the partnership
for water sustainability in bc

Convening for Action in British Columbia

Integrating the Site with the Watershed and the Stream

Primer on Rainwater Management in an Urban Watershed Context

November 2011

An initiative under the umbrella of the Water Sustainability Action Plan for British Columbia

Preface

The purpose of this Primer is to provide engineers and non-engineers with a common understanding of how a science-based approach to rainwater management has evolved since the mid-1990s:

- ☐ *First, research by Richard Horner and Chris May in Washington State identified limiting factors for stream health, and established an order-of-priority. Their findings provided a road map for integrated rainwater management.*
- ☐ *Next, the "made in BC" concept of the Rainfall Spectrum led us to look at rainfall differently. This resulted in the Water Balance Methodology and the ability to quantify and assess the hydrologic effectiveness of 'green' infrastructure.*
- ☐ *After that, a fresh look at other early engineering and biophysical research opened a window into the science of stream erosion and how it could be correlated with stream health.*
- ☐ *The synthesis of the three streams of thinking then provided the technical foundation for 'designing with nature' in order to soften the 'water footprint' of development. In BC, we have continued to build on this foundation.*

Pioneer research yielded guiding principles; these are standing the test of time. Evaluation of, and analyses using, the entire rainfall and stream discharge spectrum allows us to see new connections to stream health and to begin the process of creating effective mitigation strategies.

Updates to our scientific knowledge allow us to establish and implement more effective stream health protection as part of an ongoing adaptive management (i.e. 'learn by doing') process.

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November 2011

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Primer on Rainwater Management in an Urban Watershed Context

1. Scope

This Primer introduces building blocks that constitute the science-based foundation for rainwater management in an urban watershed context in British Columbia. The Primer:

- ☐ highlights the significance and application of pioneer research in hydrology, aquatic ecology and geomorphology;
- ☐ elaborates on how the concept of the Rainfall Spectrum has led us to look at rainfall differently;
- ☐ examines the hydrograph for a typical year, and what it means to an integrated strategy for managing the Rainfall Spectrum;
- ☐ describes the relationship between stream erosion and stream health; and
- ☐ explores the implications of protecting how rainfall reaches the stream.

BC is primarily a mountainous region. Headwater tributary streams are a predominant feature; and watershed health is very much about protection of aquatic habitat. The critical issue is the damage to and loss of habitat caused by land use change and resulting erosion of the headwater streams. BC's habitat focus contrasts with the water quality emphasis in the United States and elsewhere in Canada.

Impact of the Salmon Crisis

Looking back, the salmon crisis of the 1990s was the catalyst for action. The salmon is an icon. It is also the early warning system that there is a problem. Coastal salmon runs such as Coho, chum and pink spawn and rear in the headwater streams which are typically small. A generation ago, the ecosystem value of headwater streams was not fully appreciated. The result: streams were being lost as a consequence of rapid population growth and land development.

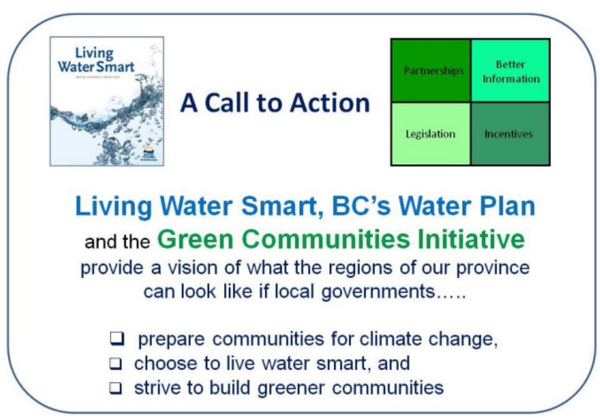
The lack of understanding and respect contributed to the decline of many wild salmon populations. And so the goal of protecting stream health became a driver for action in BC.

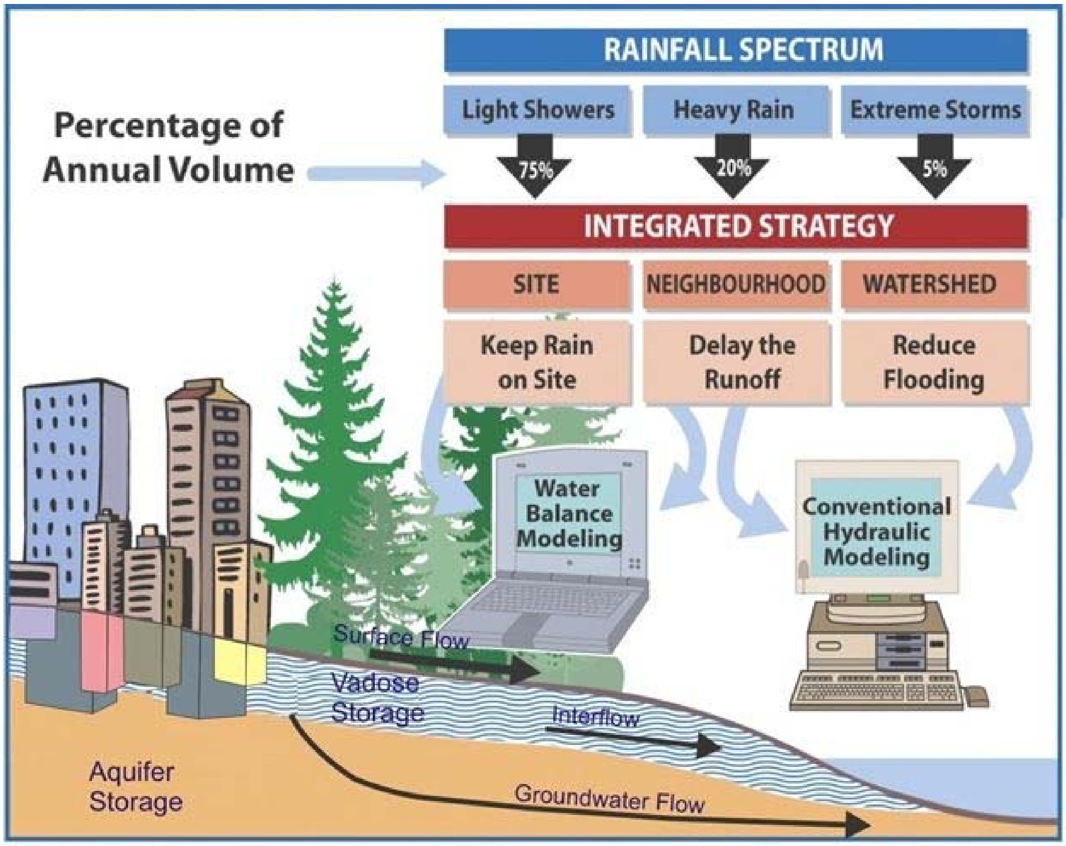
Science-Based Understanding Informs Policy and Practice

By 2002, as an implementation action resulting from enactment of the Fish Protection Act (1997), the Province released *Stormwater Planning: A Guidebook for British Columbia.* The Guidebook was a joint effort of two Ministries – Environment and Municipal Affairs. The process produced a science-based framework to guide development of the stormwater component of Liquid Waste Management Plans.

The core premise of the Guidebook is that land development and watershed protection can be compatible. This suggests that urban watershed restoration is achievable over time. The Guidebook signified a paradigm-shift. This resulted from recognition of HOW a science-based understanding could bridge the gap between high-level policy objectives and site design practices.

Shared Responsibility: In 2008, the Province put in place a policy framework that is a 'call to action' on the part of local governments. This call to action is underpinned by the notion of shared responsibility – that is, everyone needs to understand and care about THE GOAL. If all the players know their role in relation to the goal, then together British Columbians can create the future that we all want. In this case, the GOAL is to capture rain where it falls, limit surface runoff, and protect stream and watershed health.





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

Integrated Strategy for Managing the Rainfall Spectrum

Figure 1

Explanatory Notes – Key Messages:

Urban development reduces the 'vadose storage' and interflow. Therefore, restore these capabilities 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.

Definitions: '*Aquifer Storage' refers to the saturated zone where all void spaces are filled with (ground)water. 'Vadose Storage' refers to the unsaturated zone where void spaces are filled with air AND water.*

2. Science-Based Understanding

The Guidebook describes what "science-based understanding" means in practice. Also, it draws on work completed in 1999 for King County in Washington State as part of the Tri-County response to the listing of Chinook salmon as an endangered species. "A significant finding was that scientists and managers think and operate differently," states the Guidebook.

The Guidebook provides this definition: "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."

Through a science-based understanding of the relationship between hydrology and aquatic ecology, the Guidebook derived a comprehensive set of watershed protection objectives that provide an over-arching framework for rainwater management.

An Integrated Strategy

Looking at rainfall differently led to a new approach to rainwater management. Examination of all the rainfall-days in a year led to the concept of the 'rainfall spectrum'. Translating this new concept into an 'integrating strategy' then led to development of the 'water balance methodology'. Reproduced from the Guidebook, Figure 1 illustrates how these three concepts came together.

The Guidebook showed that the 'water footprint' could be reduced, applied the water balance methodology to establish performance targets for rainfall capture, and demonstrated that urban watershed restoration could be accomplished over a 50-year timeframe as and when communities redevelop.

The Guidebook emphasis is on volume control at the site scale. *Beyond the Guidebook: Context for Rainwater Management and Green Infrastructure in British Columbia* (2007) addressed the relationship between volume control and resulting flow rates in streams, and correlated stream health with stream erosion.

Historical Context

In the mid to late 1990s, widespread changes in thinking about rainwater and stormwater impacts reflected new insights in two areas: hydrology; and aquatic ecology. As explained in the Guidebook, these new insights were 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.

In BC, we have built on the foundation provided by the pioneering work of Richard Horner and Chris May and others, notably: Derek Booth, R. Christian Jones, John Maxted, Craig MacRae and Ivan Lorent. They questioned common wisdom; they undertook original research; they provided us with a science-based understanding of the importance of 'changes in hydrology'. Their work yielded guiding principles that are standing the test of time. We continue to enhance their pioneering work.

Application of Science-Based Understanding: The methodologies embedded in the Guidebook (2002) and in Beyond the Guidebook (2007) represent the synthesis of our understanding. First, the Guidebook integrated hydrology and aquatic ecology. Then, Beyond the Guidebook added geomorphology to the mix.

These "made in BC" methodologies have been developed, tested and adapted through applied research and case study applications:

- The *UniverCity Sustainability Community* on Burnaby Mountain was the genesis for the Water Balance Methodology that underpins the Guidebook.
- The City of Surrey then undertook a series of case studies that resulted in the Stream Health Methodology that underpins Beyond the Guidebook.

The Stream Health Methodology addresses the interaction of runoff (volume and duration) with the physical aspects considered important to the aquatic environment. The methodology enables correlation of green infrastructure effectiveness in reducing stream erosion or sediment accumulation in order to protect stream health.

3. Road Map for Integrated Rainwater Management

In 1996, the Center For Urban Water Resources Management at the University of Washington (in Seattle) published the landmark findings of Richard Horner and Chris May.

Factors Limiting Stream Health

Their seminal paper synthesized a decade of Puget Sound research to identify the factors that degrade urban streams and negatively influence aquatic productivity and fish survival. They demonstrated that the four factors limiting stream health are, in order-of-priority:

1. **Changes in Hydrology –** Greater volume and rate of surface runoff caused by increased impervious area and densification of road network.
2. **Disturbance and/or Loss of Integrity of the Riparian Corridor** – Clearing and removal of natural vegetation in riparian (streamside) areas.
3. **Degradation and/or Loss of Aquatic Habitat within the Stream** – Caused by erosion and sedimentation processes, bank hardening, and removal of large organic debris; aquatic habitat degradation is a direct result of changes in hydrology.
4. **Deterioration of Water Quality** - Increased sediment load due to more runoff volume causing channel erosion. Pollutant wash-off from land uses, deliberate waste discharges and accidental spills.

When published, this ranking shook conventional stormwater management wisdom in the Pacific Northwest to its foundation. If the goal is protection of aquatic resources, Horner and May proved that a water quality driven program would not achieve the goal.

Research Implications: Figure 2 illustrates the research findings for changes in hydrology (#1) and deterioration in water quality (#4). Two key messages flowed from this research: salmon would already be gone by the time pollutant loading is a factor in salmon survivability; and if we get the hydrology right, water quality typically takes care of itself.

Integration of Hydrology and Aquatic Ecology

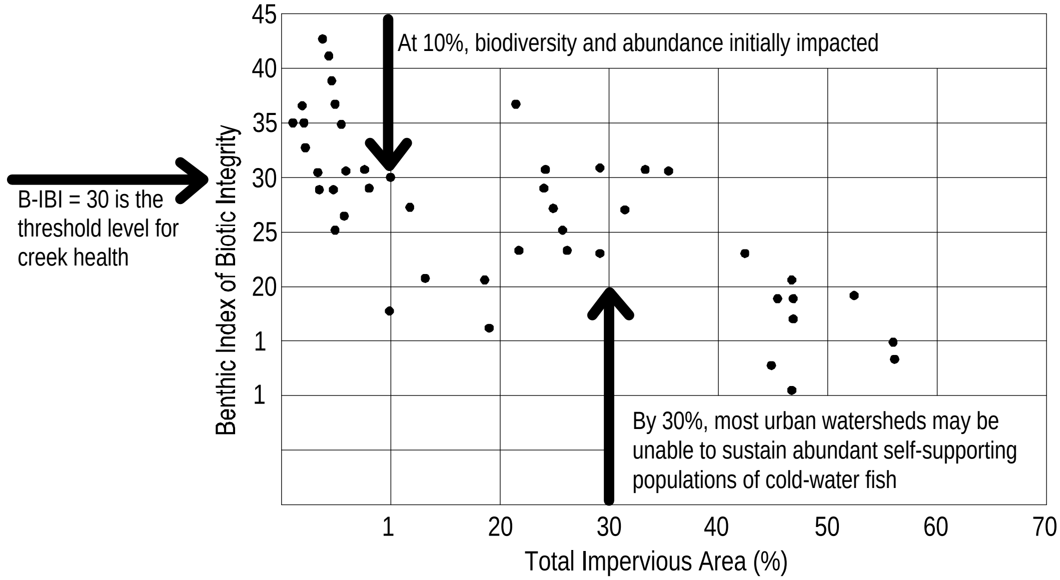
The limiting factors and order-or-priority identified by Richard Horner and Chris May provided a ‘road map’ for integrated rainwater management; and was the first building block. Their findings provided a starting point for correlating ‘changes in hydrology’ with the rainfall spectrum. This resulted in the Water Balance Methodology, the second building block.

Reference Impervious Area Levels for Land Use Planning: Recognizing that land use and stream health changes occur along a continuum, the scientific correlations presented on Figure 2 were then simplified as shown in the table below. As stated in the Guidebook, the purpose of this approach was to provide points of reference for local governments to integrate rainwater management and land use planning:

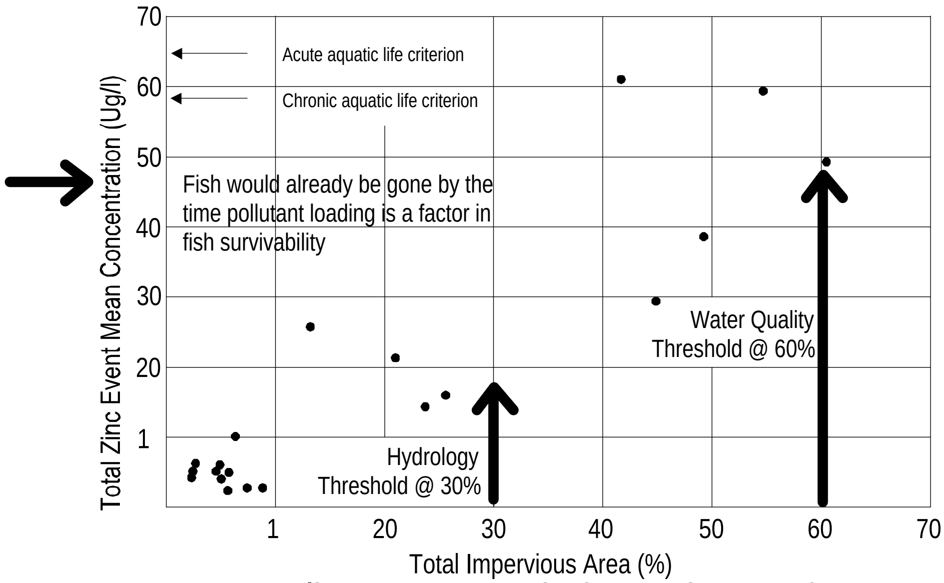
Impervious Percentage	Biophysical Significance of the Reference Level
10%	Fisheries biodiversity and abundance are initially and significantly impacted
30%	Most urban watersheds in the Pacific Northwest may be unable to sustain abundant self-supporting populations of cold-water fish
60%	Pollutant loading would theoretically be a significant factor in fish survival, except cold-water fish would likely already have been extirpated because of hydrological changes and related degradation of the aquatic habitat

Reinvention of Urban Hydrology: The Puget Sound stream health findings had a profound impact in BC. They helped to jumpstart an ecosystem approach in the local government setting. They also served as a springboard from which to reinvent urban hydrology and develop the Guidebook. With hindsight, this is part of the legacy of Richard Horner and Chris May.

Reference Levels for Land Use Planning



Creek Health (B-IBI) Versus Impervious Land Cover



Water Quality Versus Watershed Impervious Land Cover

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

Figure 2

4. The Fish Pictures

Washington State and British Columbia are geographically similar, with a wet coast and a relatively dry interior separated by mountain ranges. On the coast, Washington State's Puget Sound and British Columbia's Georgia Basin together comprise the Salish Sea. The bulk of the two populations reside in this Pacific Northwest bio-region. In terms of how rainwater management in a watershed context has evolved, there is a history of cross-border sharing and collaboration.

Cross-Border Collaboration

In the 1990s, the catalyst for collaboration was the salmon crisis. The goal of protecting stream health led some water resource practitioners to re-think how we design and build communities.

Among those leading change, Bill Derry stands out. In the 1980s, he was one of the first stormwater utility managers in Washington State. He believed so strongly in the need for scientifically-defensible research that he convinced his fellow utility managers to organize and fund a research centre at the University of Washington. He was a founding director of the Center for Urban Water Resources Management.

Translating the Science: In BC, Bill Derry's reputation for providing leadership was based on his having access to the latest scientific findings. His knowledge was a key ingredient in creating what became known as the 'fish pictures'. Based on the work of Horner and May, these images illustrated the consequences of urbanization on aquatic abundance and diversity.

These communication tools helped to develop a common understanding among broad and diverse audiences in workshop settings. Starting with the City of Kelowna in July 1998, the 'fish pictures' helped a number of municipalities in BC pass *Council Resolutions* that represented the first steps down a 'design with nature' pathway that will ultimately lead to greener, more livable communities.

Changes to the Water Balance

Figures 3 and 4 illustrate the progressive changes in hydrology and resulting impacts on stream health when land use change alters the Water Balance.

Same Rainfall, Different Runoff Pattern: Figure 3 illustrates 'changes in hydrology' as impervious area increases. A critical parameter for erosion is the number of runoff events per year that equal or exceed the magnitude and duration of the natural channel-forming event – i.e. before urbanization altered the Water Balance.

Impacts on Stream Corridor Ecology: Figure 4 is a schematic representation of the Horner and May findings, and illustrates how:

- The cumulative effects of increasing impervious area in a watershed combined with loss of riparian corridor integrity (as shown in the first two rows), alter the natural Water Balance and impact stream corridor ecology (as shown in the last two rows).
- The resulting increase in runoff volume causes watercourse erosion and progressive degradation of the channel cross-section (refer to middle row).
- The consequence of these cumulative changes is a progressive decline in stream corridor biodiversity and abundance for cold-water fish and clear water indicators, and a progressive transition to warm-water species and pollutant indicators (i.e. last two rows).

Eroded material creates turbidity, or dirty water, that can irritate fish gills and make it difficult for fish to find their food. Eroded sediments can cover spawning beds, smothering fish eggs in the gravel and possibly blocking access to spawning areas for the next generation.

The decrease in infiltration (due to replacement of soil and vegetation with hard surfaces) can also have impacts on fish because it reduces the slow, constant groundwater supply that keeps streams flowing in dry weather. This can lead to water levels that are inadequate to provide fish with access to their spawning areas, and can even cause streams to dry up in the summer.

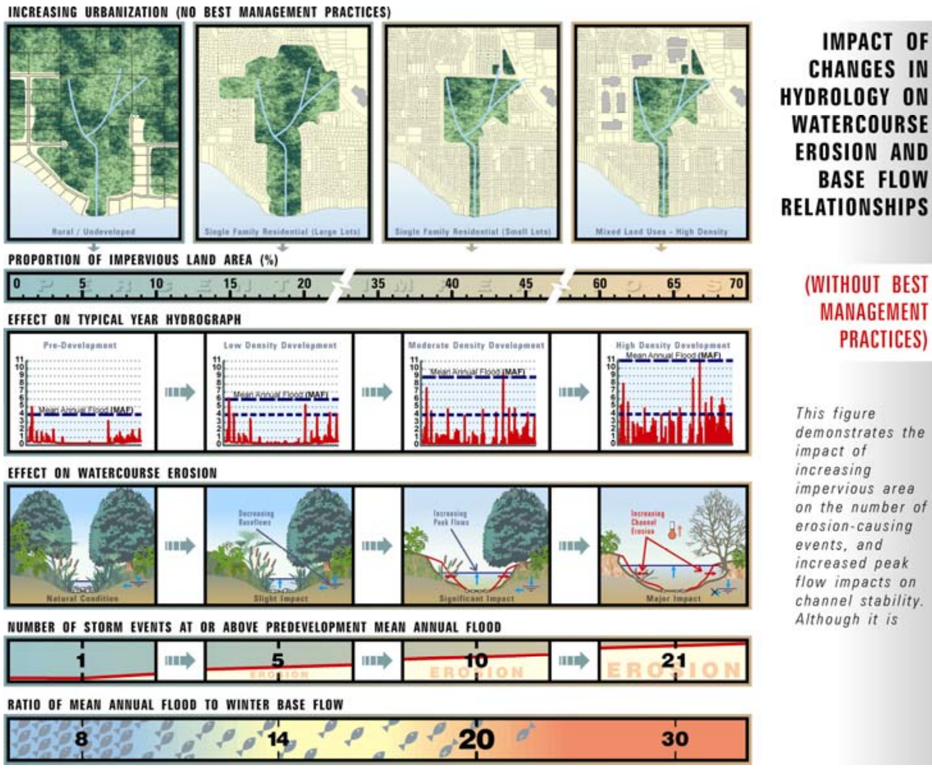


Figure 3

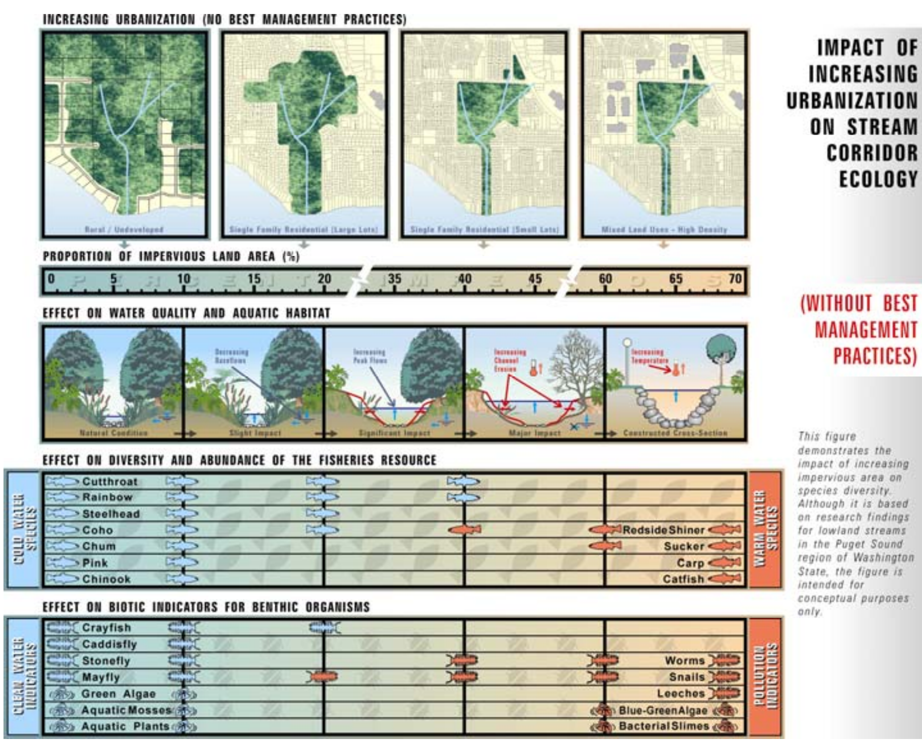


Figure 4

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

Developing a Shared Vision

Developed in 1997, Figure 5 translates scientific findings on the impacts of land use change into a decision-making tool for green infrastructure goals and objectives. It illustrates the consequences for stream corridor ecology of various attitudes towards rainwater and stormwater management.

Communication and Decision Tool: "To reach consensus on a shared vision of what is desirable and achievable for watershed protection or restoration, people need a picture of what a stream corridor could and/or should look like," states Peter Law, Chair of the Steering Committee that developed the Guidebook. "Often, the visioning process boils down to whether or not a stream corridor will have a functioning aquatic ecosystem."

Figure 5 was at the heart of stakeholder visioning processes for the ISMP case study experience that the Guidebook is founded upon. It captures the evolution of drainage planning philosophy over the past 50 years. In 1998, this graphic and the concept of 20-yr and 50-yr visions helped the Councils for the cities of Burnaby, Coquitlam, Port Moody and Kelowna make policy choices.

"By illustrating alternative visions for the long-term environmental health of stream corridors, Figure 5 provided stakeholders with clear visual choices regarding desired ISMP outcomes," continues Peter Law.

Starting Point for an Action Plan: "The process of determining an appropriate shared vision balances what is desired (or ideal) with what is technically feasible, affordable and politically palatable," states the Guidebook.

"For developed watersheds, Level 3 would be the likely starting point for an action plan, with the objective of moving from left to right over time to improve or restore watershed and stream health. For an undeveloped (or partially) developed watershed, the starting point would likely be Level 5, with the objective of preserving and protecting existing habitat values."

Adding the Dimension of Time: The Guidebook states that: "Change takes time. What is not achievable in the next five years may be quite achievable over fifty years. Integration of rainwater management with land use planning involves a timeline." The Guidebook defined general time-related objectives as follows:

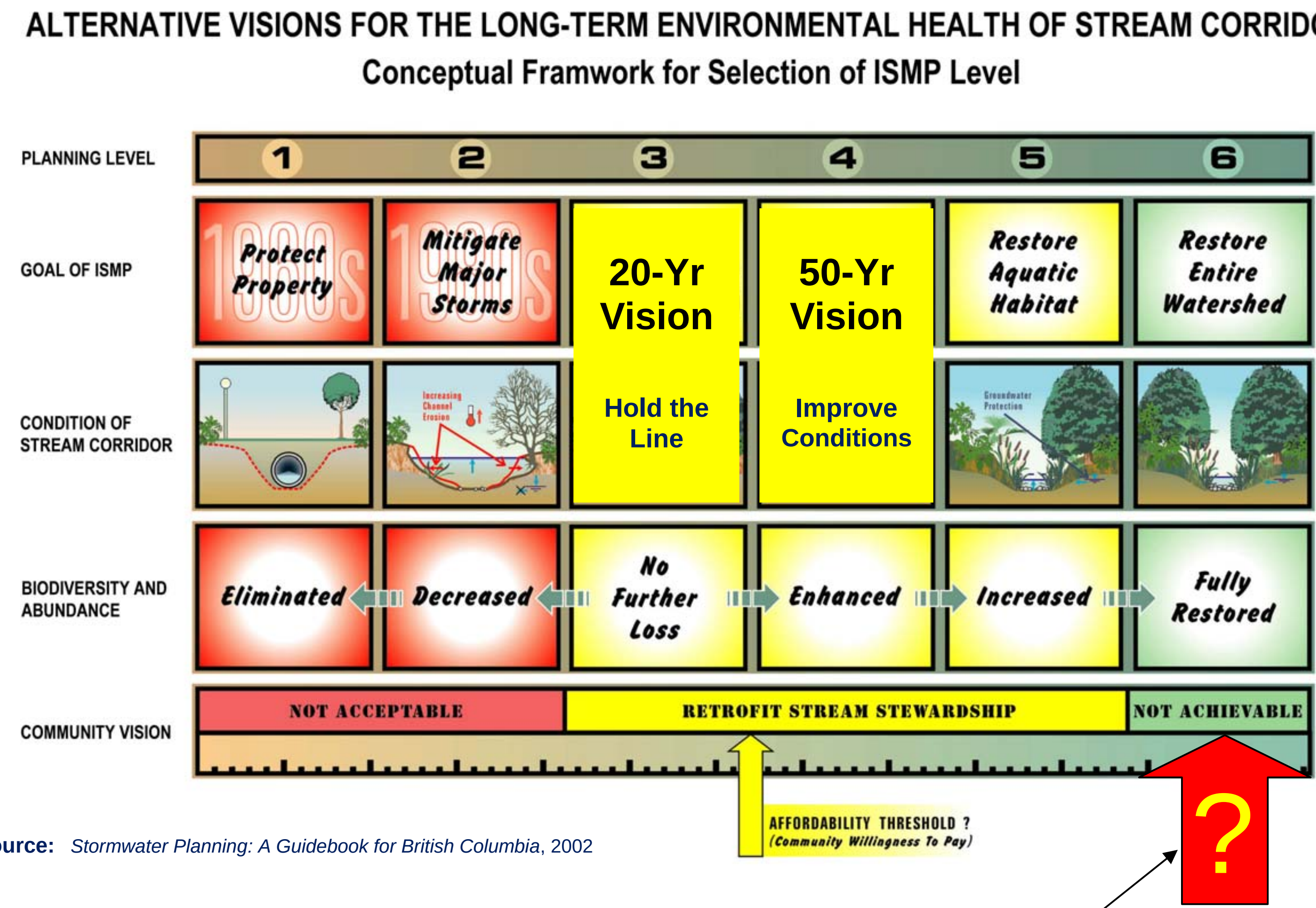
- **20-Year Vision (Preservation) –** Develop policies and implement demonstration projects that show how to succeed in achieving stream preservation (i.e. 'hold the line'), thereby building support for the 50-year vision to improve watershed and stream conditions.
- **50-Year Vision (Improvement) –** Continue to implement changes in land use and regulation that mitigate changes in hydrology at the source (i.e. improve conditions), thereby enabling watershed protection/ restoration and lasting stream improvement.

"Ongoing monitoring and assessment of progress towards a long-term vision will improve the understanding of how to blend policy, science and site design to achieve the shared vision for property, water quality and habitat protection. Building on initial successes, local governments may well decide to advance the schedule and strive for improvement within the 20-year horizon," states the Guidebook.

Reason for Optimism: For the past decade, the messaging in BC has been consistent:

> *A science-based understanding of the rainfall-runoff process is the foundation for 'designing with nature' and implementing green infrastructure that is truly effective in protecting and/or restoring watershed and stream health.*

"When the Province released the Guidebook in 2002, we thought we would be doing well if we could just *Hold the Line*. We hoped we might have enough successes after 20 years that maybe, just maybe, we would then *Improve Conditions* in the decades that followed. Well, it is 2011 and we have exceeded our own expectations. What was a dream in 2002 may now in fact be achievable," concludes Peter Law.



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

What we believed to be "unachievable" in 1998
may in fact now be within our grasp

Figure 5

5. Water Balance Methodology

The findings by Horner and May provided the inspiration to look at rainfall differently in BC. To fully understand 'changes in hydrology', it was necessary to revisit basic concepts and introduce new concepts. Building on the case study experience at UniverCity, the Guidebook formalized the concept of an **integrated strategy** for managing all the 'rainfall-days' that occur each year (Figure 1).

In 2002, this represented a major shift in thinking, from reactive to proactive. The Guidebook also highlighted the universality of certain relationships (Figures 6 and 7).

Universal Relationships

Figures 6 and 7 served two purposes. First, they showed that the distribution pattern of rainfall frequency and volume is universal even though total annual rainfall varies from region to region. Secondly, they underscored why properly implemented landscape-based solutions lend themselves to rainwater management.

A key message is that 'light showers' account for most of the annual rainfall volume; and therefore 'green' or landscape-based solutions will achieve a variety of objectives encompassing both the site and watershed scales in the urban environment

Educational Context: At the time of publication of the Guidebook in 2002, these graphics proved to be a powerful education tool because they:

- helped to change the way drainage practitioners and others view rainfall;
- focussed attention on the distinction between *rainfall capture* and *runoff control*; and
- promoted understanding of why infiltration is achievable for much of the year.

Circa 2000, there was fear and doubt that anything could be done to prevent rainwater runoff. Figures 6 and 7 were among the keys to changing the core beliefs of drainage practitioners.

Performance Targets

The Guidebook also introduced the concept of **performance targets** to facilitate implementation of the *integrated strategy* for managing the complete rainfall spectrum. To create a mind-map for practitioners, the rainfall spectrum was defined in terms of three tiers, with each tier corresponding to a component of the integrated strategy, namely:

- ☐ **Rainfall Capture** - keep rain on site by means of 'rainfall capture' measures such as rain gardens and infiltration soakaways
- ☐ **Runoff Control** - delay overflow runoff by means of detention storage ponds which provide 'runoff control'
- ☐ **Flood Mitigation** – reduce flooding by providing sufficient hydraulic capacity to 'contain and convey'

Defining rainfall tiers simply enabled a systematic approach to data processing and identification of rainfall patterns, distributions and frequencies.

Historical Context: For convenience, and to provide a starting point for analysis, the Guidebook referenced the three tiers to a value defined as the **Mean Annual Rainfall** (MAR). As our understanding of what is achievable through 'rainwater management' has grown, we have moved beyond this early concept. Looking back:

- The MAR concept was introduced in part to provide consistency with the *1992 Land Development Guidelines.*
- It established a point of departure that was familiar to practitioners so they would readily make the transition to a new way of thinking.
- In 2002, focussing attention on the MAR facilitated a paradigm-shift in the state-of-the-practice.

Introduction of the MAR focused attention upon the site level while assuming there would be benefits to the watershed and streams. Our knowledge is progressing. In 2007, Beyond the Guidebook addressed the need to take a closer look at the relationship between the rainfall spectrum and the flows actually entering streams from the watershed.

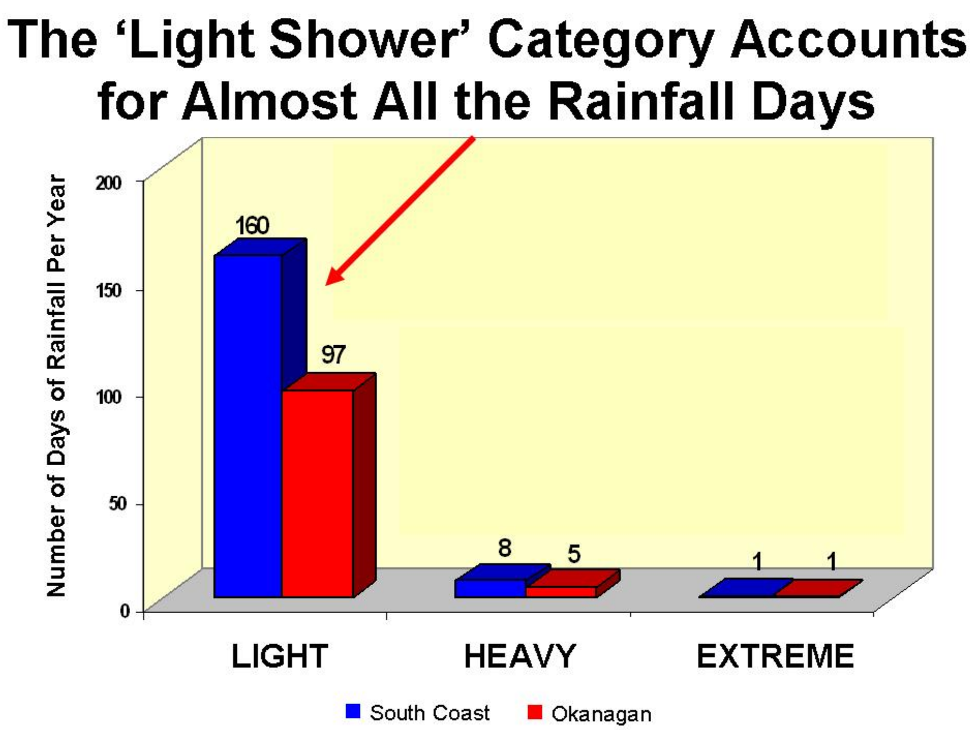


Figure 6

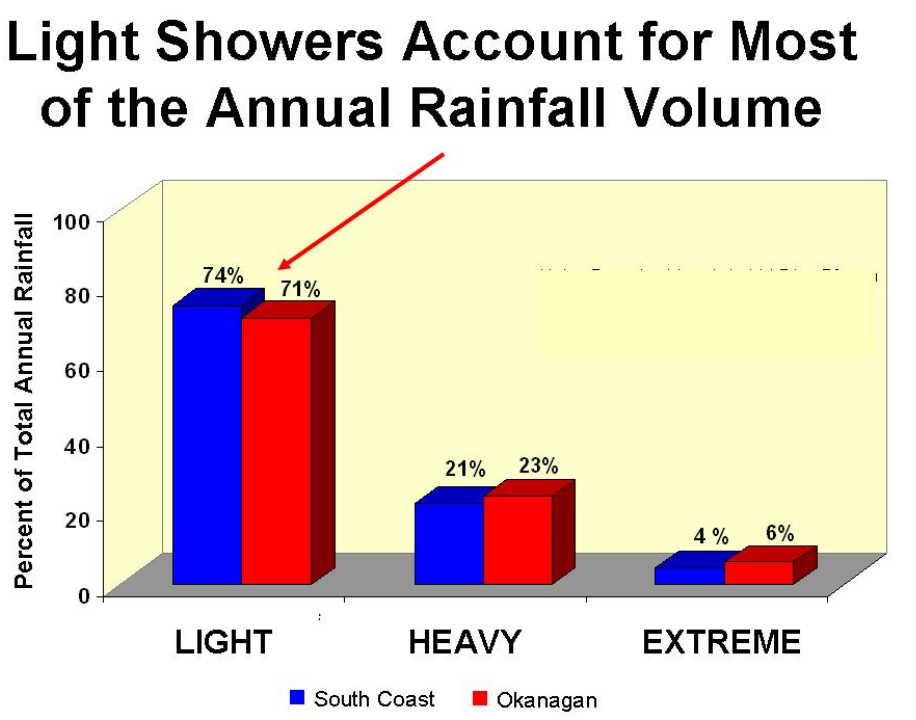


Figure 7

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

6. What Happens During A Typical Year

Before the Guidebook, the focus of drainage practice was on a handful of rainfall events because designers were interested only in statistically extreme peak flows. They used this information for sizing drainage pipes and structures. With release of the Guidebook, and then Beyond the Guidebook, all rainfall-days in a period of record are now considered because of the implications for stream health.

Variable Response to Rainfall

Figure 8 is the third building block in the process of looking at rainfall differently. It illustrates a core concept underpinning Beyond the Guidebook. The hydrograph shows that the larger of two rainfall events resulted in much less runoff. The smaller event was preceded by a period of wet weather such that more runoff resulted. In other words, watershed response to rainfall is variable.

The Implications for Stream Health: Figure 8 also shows that 90% of the total annual runoff volume corresponds to a very small runoff rate. Four conclusions can be drawn from this 'typical year':

- The 90% volume target can easily be managed through rainfall capture measures that reduce runoff volume.
- Retaining 90% of the annual rainfall volume on site would have little effect on peak runoff rates associated with the other 10%.
- Retaining 90% of the rainfall is only a part of the requirement for an effective rainwater management system.
- For the other 10% of the annual volume, it is a matter of detaining and/or conveying in accordance with the integrated strategy (Figure 1).

A key message in Beyond the Guidebook is this: move beyond a traditional analysis of drainage system response to storms, and integrate the needs of the aquatic environment vis-à-vis the amount and duration of flow in the stream.

From Rainfall-Based to Runoff-Based Approach

It was in drilling down into the relationship between 'rainfall capture' and 'runoff rate control' that Beyond the Guidebook picked up where the Guidebook left off in 2002. By addressing the factors that impact on stream health, Beyond the Guidebook drew attention to the differences between a 'rainfall-based approach' and a 'runoff-based approach' to hydrologic analysis.

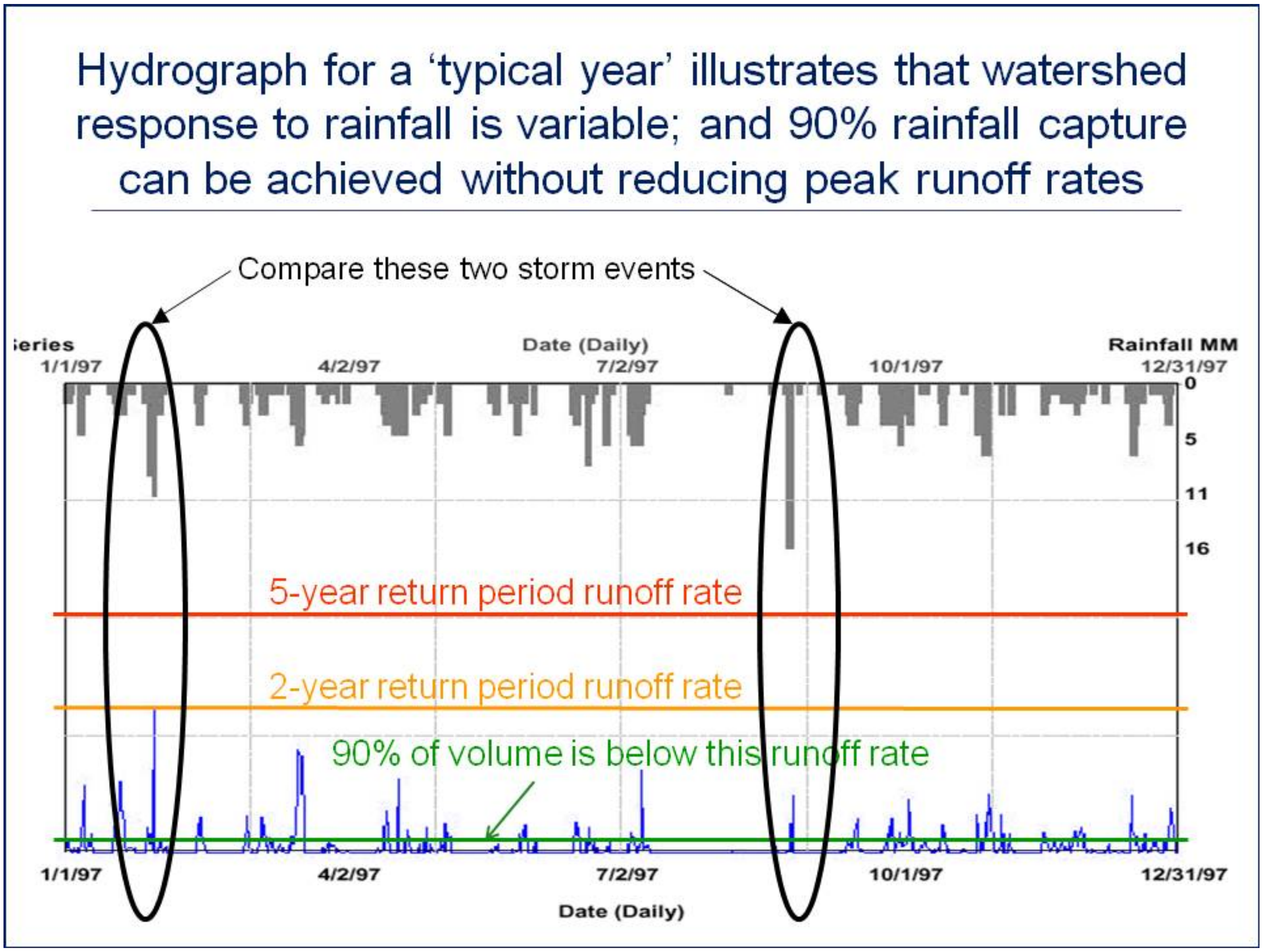
Flood Risk versus Environment Protection: A basic tenet of hydrology is that rainfall and runoff have different return periods. Yet many drainage practitioners have grown accustomed to a *Rainfall-Based Approach* that assumes a rainfall event of a specific amount will always result in the same magnitude of runoff.

The approach grew out of simple to use methodologies that address the reduction of flood risk for drainage conveyance systems. These methodologies only consider extreme storm events that occur infrequently. While acceptable for the purposes of conveyance sizing, the rainfall-based approach is not suitable when the application is environment protection.

The *Runoff-Based Approach*, on the other hand, recognizes that rainfall and runoff have different return periods. By considering how a watershed responds to rainfall, the approach addresses the interaction of runoff with the physical aspects considered important to the aquatic environment. The 'runoff-based approach' examines all the rainfall-runoff events that occur in a year.

As introduced in Section 2, stream health is a function of flow duration, and therefore correlates with stream erosion. Flow duration can be measured and verified. Also, the potential for erosion or sediment accumulation within a watershed can be assessed.

Key Message: The calculation methodology behind the 'runoff-based approach' holds the key to integrating the site with the watershed and the stream. This is explained in the next section.



Source: *Beyond the Guidebook 2010: Implementing a New Culture for Urban Watershed Protection and Restoration in British Columbia*, 2010

Watershed Hydrograph for Typical Year

Figure 8

7. Stream Health Methodology

Integrating the site with the watershed and the stream involves integration and synthesis of hydrology, aquatic ecology and geomorphology. In Beyond the Guidebook, the result is called the Stream Health Methodology. This is the fourth building block.

Historical Perspective

In a 1973 report for the United States Department of the Interior, Thomas Hammer provided this perspective on practitioner knowledge and understanding in the late 1960s:

> *"…existing knowledge regarding hydrologic effects of urbanization was quite inadequate…It was not known, for example, whether different types of impervious area have different effects on streamflow. This lack of knowledge has apparently existed because of the reluctance of natural scientists, on the one hand, to deal with…complex non-natural phenomena, and the reluctance of planners, on the other hand, to conduct research involving physical rather than social relationships."*

Looking back, the historical value of this report is the insight it provides regarding the rudimentary nature of practitioner understanding in the early 1970s. At a time when we could put a man on the moon (1969), we had not yet connected the dots between land use changes and stream erosion.

Beyond the Guidebook picks up where Thomas Hammer left off in 1973. His research included the effectiveness of buffer strips. One of the gems buried in his report is that buffer width has no correlation with stream erosion as long as drainage runoff is being piped directly to the receiving stream.

Building on Past Research

Many advances in science-based understanding occurred in the mid-1990s. Figure 9 presents capsule summaries of important pioneer research. Yet engineering practice generally did not incorporate this understanding. The Stream Health Methodology addresses this historical oversight.

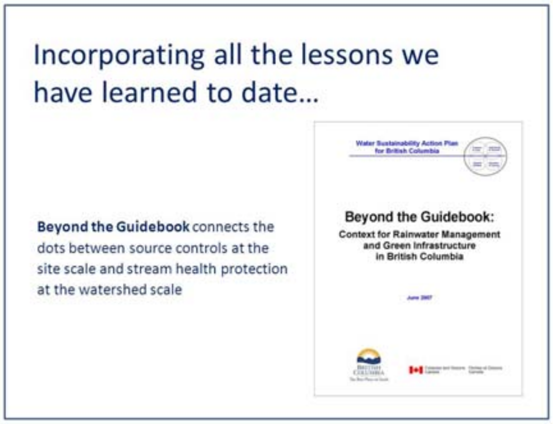
Learn from the Pioneers: The Stream Health Methodology is a synthesis of the work of Richard Horner, Chris May, R. Christian Jones, John Maxted, Craig MacRae and Ivan Lorent. In addition to the 'road map' introduced in Section 3, their work yielded the following:

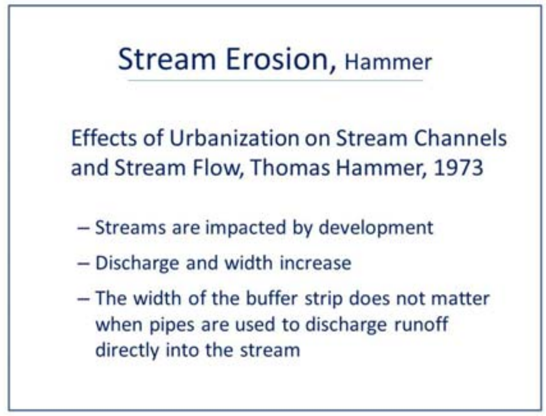
- ☐ Jones and Maxted demonstrated that aquatic biota were being impacted by urban development in spite of the engineering application and implementation of stormwater best practices.
- ☐ MacRae concluded that the use of detention basins to simply restrict flows to predevelopment rates would increase the rate of stream erosion and that different criteria were needed; and proposed an alternative based upon maintaining the distribution of shear stress across the channel from pre to post development conditions.

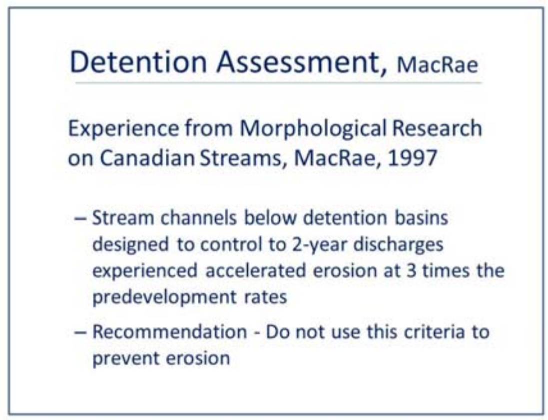
The findings by MacRae validated the earlier work of Ivan Lorent, published by the Ontario Ministry of Natural Resources in 1982. Lorent undertook a study to clarify the understanding and the processes involved in stream erosion. He questioned the then common wisdom that suggested matching pre and post development discharge rates was an adequate method of avoiding environmental impacts.

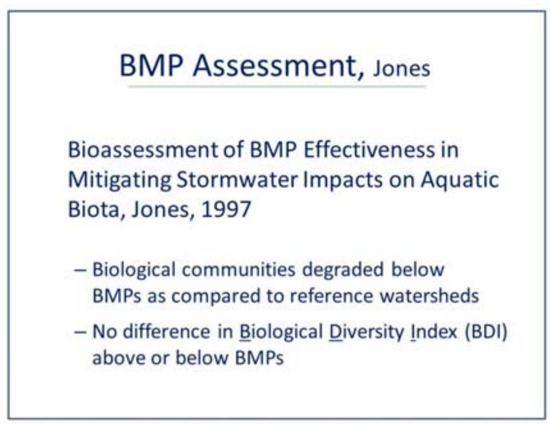
In 1982, Lorent demonstrated that the design standard using rate control to match post development flow rates to predevelopment rates could result in increased stream erosion.

Understand What Causes Stream Erosion: 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 or of the wide ranging impacts that they were trying to mitigate. Yet the way forward is foreshadowed in this quote from Larry Roesner, 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".









Pioneer Research

Figure 9

Science of Stream Erosion

Land development produces increased volumes of stream discharge combined with increased duration of discharge. The result is increased stream erosion following development. So, mitigation of the stream impacts includes controlling the combination of discharge rate and the time over which it occurs.

The Stream Health Methodology is based upon shear stress as applied to the stream bed and banks over time. This is a measure of the energy available to cause erosion in a stream. The methodology also relies on a ***continuous simulation*** of watershed response (i.e. stream discharge) to rainfall over a period of record, which would typically be several decades.

The quantitative indicators for stream erosion analysis are *Tractive Force* and *Total Impulse*.

Runoff-Based Approach: Continuous simulation is core to the science of environmental mitigation. First, it enables calculation of durations and frequencies of various occurrences of stream discharge. Secondly, it enables evaluation of all the small rainfall events that would add up and result in an impact (Figure 8).

Water resource practitioners need a tool to readily analyze, quantify and assess the effectiveness of green infrastructure measures in reducing erosion and protecting stream health. The Water Balance Model meets this need. It incorporates the Stream Health Methodology.

Stream Impact Indicators

- ❑ Changes to stream geomorphology
- ❑ Engineers **must** understand the concepts
- ❑ **Must** be easy to analyze
- ❑ **Must** be quantifiable and reproducible
- ❑ **MUST** measure mitigation effectiveness
  - Mitigation systems **can** be analyzed
  - Alternatives **can** be compared

Estimate the Tractive Force: The approach developed by Lorent and MacRae is founded on the concept of quantity of energy available to cause stream erosion (Figure 10). The approach also recognizes that some stream erosion is essential; and uses estimates of tractive force applied over time to establish the energy available to cause stream erosion and to provide a balance between pre- and post-development conditions.

The *Tractive Force* is estimated by applying this equation:

$\tau = \varphi R s$, where

φ = unit weight of water

R = hydraulic radius of flow, and

s = slope of channel

While the use of tractive force as a single measure is interesting, it only provides a snapshot of conditions within a stream and the energies associated with flow.

Estimate the Total Impulse: When we introduce the additional dimension of time and examine the tractive force applied to the stream cross section, we can then convert the measure of force into a measurement of the amount of energy being applied to a stream cross section.

The *Total Impulse* is estimated by applying this equation:

$I = \sum \tau P T$, where

τ = Tractive Force

P = wetted perimeter

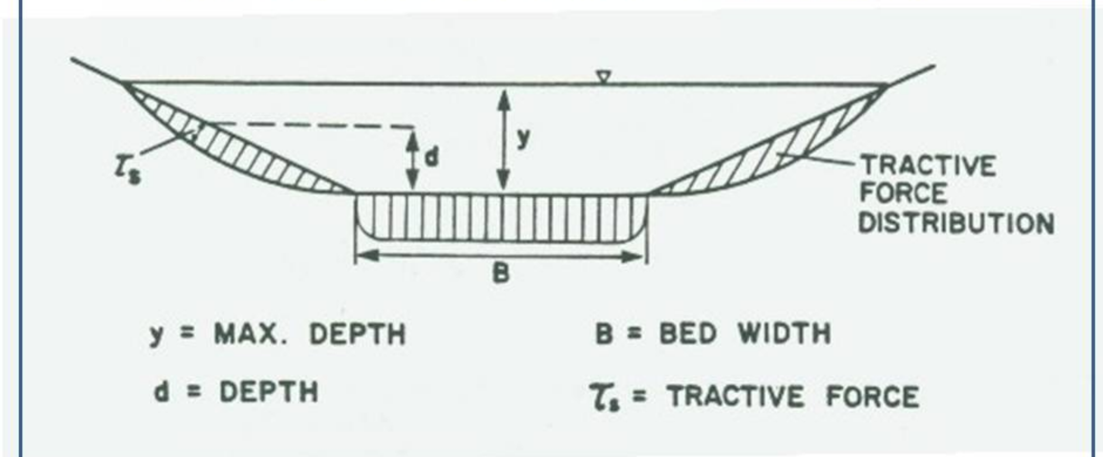
T = time

Application of this formula is particularly simple because the continuous simulation of watershed response to rainfall will provide both the discharge and depth of flow at each hour of the simulation throughout the period of simulation.

The flow conditions that would not result in movement of bed and bank material can be eliminated. This leaves only the Impulse, or total energy that would result in stream erosion. The effect of development and different mitigation schemes can be tested numerically.

Tractive Force

Based upon Tractive Force calculations



Tractive Force Equation	Impulse Equation
☐ Simple equation ✓ Applicable for a wide, open channels ☐ Include banks for narrow channels ✓ Banks are often the critical part	☐ A measure of <u>energy applied to the stream</u> cross-section in the form of friction ☐ Use duration of flow to estimate total Impulse for a range of flow depths ☐ Can exclude non-erosive tractive force ☐ Easy to include in continuous modelling

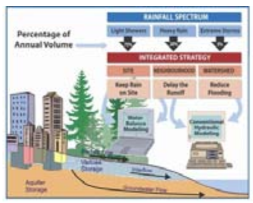
Science of Stream Erosion

Figure 10

8. How Water Reaches the Stream

Figure 1 shows the generalized flow patterns of natural and post developed conditions. Urban development reduces the 'vadose storage' and 'interflow'. Hence, the purpose of green infrastructure solutions is to capture rain where it falls, and to restore vadose storage and interflow.

This raises this question: If rainfall is captured to reduce site discharge, how does the water then get to the stream and what are the processes and timelines?



Definitions: As shown on Figure 1, 'Aquifer Storage' refers to the saturated zone where all void spaces are filled with (ground)water. 'Vadose Storage' refers to the unsaturated zone where void spaces are filled with air AND water.

Development Impacts

The unsaturated layers near the surface, the vadose zone, that exist in natural conditions are usually lost, or greatly diminished following development. The shallow groundwater flow patterns of interflow are greatly disrupted and any captured rainwater that is infiltrated would enter the deeper groundwater systems.

In watersheds underlain with clays and silts the travel time to the stream can be increased from a single season to decades, resulting in a reduction of base flow in the stream. A system that mimics the entire watershed condition would be required to mitigate for the impacts resulting from development.

This leads to a conclusion that the solution must be achieved on a watershed by watershed basis. No two watersheds are the same and would thus require different solutions. It would not be safe to assume that every infiltration system will be beneficial for stream health.

Protect Interflow

"Rainwater management has developed far beyond the simplistic assumptions that created the detention ponds of the 1980s. It is now time to take another leap forward, albeit by moving sideways, and recognize near surface lateral water flow, otherwise known as 'interflow'," states Alan Jonsson, Habitat Engineer with Fisheries and Oceans Canada.

"Interflow is often the dominant drainage path in glaciated landscapes of British Columbia. Even undeveloped sites that are founded on till and bedrock rarely show overland flow because of interflow pathways. Interflow has been traced flowing at velocities that are 1/200th as fast as channel flows on a similar gradient. It is not hard to imagine the beneficial effect that this has in prolonging flows from rainfall to first-order streams."

""Unlike deeper aquifer fed groundwater, interflow water is often rich in dissolved organic carbon and other nutrients. It is this flow that feeds hundreds of small ephemeral streams throughout the Lower Mainland."

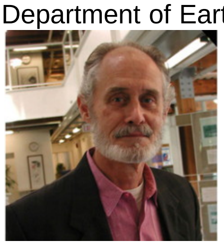
When we acknowledge the role of interflow and its incredible ability to absorb and slowly discharge precipitation, we are led to the realization: a watershed's hydrology can be severely degraded without any increase in impervious area. All that is required is a loss of functional soil layer and/or the addition of ditches or perforated pipes and presto, one 'urbanized' watershed. Conventional watershed health metrics such as total impervious area can under estimate impacts where interflow dominates."

"The lesson is that the interflow system is an incredibly important and yet fragile component of a watershed. It is critical for maintaining stream health and our fishery resource. Where the system is still operating it must be protected; where human activity will cause an alteration to its function, then replacement systems must be created that will mimic its operation to prevent any additional impacts to the stream and our resource," concludes Alan Jonsson.

Understand How a Watershed Functions

"We need to understand the sub-systems that are in play between the time that rainfall is received at the top of the tree canopy and the time that it actually gets to the stream as streamflow or other kinds of releases. THAT'S THE KEY TO THE WHOLE SYSTEMS APPROACH. If we unlock that key, if we can just begin to get a handle on that, then we can then begin to put in place the appropriate kinds of measures (to protect watershed health)," states Will Marsh, author of ***Landscape Planning: Environmental Applications,*** a classic textbook.

Will Marsh came to BC from the University of Michigan-Flint where he was Chairman of the Department of Earth and Resource Sciences and



a Director of the Laboratory for Land and Water Management. He is currently an Adjunct Professor in the Landscape Architecture Department at the University of British Columbia.

"Watersheds are not all created equal. And when we begin to examine them, we find that they function in all kinds of different ways. And what I often see missing in most engineering methodologies is an understanding of how a particular watershed actually functions."

Watersheds as "Partial Area Systems": "J.D. Hewlett at the University of Georgia studied forested watersheds in the southern Appalachian Mountains for 20 years. Even during intensive rainstorms, he found that forested watersheds never produce overland flow. Streams received all their discharge from interflow." (J.D. Hewlett is the author of ***Principles of Forest Hydrology***, published in 1982.)

"Research by Tom Dunne at the University of California showed that most of the watersheds that we are dealing with in North America function as 'partial area systems'. This means that only a fraction of the watershed - as little as 20%,10% or 5% - actually makes a direct discharge contribution to streamflow, even during the biggest and wettest events."

"In British Columbia, depression storage in a forested watershed is the single biggest reservoir of water during wet weather periods. Yes, depression storage! When you walk through second growth watersheds in BC, it is hard walking across them because they are so 'bumpy'. And, if you go out there during a heavy rainstorm, guess where most of the water is going? It is going into depressions."

Ask Five Questions: "Most of the watersheds that we have in BC, in particular the smaller ones, function at best as 'partial-area' systems. Also, most of them function as interflow systems. This means they have never seen overland flow. So, when we come into a problem area, before we start thinking about best management practices and computer models, we have to ask some basic questions:

1. What kind of watershed system are we in?
2. Where are we in that system?
3. How does the system function at that particular location/site?
4. What is the site's role in the larger system?
5. How do we then begin to coordinate the site's hydrologic function with whatever we put there such that our occupancy turns out to be invisible to the system?"

"During the planning and design stages of a project, we really have to begin to pay attention to how things function. Before advancing the engineering, it would help to bring a little natural science into this - for example, some elementary physiography. We too often jump too quickly to the engineering computations about this method or that method....when what we really need is a basic understanding of the land and its functions followed by application of appropriate landscape planning and design measures. In other words, think like a watershed,' concludes Will Marsh.

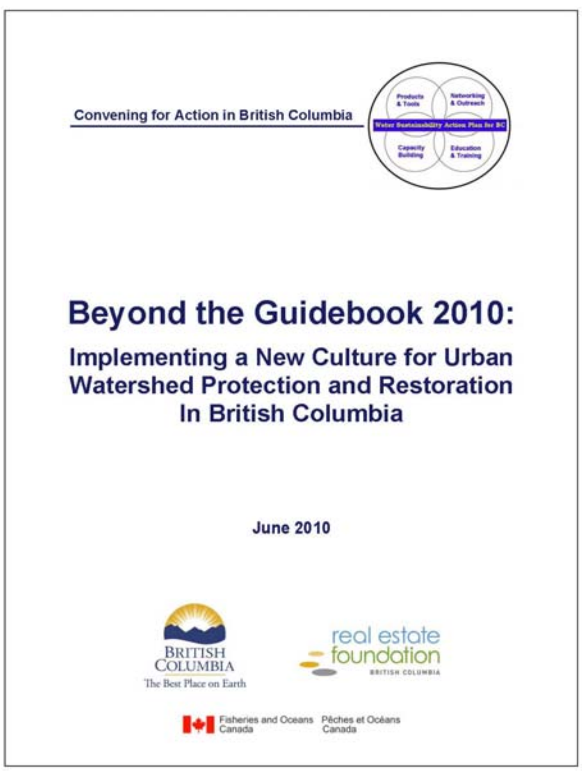
Water Balance Methodology: The goal is to re-establish the connection to the stream. The modified systems that are simulated in the Water Balance Model strive to mimic the interflow system by providing storage, and by providing the baseflow discharges.

9. Beyond the Guidebook 2010

In October 1997, a focus group convened by the Union of British Columbia Municipalities (UBCM) set in motion a chain of outcomes that culminated in *Stormwater Planning: A Guidebook for British Columbia* (2002). This was a catalyst for change that has resulted in BC achieving international recognition as a leader in implementing green infrastructure.

Beyond the Guidebook 2010 is the story of what has been accomplished on the ground over the past decade. It demonstrates that the practitioner culture in BC is changing as an outcome of collaboration, partnerships and alignment. It also provides local governments with 'how to' guidance for developing outcome-oriented urban watershed plans.

The rollout of Beyond the Guidebook 2010 commenced in September 2010 at the Annual UBCM Convention.



Convening for Action in British Columbia

Beyond the Guidebook 2010:

Implementing a New Culture for Urban Watershed Protection and Restoration In British Columbia

June 2010

The New Business As Usual

Chapter 1 is the 'call to action'. The future desired by all will be created through alignment of federal, provincial, regional and local policies and actions

Chapter 2 provides an overview of why the Guidebook was a catalyst for action to implement a 'design with nature' approach.

Chapter 3 describes the steps in an incremental process that has been building practitioner capacity for the past decade in BC.

Chapter 4 introduces the stories of three regional initiatives; they demonstrate that the practitioner culture is changing.

Chapter 5 describes the inter-connected elements of a 'top down-bottom up' *Outreach & Continuing Education Program*.

Chapter 6 describes six outcomes resulting from local governments embracing a 'top down-bottom up' strategy to leading and implementing change.

Chapter 7 provides local governments with guidance regarding the "ISMP course correction".

Guiding Principles

"After reflecting on all the stories told in Beyond the Guidebook 2010, I am just blown away at how the original Stormwater Planning Guidebook really foreshadows how this subject has moved forward over the past 10 years," reflects Peter Law, Guidebook Chair.

"We coined the acronym **ADAPT** in the 2002 Guidebook, and I am pleased to see how so many sectors of the land development industry (from local government planners to design engineers to backhoe operators) in British Columbia have taken up the challenge to find more sustainable solutions in developing land in a way that is not harmful to the environment. I am proud to have been part of this team approach to finding integrated solutions," concludes Peter Law.

As shown on Figure 11, ADAPT is the acronym for five guiding principles of integrated rainwater management.

ADAPT

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

Source: Executive Summary (*pages ES-3 through ES-6*),
Stormwater Planning: A Guidebook for British Columbia, 2002

Guiding Principles of Integrated Rainwater Management

Figure 11