decisions for their ability to meet stormwater management objectives, both at the scale of the individual development site and the watershed.

In Phase 1, to be completed by June 2003, the existing water balance model is being converted to a new operating platform complete with graphical user interface (GUI) that will allow for more efficient data storage procedures, faster performance, increased portability, more flexible output options, and easier technical enhancement as the state-of-the-science evolves.

Members of the Inter-Governmental Partnership are participating actively in enhancement of the model and graphic user interface, and will be the first recipients of the resulting *Water Balance Model for British Columbia* (hereinafter referred to as 'the WBM'). Subsequent project phases may involve field testing and calibration of key model assumptions, and linking the model to regional GIS and precipitation databases.

Project Vision for WBM Application

A "project vision" is the image or understanding of what the project will accomplish, and what will be different at the end of the project. The British Columbia Guidebook demonstrates how to establish science-based performance objectives to mimic the hydrology of a natural forest. This outcome can be achieved through a combination of rainfall capture and runoff control techniques. The WBM is an extension of the Guidebook, and is intended to be a 'decision support /scenario modeling tool' that will help local governments and landowners make better land development decisions.

The over-arching project goal in enhancing the WBM is to facilitate changes in land development practices so that in future sites and subdivisions will be designed to function hydrologically like a natural forest that has 10% impervious area. To accomplish this goal, the GUI (graphical user interface) for the WBM must be easy to understand and simple to use.

The enhanced WBM will be an *Access*-based, web-accessible platform. There are two audiences for the model output: engineers and planners who want detailed data; and elected councils and the public who want only the big picture. Account access privileges will be tiered as follows:

- **Public access** will be to the completed product and with limited model flexibility.
- **Project partners** will have access to developmental models, including opportunities to download model databases.
- **Scientific authority** will have access to manipulate algorithms, manage and update user profiles.

A distinguishing feature of the WBM is the level of detail that it enables with respect to site design. This provides a significant capability to test 'what if' scenarios related to zoning bylaw changes.

Reducing the Volume of Runoff

Drainage engineers have traditionally thought in terms of flow rates rather than volumes. In fact, at the site level, we need to focus on how much rainfall volume has fallen, how to capture the excess, and what to do with it. British Columbia is leading the way in North America in developing and implementing innovative criteria and methodologies for reducing excess runoff volumes at the source, where rain falls.

What the Science is Telling Us

A science-based understanding of how land development impacts watershed hydrology and the functions of aquatic ecosystems provides a solid basis for making decisions to guide early action where it is most needed.

The science is explicitly telling us that major biophysical changes occur once the impervious percentage of a watershed reaches about 10%. Beyond this threshold, a change in the water balance may trigger be expected to trigger watercourse erosion, which in turn would degrade or eliminate aquatic habitat. This implies that, where urban land use densities approach this threshold level, the focus should be on what needs to be done at the site level to effectively mimic a watershed with less than 10% impervious area and reduce runoff volumes to similar levels. As documented in the British Columbia Guidebook, the science also indicates that capturing rainfall at the source for the frequent, lower intensity events will in large part help maintain or restore the natural Water Balance.

Research on the Effects of Urbanization on Fish

Aquatic habitats that influence the abundance of salmon and trout are the outcome of physical, chemical and biological processes acting across various scales of time and space. The environmental conditions that result from these processes provide the habitat requirements for a variety of species and life history stages of fish and other stream organisms.

Decline of Wild Salmon

Whether in pristine or heavily urbanized watersheds, the basic requirements for survival of salmon and trout are the same. These basic requirements include: cool, flowing water free of pollutants and high in dissolved oxygen; gravel substrates low in fine sediment for reproduction; unimpeded access to and from spawning and rearing areas; adequate refuge and cover; and sufficient invertebrate organisms (insects) for food.

Over the past century, salmon have disappeared from over 40% of their historical range, and many of the remaining populations are severely depressed (Nehlsen *et al*. 1991). There is no one reason for this decline. The cumulative effects of land use practices, including timber harvesting, agriculture and urbanization have all contributed to significant declines in salmon abundance in British Columbia (Hartman *et al*. 2000).

Puget Sound Findings

In the Puget Sound region of Washington State, a series of research projects have been underway for over 10 years to identify the factors that degrade urban streams and negatively influence aquatic productivity and fish survival. The streams and sites under examination represent a range of development intensities from nearly undisturbed watershed conditions to watersheds that are almost completely developed in residential and commercial land uses (Horner 1998).

For each watershed, detailed continuous simulation hydrologic models were prepared and calibrated to rainfall and runoff data. Physical stream habitat conditions, water quality, sediment composition, sediment contamination, and fish and benthic organism abundance and diversity were measured and documented for each site.

The studies found that stream channel instability is a result of the urbanization of watershed hydrology. The alteration of a natural stream's hydrograph is a leading cause of change in instream habitat conditions. The physical and biological measures generally changed most rapidly during the initial phase of watershed development, as total impervious area changed from 5% to 10%. With more intensive urban development in the watershed, habitat degradation and loss of biological productivity continues, but at a slower rate (Horner 1998).

The role of large woody debris in streams was recognized as a key factor in creating complex channel conditions and habitat diversity for fish. Both the prevalence and quality of large woody debris declined with increasing urbanization. In addition, development pressure has had a negative impact on streamside (riparian) forests and wetlands, which are critical to natural stream functioning.

The impacts of poor water quality and concentrations of metals in sediments did not show significant impact to aquatic biological communities until urbanization increased above approximately 50% total impervious area.

Instream habitat conditions had a significant influence on aquatic biota. Streambed quality, including fine sediment content and channel stability, affected the benthic macro invertebrate community (as measured by the multi-metric Benthic Index of Biological Integrity (B-IBI) developed by Karr (1991)). Negative impacts to fish and fish habitat from sedimentation related to urban development have been documented (Reid *et al*. 1999). The composition of the salmonid community was also influenced by a variety of instream physical and chemical attributes.

Summary of Puget Sound Findings

Alterations in the biological community of urban streams are a function of many variables representing conditions that are a result of both immediate and remote environmental conditions in a watershed. The research findings clearly demonstrate that the most important impacts of urbanization that degrade the health of streams, in order of importance, are:

- Changes in hydrology
- Changes in riparian corridor
- Changes in physical habitat within the stream, and
- Water quality

British Columbia Findings

Within the Georgia Basin of British Columbia, population pressures have caused urban sprawl, resulting in habitat loss (B.C. MELP 2000). Freshwater fish population declines in this region are a partial result of rapidly expanding urban development (Slaney 1996).

The aquatic ecosystems most directly affected by urbanization are the small streams and wetlands in the lowlands of the Georgia Basin and lower Fraser River Valley. These ecosystems are critical spawning and rearing habitat for several species of native salmonids (both resident and anadromous). In the Lower Fraser Valley, 71% of streams are considered threatened or endangered, and a further 15% have been lost altogether as a result of urban growth (B.C. MELP 2000).

A Science-Based Understanding

The widespread changes in thinking about stormwater impacts that began in the mid to late 1990s reflect new insights in two areas:

- Hydrology, and
- Aquatic ecology

These new insights are the result of improved understanding of the causes-and-effects of changes in hydrology brought about by urban development, and the consequences for aquatic ecology. As we gain new knowledge and understanding of what to do differently, a central issue for watershed protection becomes:

- What is the proper balance of science and policy that will ensure effective implementation and results?

King County in Washington State addressed this question in 1999 as part of the Tri-County response to the listing of chinook salmon as an endangered species in Puget Sound. A significant finding was that scientists and managers think and operate differently. This led to the following recommendations:

- An interface is needed to translate the complex products of science into achievable goals and implementable solutions for practical resource management. This interface is what we now call a science-based understanding.
- A reality for local government is that management decisions need to be made in the face of significant scientific uncertainties about how exactly ecosystems function, and the likely effectiveness of different recovery approaches.
- The best path forward is a dynamic, adaptive management approach that will allow local governments to monitor the effectiveness of their regulatory and management strategies and make adjustments as their understanding grows.
- In a co-evolving system of humans and nature, surprises are the rule, not the exception; hence, resilience and flexibility will need to be built into the management system.

Through a science-based understanding of the relationship between hydrology and aquatic ecology, the British Columbia Guidebook has derived a comprehensive set of water balance, hydrology/water quality and biophysical objectives that provide an over-arching framework for watershed protection.

Eliminate the Source of Problems

Understanding the cause-and-effect relationship between hydrology and biology has provided the basis for a paradigm-shift in stormwater management in British Columbia - from a traditional approach that only deals with consequences, to one that also eliminates the sources of problems.

Dealing with consequences is the traditional end-of-pipe engineering approach that is reactive in solving problems after the fact. Eliminating the causes of problems involves an integrated approach to source-control that is proactive in preventing problems from occurring.

In addition to being a partner in both the Guidebook and WBM initiatives, the GVRD has also developed *Integrated Stormwater Management Planning - Terms of Reference Template*[6] as part of its regulatory commitment to the Province. The Template supports and encourages the use of the water balance methodology for both greenfield and retrofit watersheds, particularly to assess the effectiveness of stormwater source controls.

Regulatory Overview

In British Columbia, the *Local Government Act* has vested the responsibility for drainage with municipalities. With the statutory authority for drainage, local governments can be held liable for downstream impacts that result from changes to upstream drainage patterns – both volume and rate. The *Act* also enables local governments to be proactive in implementing stormwater management solutions that are more comprehensive than past practice. Furthermore, a stormwater component is a requirement for approved *Liquid Waste Management Plans* (LWMPs). Guidelines for developing an LWMP were first published in 1992. LWMPs are created by local governments under a public process in co-operation with the Province.

An Official Community Plan Provides the Foundation for a Stormwater Management Plan

There is a clear link between the land use planning required of local governments in the *Local Government Act* and the LWMP process. In most cases where an *Official Community Plan* (OCP) is in place, the local government planning statement (bylaw) will form the basis for an LWMP. The purposes of an LWMP are to minimize the adverse environmental impacts of the OCP and ensure that development is consistent with Provincial objectives.

OCPs tend to be led by planners, with input from engineers on infrastructure sections. LWMPs tend to be led by engineers, with little or no input from planners. Both processes involve approval by a Local Council or a Regional Board. In some cases, an LWMP process may be a trigger that focuses attention on stormwater management. In other cases, public concern related to flooding or habitat loss may be the trigger. An OCP public process may communicate public interest in raising local environmental and habitat protection standards. Whatever the motivation, at the end of the process an OCP should include goals and objectives for stormwater management. These goals and objectives, or a variant of them, might first reside in an LWMP, and then be adapted to the OCP in the next review process. Or they may originate in the OCP process, and then be detailed through an LWMP. Either approach is entirely acceptable.

Integrated Stormwater Management Planning

In British Columbia, the term *Integrated Stormwater Management Plan* (ISMP) has gained widespread acceptance by local governments and the environmental agencies to describe a comprehensive approach to stormwater planning. The purpose of an ISMP is to provide a clear picture of how to be proactive in applying land use planning tools to protect property and aquatic habitat, while at the same time accommodating land development and population growth.

Stormwater Planning: A Guidebook for British Columbia

Stormwater management in British Columbia is a key component of protecting quality of life, property and aquatic ecosystems. The science and practice of stormwater management is constantly evolving, in British Columbia and around the world. Within British Columbia, the range of stormwater management activity varies from completely unplanned in many rural areas, to state-of-the-art in some metropolitan centres. The purpose ***of Stormwater Planning: A Guidebook for British Columbia*** is to provide a framework for effective stormwater management that is usable in all areas of the province.

The Guidebook presents a methodology for moving from planning to action that focuses the limited financial and staff resources of governments, non-government organizations and the development community on implementing early action where it is most needed. The Guidebook is organized in three parts: Part A defines the problem, Part B provides solutions and Part C defines the process. The Guidebook provides a comprehensive understanding of the issues and a framework for implementing an integrated approach to stormwater management. Case study experience underpins the approaches and strategies that are presented in the Guidebook.

Guidebook Overview

Part A – Why Integrated Stormwater Management?

Part A identifies problems associated with traditional stormwater management and provides the rationale for a change from traditional to integrated stormwater management. Some guiding principles of integrated stormwater management are introduced. Part A also builds a science-based understanding of how natural watersheds function and how this function is affected by land use change.

Part B – Integrated Stormwater Management Solutions

Part B outlines the scope and policy framework for integrated stormwater management, and presents a three-step, cost-effective methodology for developing stormwater solutions.

Step #1 - Identify At-Risk Drainage Catchments: A methodology is presented for identifying at-risk drainage catchments to focus priority action. The methodology relies on a roundtable process that brings together people with knowledge about future land use change, high-value ecological resources and chronic flooding problems. The key is effective integration of planning, engineering and ecological perspectives.

Step #2 - Set Preliminary Performance Targets: A methodology is presented for:

- Developing watershed performance targets based on site-specific rainfall data, supplemented by streamflow data (if available) and on-site soils investigations

- Translating these performance targets into design guidelines that can be applied at the site level to mitigate the impacts of land development

This portion of the Guidebook also documents British Columbia case studies of stormwater policies and science-based performance targets applied to both greenfield and urban retrofit scenarios.

Step #3 - Select Appropriate Stormwater Management Site Design Solutions: Guidance is provided for selecting appropriate site design solutions to meet performance targets source control and runoff conveyance. Case study examples are provided of:

- Design and performance of stormwater source controls for various land uses
- Watershed scale modelling of the effectiveness of site design solutions

Part C – Moving from Planning to Action

Part C describes a process that will lead to better stormwater management solutions. The role and design of action plans are introduced to bring a clear focus to what needs to be done, with what priority, by whom, with related budgets. Tips are provided on processes that produce timely and high-quality decisions. Part C also provides guidance for organizing an administrative system and financing strategy for stormwater management. A final section on building consensus and implementing change describes how to develop a shared vision and overcome barriers to change.

Two acronyms, *ADAPT* ***and*** *CURE****, provide a useful summary of the principles and elements of integrated stormwater management, as described below.***

ADAPT – The Guiding Principles of Integrated Stormwater Management

The acronym **ADAPT** summarizes five guiding principles for integrated stormwater management. The Guidebook is based upon these five principles.

Agree that stormwater is a resource

Design for the complete spectrum of rainfall events

Act on a priority basis in at-risk drainage catchments

Plan at four scales – regional, watershed, neighbourhood & site

Test solutions and reduce costs by adaptive management.

Guiding Principle 1 - Agree that Stormwater is a Resource

Stormwater is no longer seen as just a drainage or flood management issue but also a resource with both benefits and deleterious effects on:

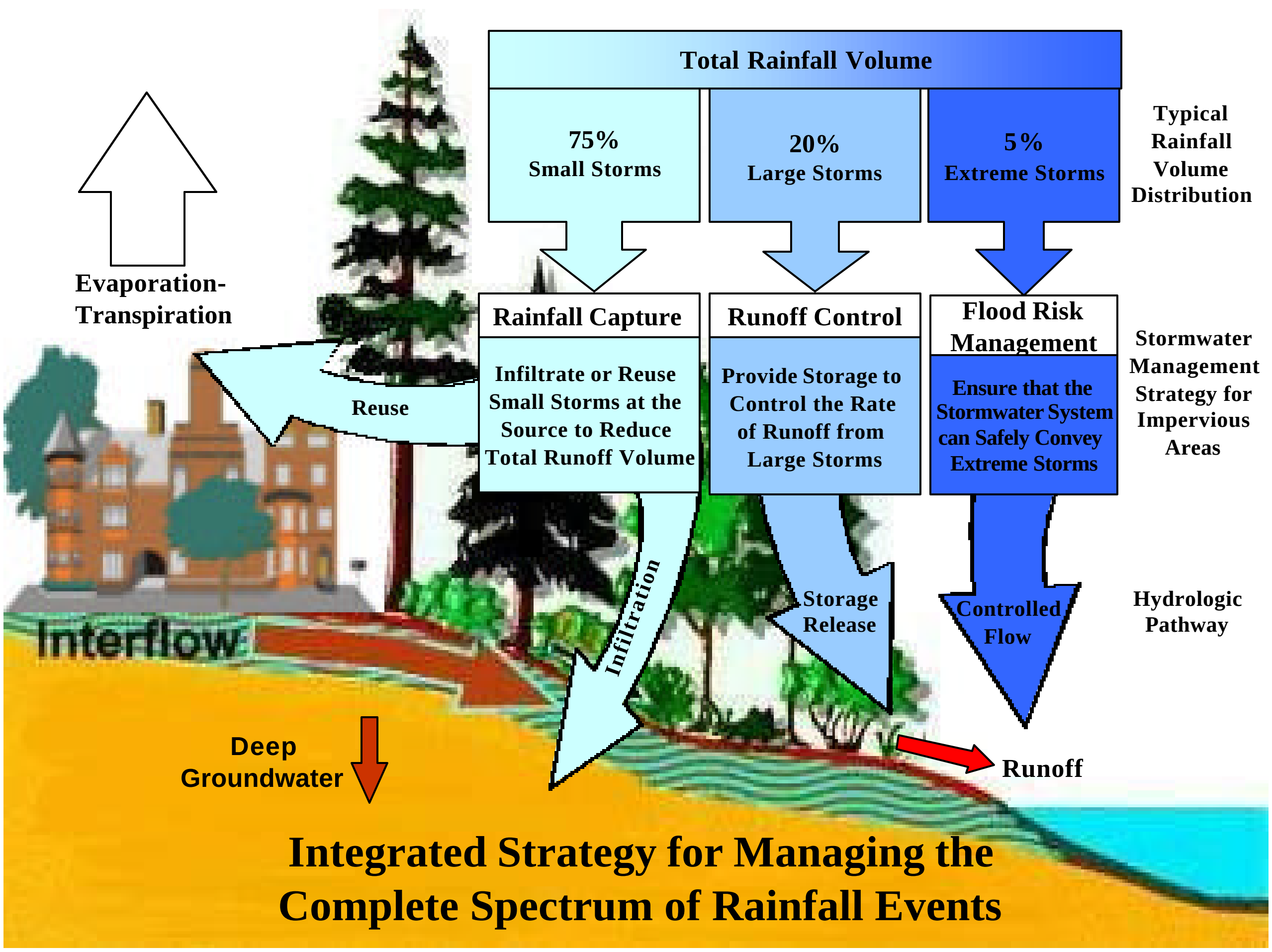
- fish and other aquatic species
- groundwater recharge (for both stream summer flow and for potable water)
- water supply (e.g., for livestock or irrigation)
- aesthetic and recreational uses

Guiding Principle 2 - Design for the Complete Spectrum of Rainfall Events
Integrated stormwater solutions require site design practices that provide:

- **Rainfall Capture for Small Storms (runoff volume reduction and water quality control)** – Capture the low intensity, frequently occurring rainfall events at the source (building lots and streets) for infiltration and/or re-use.
- **Runoff Control for Large Storms (runoff rate reduction)** – Store the runoff from the infrequent large storms (e.g., a mean annual rainfall), and release it a rate that approximates the natural forested condition.
- **Flood Risk Management for the Extreme Storms (peak flow conveyance)** – Ensure that the drainage system can safely convey extreme storms (e.g., a 100-year rainfall).

The Integrated Strategy for Runoff Volume Management

Guiding Principle 2 forms the foundation of integrated stormwater solutions that mimic the most effective stormwater management system of all - a naturally vegetated watershed. The 'integrated strategy' for managing the complete spectrum of rainfall events is built around an understanding of the Natural Water Balance. The strategy has three components – *retain* the small frequent events, *detain* the large events, and *convey* the extreme events - as illustrated below.



The WBM enables modelling of all three components of the integrated strategy. It can be used to evaluate how well alternative strategies (including combinations of stormwater source control and off-site detention) can reduce the runoff from development areas, and how this translates into benefits at the watershed level. Source control options include bioretention, infiltration facilities, rainwater capture and re-use, and green roofs. The WBM can also be used to evaluate the impacts of population growth and climate change scenarios.

The Target Condition for a Healthy Watershed

The target condition for any watershed is defined by the Water Balance, water quality and streamflow characteristics of that watershed with less than 10% impervious area. The target relates to *existing* conditions for relatively undeveloped watersheds (i.e., new development scenarios) and *historical* conditions for developed watersheds (i.e., retrofit scenarios). In order to achieve the target condition, the total annual runoff volume must be limited to10% (or less) of total annual rainfall volume. This means that 90% of annual rainfall must be returned to natural hydrologic pathways (e.g., infiltration and evapo-transpiration) or harvested for re-use. Capturing the frequent small rainfall events at the source will, in large part, maintain or restore the natural Water Balance and achieve the above targets. The Guidebook explains how to achieve the above water balance targets at the site scale, and how to apply the Water Balance Model to assess the feasibility of reducing runoff volume at the watershed scale over time in conjunction with land redevelopment.

Comparison with Conventional Stormwater Management

Conventional 'flows-and-pipes' stormwater management is limited because it focuses only on the fast conveyance of the extreme storms and often creates substantial erosion and downstream flooding in receiving streams. Similarly, a detention-based approach is only a partial solution because it allows the small storms that comprise the bulk of total rainfall volume to continue to create erosion and impacts on downstream aquatic ecosystems. Neither of these approaches fully prevents the degradation of aquatic resources or flooding risks to property and public safety. In contrast, the Guidebook approach is to eliminate the root cause of ecological and property impacts by designing for the complete spectrum of rainfall events. Solutions described in the Guidebook include conventional, detention, infiltration and re-use approaches for rainfall capture, runoff control and flood risk management.

Guiding Principle 3 - Act on a Priority Basis in At-Risk Drainage Catchments

Focus priority action should be focused in at-risk drainage basins where there is both high pressure for land use change and a driver for action. The latter can be either:

- a high-value ecological resource that is threatened
- an unacceptable drainage problem

The stormwater management policies and techniques implemented in at-risk catchments become demonstration projects.

Guiding Principle 4 - Plan at Four Scales – Regional, Watershed, Neighbourhood and Site

Integrated stormwater management must be addressed through long term planning at each of the regional, watershed, neighbourhood and site scales.

- **At the Regional and Watershed Levels –** Establish stormwater management objectives and priorities
- **At the Neighbourhood Level** – Integrate stormwater management objectives into community and neighbourhood planning processes
- **At the Site Level** – Implement site design practices that reduce the volume and rate of surface runoff and improve water quality

Guiding Principle 5 - Test Solutions and Reduce Costs by Adaptive Management

Performance targets and stormwater management practices should be optimized over time based on:

- monitoring the performance of demonstration projects
- strategic data collection and modeling

As success in meeting performance targets is evaluated, the stormwater management program can be adjusted as required.

CURE – The Elements of an Action Plan

The acronym **CURE** focuses attention on the four key types of actions that must all work together to implement integrated stormwater management solutions:

- CAPITAL INVESTMENT – Short-term capital investment will be needed to implement early action in at-risk drainage basins. Improvements to existing drainage system are often the most significant capital investments required. A financing plan should provide an ongoing source of funds for watershed improvements.

- UNDERSTANDING SCIENCE – Improved understanding of a watershed, the nature of its problems, and the effectiveness of technical solutions is key to an adaptive approach. Stormwater management practices can be optimized over time through the monitoring of demonstration projects, combined with selective data collection and modeling.

- REGULATORY CHANGE – Changes in land use and development regulations are needed to achieve stormwater performance targets. Changes to land use planning and site design practices are needed to eliminate the root cause of stormwater related problems. These changes must be driven by regulation.

- EDUCATION AND CONSULTATION – Changes to land use planning and site design practices can only be implemented by building support among city staff, the general public and the development community through education and consultation.

Translating a Vision into Action

It is important to establish a long term shared vision at the start of any watershed planning initiative. A vision that is shared by all stakeholders provides direction for a long-term process of change. The vision becomes a destination, and an action plan provides a map for getting there. Actions plans must be long term, corresponding to the time frame of the vision. Action plans must also evolve over time. Ongoing monitoring and assessment of progress towards a long term vision will improve understanding of the policy, science and site design components of integrated stormwater management. This improved understanding will:

- Lead to the evolution of better land development and stormwater management practices
- Enable action plans to be adjusted accordingly

An adaptive management approach to changing stormwater management practices is founded on learning from experience and adjusting for constant improvement.

Building Blocks

The Guidebook elaborates on three fundamental objectives that become building blocks for a long-term process of change:

- **Achievable and Affordable Goals -** Apply a science-based approach to create a shared vision for improving the health of individual watersheds over time
- **Participatory Decision Process** - Build stakeholder consensus and support for implementing change, and agree on expectations and performance targets
- **Political Commitment –** Take action to integrate stormwater management with land use planning

The Water Balance Model: A Tool for Stormwater Source Control Modelling in a Watershed Context

For the past thirty years, there has been a fixation on peak flow control through the use of detention ponds for all flood events from the 2-year through 100-year floods, and the conveyance of major flood events caused by urban developments of all kinds. The recently developed software focus has been on the user interfaces, but not on the hydrology engine; and certainly not on improvements in the science of infiltration.

Traditional applications of hydrology models reflect "peak flow thinking" at a watershed or macro scale. But the models may not be appropriate for simulating what happens at the site scale, nor for assessing the effects of storm runoff volume changes caused by urban development.

The missing link in urban hydrology has been a tool that quantifies the benefits, in terms of reducing stormwater runoff volume at the site level, of installing source controls under a variety of circumstances. The water balance modeling approach was developed to demonstrate how to meet performance targets for water balance management at the site, neighbourhood, drainage catchment, and watershed scales. The WBM assists local governments to integrate land use planning with volume-based analysis of stormwater management strategies.

The volume-based approach that is being implemented in British Columbia picks up the baton that Dr. Ray Linsley started more than a generation ago. As a professor of Civil Engineering at Stanford University, and later as a consulting engineer, Linsley pioneered the development of continuous hydrologic simulation as the foundation for water balance management. He has received world-wide recognition for his vision and his contributions to the field of hydrology and continuous hydrologic simulation modelling:

- In the 1960s, Linsley championed the paradigm-shift from empirical relationships to computer simulation of hydrologic processes. He had little or no use for "simple hydrology" and the many simple equations that were used to represent the hydrologic cycle.
- Linsley fought a difficult war to replace the established procedures that had been used for many years, and that continue to be used in most urban hydrologic analyses throughout North America and in other locations around the world. He believed that continuous simulation was the only hydrology that should be used for most design and analysis applications.
- Linsley's pioneering efforts resulted in development of the well-known HSPF Model. This continues to be the hydrologic simulation tool of choice in many parts of North America, notably Washington State where its use is mandated by the Department of Ecology, even though it is a complex model with great data input needs.

Somewhat ironically, the "hydrology engine" for HSPF and other contemporary models (such as SWMM) is based on 1930s and 1940s science. As reported by Linsley in a 1976 article:

- In 1933 - Horton first proposed the concept of infiltration, which is at the heart of continuous simulation.
- In 1934 - Zoch first suggested the use of routing to develop the runoff hydrograph.
- In 1942 - Linsley and Ackerman introduced the idea of continuous soil moisture accounting.

The power of the WBM is in the engine that instantly, interactively, and transparently models hydrologic processes at the site level, including the processes that govern the movement of water through soil and vegetation. This engine incorporates algorithms that simulate how runoff is generated at the site level and generates a continuous simulation of the runoff from a development site, neighbourhood, drainage catchment, or watershed. The WBM simulates five source control categories:

- Impervious Controls
- Absorbent Landscaping
- Infiltration Facilities
- Green Roofs
- Rainwater Re-Use

The WBM provides local governments with the means to integrate land use planning with stormwater management. It is a decision support and scenario modelling tool that is used to:

- Visualize the 'how to' details of source control implementation
- Model scenarios at the site, neighbourhood and watershed scales
- Make decisions through a scientifically defensible, interactive and transparent process.

The WBM has a wide range of application possibilities, including:

- Design of volume-based stormwater controls
- Site performance assessment
- Evaluating opportunities for urban retrofits
- Volume-based watershed trading for urban stormwater management
- Watershed management optimization
- Analysis of changes in rainfall patterns
- Public education and outreach

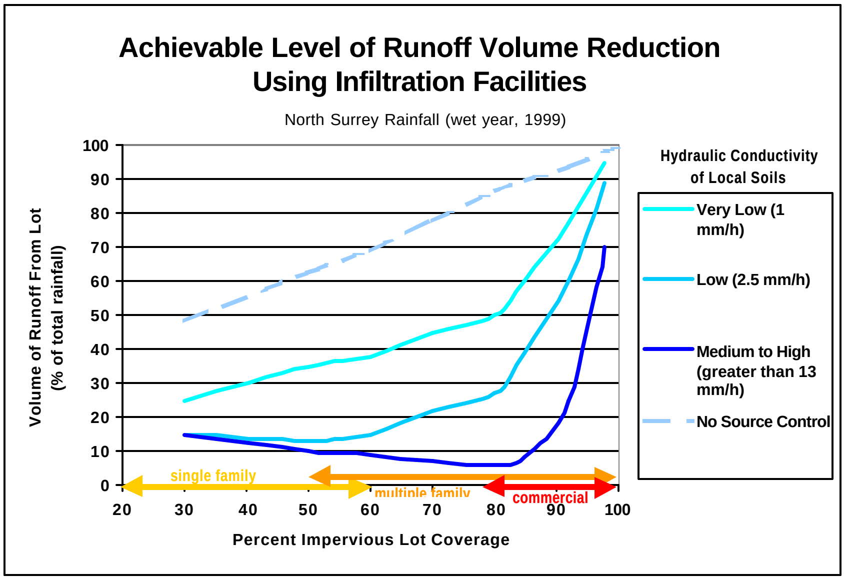
The WBM has enabled evaluation of the hydrologic performance of stormwater source controls (e.g., bioretention, infiltration facilities, rainwater capture and re-use, green roofs) and stormwater detention. It provides a continuous simulation of the runoff, given these inputs:

- Continuous rainfall data (any time increment)
- Evapotranspiration data
- Extent and distribution of land use types
- Site design parameters for each land use type
- Soil and groundwater information
- Information on stormwater controls
- Seasonal change in rainfall patterns due to climate change

The sensitivity of source control performance to any of these model inputs can be tested by comparing modelled scenarios. The output hydrograph generated by the WBM can become an input to a wide range of hydraulic routing models. WBM hydrographs represent a major improvement over conventional hydrologic simulation. In the Greater Vancouver Region, the WBM has been used to assess the potential for urban watershed restoration over a 50-year timeframe. The WBM has made it possible to:

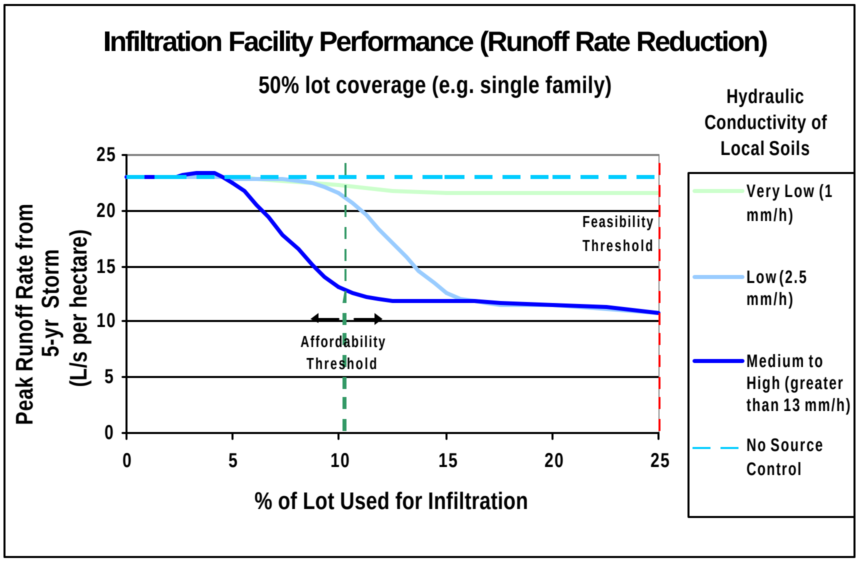
- Identify affordability and feasibility thresholds
- Develop evaluation criteria for cost-benefit analysis
- Generate watershed-specific performance relationships

The following figures illustrate the types of relationships that have been developed using the WBM, and that are presented in the Guidebook:



Where soils have medium or better hydraulic conductivity, runoff volume could be reduced to about 10% of total rainfall for all but the highest coverage land uses.

Significant levels of runoff volume reduction can also be achieved in soils with poor hydraulic conductivity.



Reductions in runoff rates using infiltration facilities depend on the hydraulic conductivity of local soils and the amount of area provided for infiltration.

Affordability thresholds govern infiltration facility sizes for lower surface coverage land uses, and feasibility thresholds govern for higher coverage land uses.

Summary

Recent stormwater initiatives in British Columbia include:

- Publication of ***Stormwater Planning : A Guidebook for British Columbia***
- Publication of ***Integrated Stormwater Management Planning - Terms of Reference Template***
- Development of the ***Water Balance Model for British Columbia***
- Evaluation of ***Stormwater Source Control Effectiveness*** at the site, neighborhood and watershed scales

To protect property, aquatic habitat and water quality, British Columbia has:

- Recognized the logical link between surface runoff volume and impacts on watershed health
- Embraced the integration of land use planning with stormwater management
- Established performance objectives for designing communities that function hydrologically like naturally forested systems

The paradigm-shift from an approach that only deals with consequences, to one that also eliminates the causes, has resulted in a re-invention of urban hydrology:

- There was a need for a tool that realistically simulates how runoff is actually generated at the site level
- The WBM is a stormwater planning and site design tool that evolved in two stages:
  - Initially through the Burnaby Mountain Project – to achieve watershed protection objectives
  - Subsequently through the GVRD Project - to evaluate the effectiveness of a range of source control options (e.g., absorbent landscaping, infiltration facilities, rainwater re-use, green roofs) under a range of operating conditions (i.e., land use, soil and rainfall)

Conclusion

The ***Water Balance Model for British Columbia*** provides an effective decision support tool for local governments to integrate land use planning with stormwater management, and to evaluate the potential for developing or re-developing *communities that function hydrologically like naturally forested or vegetated systems*. The tool creates an understanding of *how*, and *how well*, stormwater source control strategies for runoff reduction would be expected to achieve watershed protection and/or restoration objectives.

Bibliography

The following is a partial list of publications on the aquatic impacts from urban development and stormwater in British Columbia and Washington State:

- BC Ministry of Environment, Lands and Parks and Environment Canada. 2000. Water Quality Trends in Selected British Columbia Waterbodies. http://wlapwww.gov.bc.ca/wat/wq/trendsWQS/index.html
- BC Ministry of Environment, Lands and Parks. 2000. Environmental Trends in British Columbia, 2000. http://wlapwww.gov.bc.ca/soerpt/
- Hartman, G.F., Groot, C., and Northcote, T.G. 2000. The Ball is Not in Our Court. *In* Sustainable Fisheries Management: Pacific Salmon. *Edited by* E. Eric Knudsen, C.R. Stewart, D.D. MacDonald, J.E. Williams and D.W. Rieser. Lewis Publishers, Boca Raton, FL. pp. 31-49.
- Horner, Richard, and May, C. 1998. Watershed Urbanization and the Decline of Salmon in Puget Sound Streams. *In* Salmon in the City May 20-21, 1998, Mount Vernon Washington, Abstracts. *Edited by* Anonymous. pp. 19-40.
- Karr, J.R. 1991. Biological Integrity: A long neglected aspect of water resources management. Ecological Applications 1(1): 66-84 *in* Horner, Richard, and May, C. 1998. Watershed Urbanization and the Decline of Salmon in Puget Sound Streams. *In* Salmon in the City May 20-21, 1998, Mount Vernon Washington, Abstracts. *Edited by* Anonymous. pp. 19-40
- Nehlsen, W. Williams, J.E. and J.A. Lichatowich. 1991. Pacific salmon at a crossroads: stocks at risk from California, Oregon and Washington. Fisheries. Vol 16, No.2 American Fisheries Society. Bethesda, MD. Pp 4-21.
- Reid G., and Michalski, T. 1999. Status of Fish Habitat in East Coast Vancouver Island Watersheds. *In* At Risk. Proceedings of a Conference on the Biology and Management of Species at Risk. *Edited by* L. Darling. BC Ministry of Environment, Lands and Parks, Victoria, BC. pp. 355-367.
- Slaney, T.L, Hyatt, K.D., Northcote, T.G., and Fielden, R.J. 1996. Status of Anadromous Salmon and Trout in British Columbia and Yukon. American Fisheries Society 21: 20-35.

---

[1] IGP Liaison & Project Coordinator

[2] Chair, British Columbia Inter-Governmental Partnership for Development of a Water Balance Model

[3] Co-chair, Inter-Agency Steering Committee for Stormwater Planning Guidebook; and
Co-chair, British Collumbia Inter-Governmental Partnership for Development of a Water Balance Model

[4] Facilitator, Greater Vancouver Regional District Stormwater Inter-Agency Liaison Group

[5] The Stormwater Planning Guidebook is available on the Ministry's website at : http://walpwww.gov.bc.ca/epdpa/mpp/stormwater/stormwater.html

[6] Integrated Stormwater Management PlanningTerms of Reference Template, prepared by KWL for the GVRD, 2002. http://www.gvrd.bc.ca/services/sewers/drains/Reports