Integrating the Site with the Watershed and the Stream

Primer on Urban Watershed Modelling to Inform Local Government Decision Processes

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 regarding 'appropriate and affordable' computer modelling. A guiding principle is that the level and/or detail of modelling should reflect what information is needed by local government to make an informed decision. The Primer addresses two dimensions of an ISMP (Integrated Stormwater Management Plan):

- ☐ ***The Watershed** – where the focus is on performance targets for rainfall capture and runoff control.*
- ☐ ***The Storm Sewer System** – where the focus is on pipe discharge capacity and level-of-service for flood protection.*

To provide local governments with a starting point for applying lessons learned over the past decade, this Primer elaborates on:

- ***Performance Targets:** brings forward a synopsis of key information from 'Stormwater Planning: A Guidebook for British Columbia'*
- ***Levels-of-Service**: explains why and how the major financial challenge resulting from the 'unfunded infrastructure liability' is a driver for a life-cycle approach to asset management and renewal*
- ***Screening / Scenario Tools:** introduces the 'Drainage Infrastructure Screening Tool' for establishing priorities and making budget decisions for storm sewer system upgrading; and describes the application of the 'Water Balance Model powered by QUALHYMO' for establishing watershed-specific performance targets.*

From the stream health perspective, appropriate and effective green infrastructure is a way to increase the level-of-service. Expressed another way, green infrastructure that restores the rainfall absorption capacity of the watershed landscape will increase the level of ecological protection.

*For storm sewer systems, the process of establishing an acceptable **'Level-of-Service**' will require local governments to review, examine, and justify the existing standards and how to transition into the future where costs must be balanced against public needs and expectations.*

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'Urban Watershed' Explained

The term 'urban watershed' is a metaphor for those watersheds, or parts of watersheds, over which local governments exert control through regulation of land use. The distinction is important because:

- In Metro Vancouver and in the Capital Regional District, for example, the majority of municipalities completely encompass their watershed areas (or else share them with adjoining municipalities).
- Outside the major metropolitan regions, on the other hand, municipalities tend to be located at the bottom end of wilderness watersheds that are subject to provincial regulation.

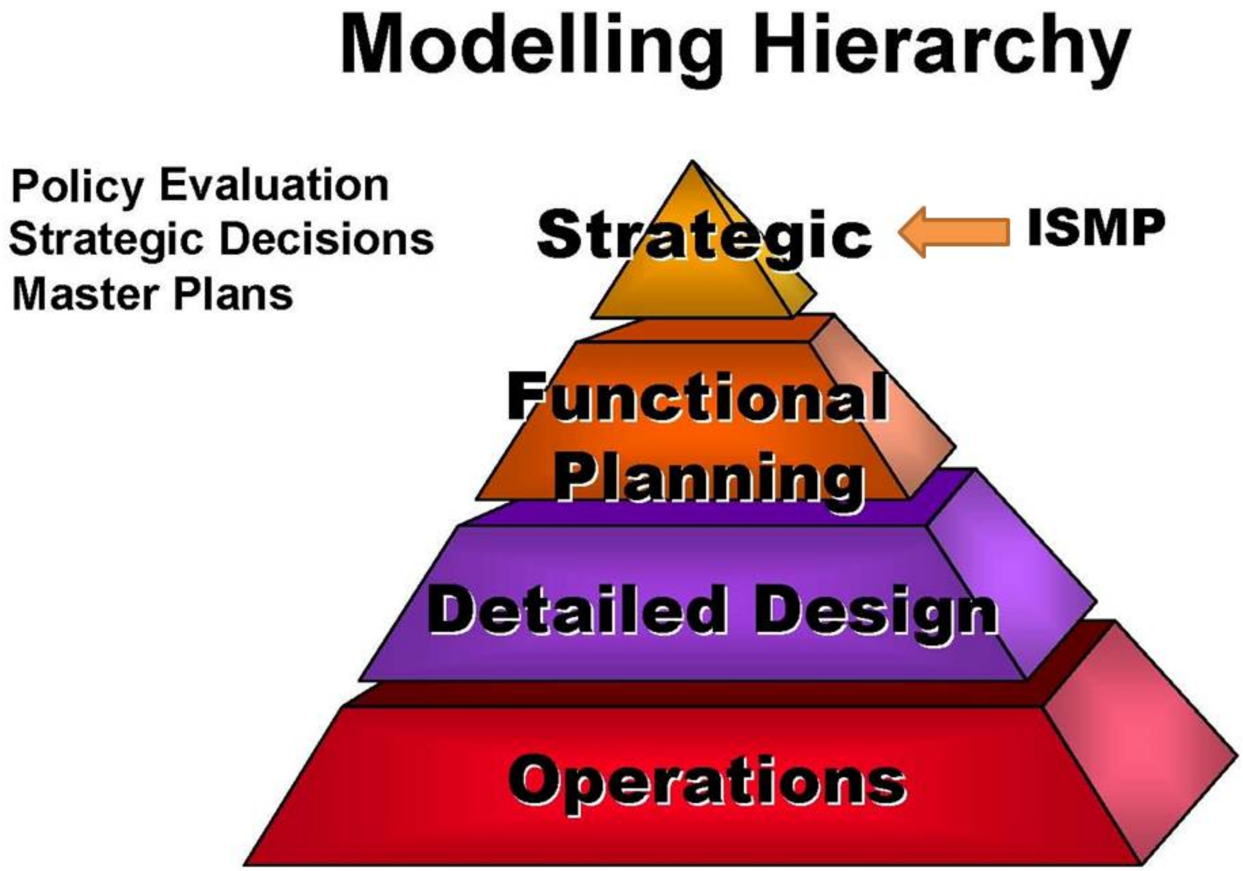
In British Columbia, the term 'local government' encompasses municipalities and regional districts. The distinction is noteworthy because municipalities and regional districts are governed by the *Community Charter* and *Local Government Act*, respectively.

The *Community Charter* empowers municipalities with extensive and very specific tools to proactively manage the complete spectrum of rainfall events. These tools enable them to achieve watershed goals and objectives. Although the *Local Government Act* provides regional districts with similar enabling powers to establish a drainage function within a service area boundary, regional districts that do not have such a service do not have the same regulatory powers as municipalities. The Ministry of Transportation and Infrastructure has historically regulated drainage in electoral areas.

British Columbia case law makes clear the responsibility of municipalities to manage runoff volume to prevent downstream impacts. An increasingly important corollary to that responsibility is the need to work from the regional down to the site scale, to maintain and advance watershed health to ensure that both water quantity and quality will be sustained to meet both ecosystem and human health needs.

While a municipality has control over HOW rainwater runoff is generated and managed within its residential, commercial and industrial land uses, it does not have the same ability to regulate watershed activities that are taking place outside its municipal boundaries.

In summary, in this document **'urban watershed'** refers to drainage tributary areas within which zoning and land use are under the jurisdiction of municipalities or areas for which a regional district has established a drainage service.



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

Levels of Drainage Modelling

Figure 1

1. Background / Context

The separate *Primer on Rainwater Management in an Urban Watershed Context* and this Primer are companion documents. The former provides an overview of the science-based understanding that led to development of both the **Water Balance Methodology** and the **Stream Health Methodology**. Now, this Primer describes the application of these two methodologies for the purposes of scenario modelling that will inform decision-making by local governments.

The Goal: Integrated Solutions

In the 1990s, the genesis for ISMPs (Integrated Stormwater Management Plans) was a desire to integrate the community, engineering, planning and environmental perspectives to produce *integrated solutions*. Local governments knew they had to do business differently in order to protect and/or restore watershed health.

Doing business differently meant moving beyond 'master drainage planning'. This included re-thinking the function of computer modelling in establishing watershed objectives and targets. Over the past decade, however, an apparent disproportionate emphasis by the engineering community on pipe-by-pipe computer evaluation of storm sewer capacities has had unintended consequences for ISMPs.

Unintended Consequences: In its Final Report to the Metro Vancouver Board in July 2009, the advisory Liquid Waste Management Plan Reference Panel provided this assessment:

> *"ISMPs that do not integrate land use and drainage planning are resulting in unaffordable multi-million dollar infrastructure budget items that become municipal liabilities, without providing offsetting stream health benefits."*

The unfunded infrastructure liability has had a paralyzing effect on municipal decision-making. To deal with the paralysis, the Reference Panel recommended that municipalities re-focus ISMPs on watershed targets and outcomes. This initiated the 'ISMP Course Correction'.

ISMP Course Correction

In November-December 2010, the Partnership released a 5-part series about considerations driving the *ISMP Course Correction*. A Summary Report followed in February 2011, consolidated key findings, and provided guidance to those about to embark upon an ISMP process.

City of Surrey Example: This ISMP Course Correction Series of documents drew attention to successful approaches and wisdom gained by local government leaders – for example, the City of Surrey has a guiding philosophy that is captured colloquially as follows:

- Put on your boots and go for a walkabout
- After that, integrate stakeholder views
- Think through what you are proposing
- Then, and only then, do your modeling

The 'mind-map' above provides the context for what follows in this Primer about an appropriate and affordable approach to watershed modelling.

Modelling Hierarchy

Figure 1 on the page opposite is reproduced from *Stormwater Planning: A Guidebook for British Columbia*, released in 2002. It illustrates the four main levels (or applications) of drainage modelling. The modelling pyramid is based on the principle that the level and/or detail of modeling should reflect what information is needed to make an informed decision:

1. Why build a model?
2. How will it be applied?
3. What problems will it help solve?

Moving down the pyramid reflects an increasing level of detail, and hence investment of local government resources.

Key Message: The Guidebook stated that the modelling component of an ISMP "should be at a strategic (i.e. conceptual or overview) level to provide basic information that will support the local government decision process". The *ISMP Course Correction* reaffirms this core tenet.

2. Scope of Primer

The desired outcome in undertaking 'appropriate and affordable' scenario modelling is to inform decision-making. To provide local governments with a starting point for doing business differently, this Primer elaborates on these three aspects of watershed modelling:

- ☐ Performance Targets
- ☐ Levels-of-Service
- ☐ Scenario / Screening Tools

The Primer brings forward relevant principles from the Guidebook to provide a framework; and provides a synopsis of what the Partnership has learned over the past decade.

Beyond the Guidebook

In 2002, the Guidebook demonstrated how to bridge the gap between policy and site design, with emphasis on volume control at the site scale. By advancing a performance target approach, the Guidebook initiated a drainage paradigm-shift in BC. Subsequently:

- **June 2007:** Release of *Beyond the Guidebook* foreshadowed the Province's Living Water Smart and Green Communities initiatives a year later in 2008. Also, Beyond the Guidebook addressed the relationship between volume control and resulting flow rates in streams.
- **September 2010:** The inter-governmental partnership commenced the rollout of *Beyond the Guidebook 2010* at the annual convention of BC local governments. This guidance document tells the stories of those leading change in BC and provides guidance vis-à-vis the ISMP Course Correction.

Table 2 in Beyond the Guidebook 2010 identifies what local governments will need to do to protect or restore stream health. Originally released in 2008, it presents a conceptual framework for setting watershed-specific performance targets and then implementing them at the development scale. There must be clear linkages between the targets and development approval processes.

Transition into the Future

The framework presented in Table 2 envisions a level-of-service approach to setting watershed-specific runoff targets. It identifies questions that need to be asked when evaluating the acceptability of targets (see Section 3).

From the stream health perspective, appropriate and effective green infrastructure is a way to increase the level-of-service. Expressed another way, green infrastructure that restores the rainfall absorption capacity of the watershed landscape will increase the level of ecological protection.

The process of establishing an acceptable ***'Level-of-Service***' (see Section 4) will require local governments to review, examine, and justify the existing standards and how to transition into the future where costs must be balanced against public needs and expectations.

Drainage Infrastructure: Looking ahead, Section 5 introduces a drainage infrastructure screening tool that will enable engineers to cost-effectively assess storm sewer capacities.

Watershed-Specific Targets: Table 2 may also be viewed as a road map to a destination. In one page, it summarizes what needs to be done. Some local governments are progressing along the road map, yet work remains to be done to bring Table 2 to life for all local governments:

- On the one hand, methodologies and tools to establish appropriate watershed-specific targets exist.
- On the other hand, case study examples to demonstrate what integration looks like at multiple scales are still works-in-progress.

The focus of this Primer is on providing the reader with a consolidated understanding of performance targets and the function of modelling. The Guidebook provided a point of departure for implementing an adaptive approach to setting watershed targets. The Water Balance Model (see Sections 6 and 7) was then developed as an extension of the Guidebook to assess how to meet those targets.

Table 2 (*brought forward from Chapter 7 in 'Beyond the Guidebook 2010'*)

Developing Outcome-Oriented Watershed Plans:
Framework for Moving from Planning to Action

Action	Level of Commitment
Complete and implement integrated rainwater/stormwater management plans that are **affordable and effective i**n protecting or restoring Watershed Health	▪ Local governments, in collaboration with senior governments, develop Integrated Plans that enable implementation of integrated strategies for greening the built environment; and include establishing watershed-specific runoff targets (for managing the complete rainfall spectrum) that make sense, meet multiple objectives, are affordable, and result in net environmental benefits at a watershed scale. (*Note: To date, "integrated drainage plans" have typically been called "ISMPs" pursuant to the nomenclature established in Chapter 9 of the 2002 Guidebook. The time has come to describe truly integrated plans as "Watershed Blueprints" to capture the paradigm-shift from pipe-and-convey 'stormwater management' to landscape-based 'rainwater management' that restores watershed function over time)*
	▪ Local governments, in collaboration with senior governments, establish watershed targets that are characteristic of actual conditions in watersheds, recognizing that there will be different strategies for already developed versus partially developed watersheds.
	▪ Local governments, in collaboration with senior governments, evaluate the acceptability of watershed-specific runoff targets on the basis of an evaluation framed by these three questions: 1. What target will achieve the watershed health objective? 2. What needs to be done to make the target achievable? 3. Do the solutions meet the test of affordability and multiple objectives?
	▪ Local governments, in collaboration with senior governments, implement green infrastructure solutions that result in effective rainfall management at the site, catchment and watershed scales.
Embed landscape-based strategies in neighbourhood concept plans	▪ Local governments develop rainwater/stormwater and land use plans through an inter-departmental process that is collaborative and integrated. ▪ Local governments provide guidance as to how watershed-specific targets can be met at the development scale.

Source: **Commentary on Effective Municipal Rainwater/Stormwater Management and Green Infrastructure to Achieve Watershed Health**, April 2008

Released jointly by the Green Infrastructure Partnership and the Inter-Governmental Partnership in conjunction with the consultation process for Metro Vancouver's *Integrated Liquid Waste & Resource Management Plan*

The Commentary is accompanied by a paper titled *Beyond the Guidebook: Establish Watershed-Specific Runoff Capture Performance Targets*, released at the 2008 Water Balance Model Partners Forum.

3. Watershed-Specific Performance Targets

The Guidebook articulated a guiding principle that "performance targets at the watershed scale provide a starting point to guide the actions of local government in the right direction". This set the stage for translating those targets into appropriate site design criteria that would then provide local government staff and developers with practical guidance for achieving the goal of stream health protection.

The litmus test for an acceptable **Watershed Target** is that resulting rainwater management solutions make sense, are affordable and result in net environmental benefits at a watershed scale. The Guidebook explains that "for a performance target to be implemented and effective, it must also have feedback loops so that adjustments and course corrections can be made over time."

Target Watershed Condition

A physically-based target condition can be established based on an understanding of geomorphology and stream characteristics. In order to be achievable, the target condition must be translatable into performance targets that can be applied to rainwater management practice.

Because changes in Water Balance and hydrology are the primary source of rainwater runoff impacts on stream health, it is necessary to establish performance targets for managing **RUNOFF VOLUME** and **RUNOFF RATE**.

Protect or Restore the Water Balance: The Guidebook introduced the Water Balance Methodology for:

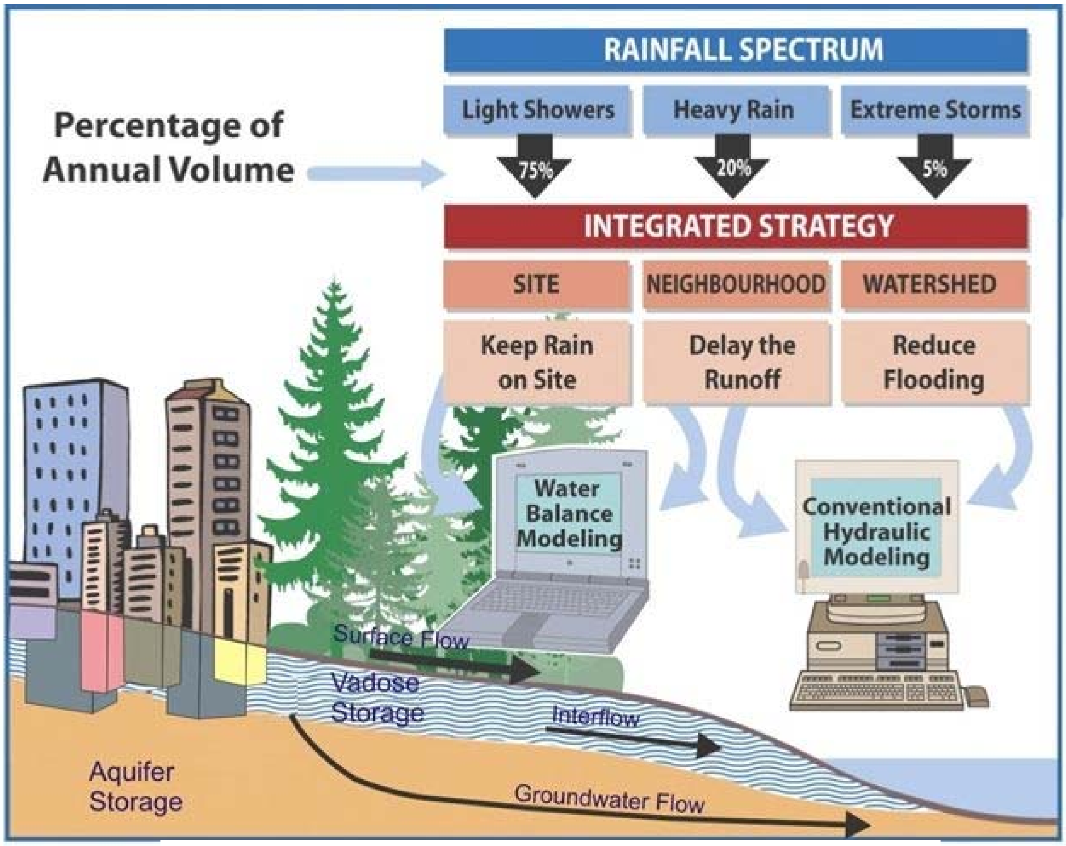
- Developing watershed performance targets based on site-specific rainfall data, supplemented by streamflow data (if and when available) and on-site soils investigations; and
- Translating these performance targets into design guidelines that can be applied at the site level to mitigate the impacts of land development.

The Guidebook emphasizes that performance targets and rainwater management practices be optimized over time based on monitoring the performance of demonstration projects; and strategic data collection and modeling. As success in meeting performance targets is evaluated, rainwater management programs can be adjusted because: ***We change direction when the science leads us to a better way***.

Relationship of the Rainfall Spectrum to Watershed Objectives: The Guidebook 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 (Figure 2), 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'; and
- **Flood Mitigation** – reduce flooding by providing sufficient hydraulic capacity to 'contain and convey'.

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



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

Integrated Strategy for Managing the Rainfall Spectrum

Figure 2

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.*

Setting Performance Targets

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

Synthesize Complexity: The Guidebook states that:

"For a performance target to be implemented and effective, it must be quantifiable…. To be understood and accepted, a performance target needs to synthesize complexity into a single number that is simple to understand and achieve, yet is comprehensive in scope. A runoff volume-based performance target for rainfall capture and rate control fulfills these criteria."

Volume-based thinking is an integral element of a paradigm-shift that views watersheds as a fully integrated system where creek headwaters originate at rooftops and roads…. The implications are far-reaching because a volume-based approach to stormwater management touches on virtually every aspect of land use planning and site design.

Volume-based thinking leads directly into landscape architecture, green roofs, urban reforestation, interflow and groundwater recharge, and water re-use." (source: page 6-1)

Cumulative Impacts or Cumulative Benefits at the Site Level: The Guidebook states that:

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

In order to achieve the target condition for a healthy watershed as a whole, cumulative impacts must be managed at the site level. This means that rainwater systems at the site level must be designed to achieve the runoff volume and rate targets." (source: p 6-5)

Framework for ISMP Analysis: The runoff volume and rate targets presented in Guidebook Chapter 6 provide a reference point that is based on the Water Balance and hydrology of a healthy watershed. To determine whether these targets are realistic or achievable for a given watershed the Guidebook states that an ISMP must answer the following questions (reference: p 6-8):

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

Establish an Appropriate Starting Point: The Guidebook describes the need for flexibility in setting performance targets:

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

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

Continuous Water Balance modeling can be applied to determine what is effective and affordable." (source: p 6-8)

Use Performance Targets to Quantify Watershed Objectives

The Guidebook states that, in general, a watershed planning process must address the following fundamental question:

> *"How can the ecological values of stream corridors and receiving waters be protected and/or enhanced, and drainage-related problems prevented, while at the same time facilitating land development and/or redevelopment?"* (source: page 9-1)

As discussed in the Guidebook, performance targets provide a quantifiable way of measuring success in protecting (or restoring) a watershed, and for identifying what needs to be done to achieve a given environmental protection objective.

- Desired protection objectives for significant stream reaches can be translated into performance targets for reducing runoff volume from the catchments draining into those reaches.
- For catchments upstream of chronic flooding locations, a more appropriate performance target may be to reduce peak runoff rates from large rainfall events.
- Other performance targets relating to the preservation/restoration of significant natural features, measurement of stream health, protection/improvement of water quality, or in-stream enhancements can also be established.

A key principle is to establish performance targets that relate directly to the watershed objectives.

Once watershed objectives have been established, alternative scenarios for achieving those objectives have been generated, and the data needed to evaluate the effectiveness of these scenarios has been collected, the next step is to evaluate the alternatives and make decisions. These decisions will provide the basis for developing plans for habitat enhancement, flood risk mitigation and relevant land development actions.

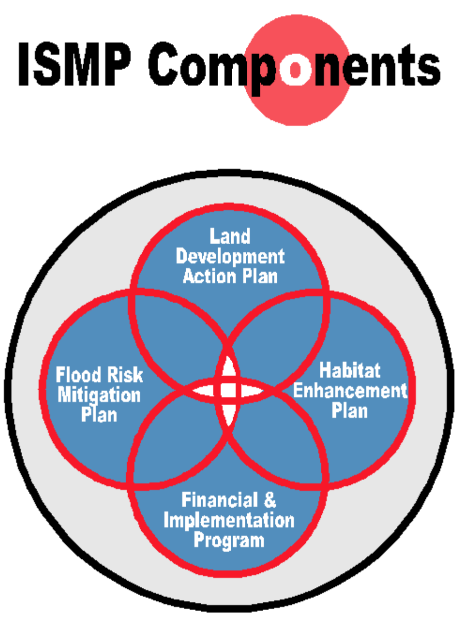
Model Alternative Scenarios: Scenario modeling is used to assess a range of performance targets, and evaluate options for achieving these targets. Furthermore, scenario modeling involves consideration of the complete spectrum of rainfall events that typically occur in a year. The Guidebook states that:

"The balance between the above three components depends on the watershed objectives.

- *Stream protection/restoration objectives would likely govern scenarios that emphasize source control (e.g. infiltration, rainwater re-use), along with other possible options, such as riparian corridor protection.*
- *Flood management objectives would likely govern scenarios that place more emphasis on detention and conveyance.*

The key is to determine which scenario or blend of scenarios has the best 'fit' to address a range of watershed objectives.

A key aspect of scenario development will be to consider what can be done at the site level to retain the small events, given constraints such as soil conditions, hydrogeology, topography and land use. Further data collection may be required to assess the feasibility of achieving performance targets." (source: page 9-14)



Runoff Volume Target

In 2002, the science was explicitly telling us that major biophysical changes occur once the impervious percentage of a watershed reaches about 10%. Beyond this threshold, the change in the Water Balance triggers watercourse erosion, which in turn degrades and /or eliminates aquatic habitat.

The science was also explicitly telling us that where urban use densities are produced, the focus should be on what needs to be done at the site level to effectively mimic a watershed with only 10% impervious area, and in so doing reduce runoff volume to the same 10% level.

Protect Stream and Watershed Health: The Guidebook addressed the question of what could be done at the site level to protect stream and watershed health; and presented the following rationale for early action:

"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.

Common sense says that we now have sufficient science-based knowledge and understanding for local government to make some decisions, and to get on with implementing early action in at-risk areas. More data to refine the science is desirable when there is time and resources; however, there will be situations where excessive data collection becomes a barrier to effective action in the face of an immediate risk.

Strategic data collection is required to understand the historic Water Balance, the current Water Balance if the watershed is partially developed, and the proposed changes to land use in the watershed.

Looking ahead, the objectives of most Integrated Stormwater Management Plans (ISMPs) will include trying to maintain or restore the natural Water Balance as development or re-development proceeds. Improved understanding of how to do that will evolve through demonstration projects that test and refine solutions to aquatic habitat and receiving water quality challenges." (Source: p 2-11)

Establish An Achievable Target: To provide a starting point for early action, the Guidebook referenced the Water Balance Methodology to a **healthy watershed**, defined as one where the proportion of impervious area is below the 10% threshold for runoff volume. As noted in the previous section, the Guidebook defined 'rainfall tiers' to enable a systematic approach to data processing and identification of rainfall patterns, distributions and frequencies.

A key finding was that the frequently occurring, light to medium rainfalls account for 90% of the total annual rainfall volume. This established that rainfall capture is achievable. This finding provided the initial basis for establishing a Rainfall Capture Target to prevent surface runoff from the *impervious* portions of a development site; however, the Guidebook also cautions that:

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

Based on these assessments, catchment-specific performance targets and design guidelines for achieving these targets can be established. These catchment-specific targets and guidelines will then provide direction for all land development projects within each catchment." (source: p 6-20)

Runoff Rate Target

The Guidebook emphasizes that a combination of *Runoff Capture* and *Rate Control* is necessary to mimic the rate of interflow in a naturally vegetated watershed. Interflow is defined as the portion of rainfall that soaks into shallow ground and moves slowly through soils to streams. To provide a starting point for early action in achieving runoff control, the Guidebook identified the goal of **maintaining the natural Mean Annual Flood** as the runoff rate target.

The Mean Annual Flood (MAF) is defined as the channel-forming event; as the MAF increases with development, stream channels erode to expand their cross-section, thereby degrading aquatic habitat.

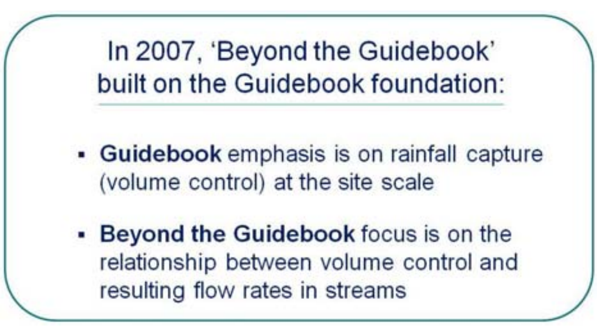
Beyond the Guidebook: It was in addressing the inter-relationship between Runoff Capture and Rate Control that *Beyond the Guidebook* picked up where the Guidebook left off in 2002. The Guidebook had focused attention upon the site level while assuming there would be benefits to the watershed and streams. By 2007, our knowledge had progressed, and it was clear that the next step was to correlate the rainfall spectrum with all the flows entering tributary streams from the watershed.

Further to the above, the Beyond the Guidebook initiative represents the initial 'course correction' in response to a concern that had emerged:

- Runoff volume targets for rainfall capture were often being applied in an overly simplistic manner.
- This seemed to be because people had forgotten that rainfall does not equal runoff, and that physical processes are complex.
- This apparent disconnect in understanding was having unintended consequences in terms of the target-setting process.

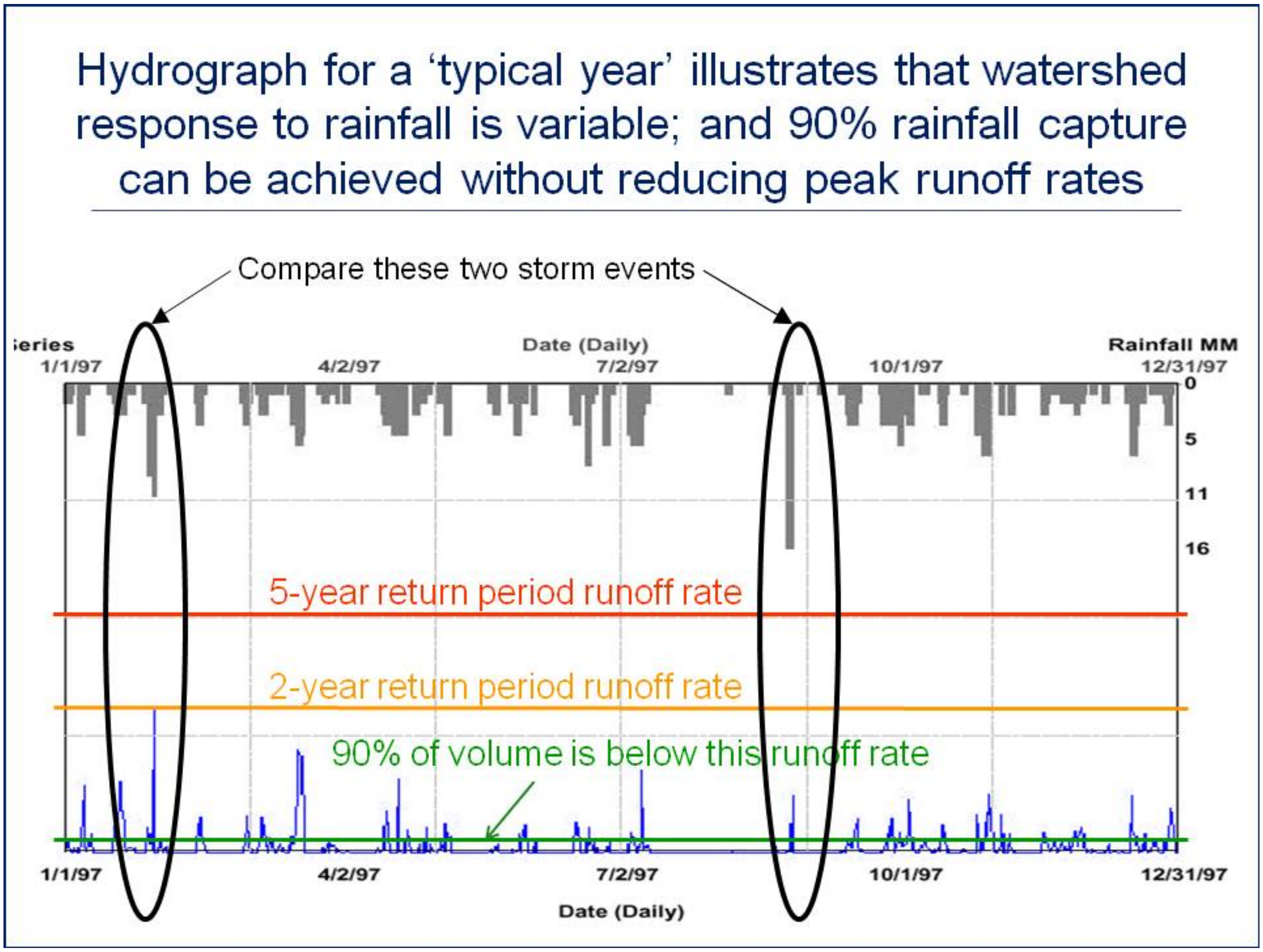
Figure 3 on the page following was developed as a communication tool to address the above concern. This graphic shows some of the complex processes involved in a watershed between the time rain falls and when it reaches the stream. Plotted from the top are the daily rainfall amounts in millimetres and from the bottom is the discharge from the subject watershed.

The ability to assess the interaction of rainfall and runoff became critical to going "beyond the Guidebook" in order to establish reasonable and achievable performance targets.



Rainfall-Based vs Runoff-Based Approach: 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.

The *Rainfall-Based Approach* grew out of simple to use methodologies that address the reduction of flood risk for drainage conveyance systems. The R*unoff-Based Approach*, on the other hand, leads to the analysis of runoff and its interaction with the physical aspects considered important to the aquatic environment.



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 3

4. Levels-of-Service

Section 1 introduced the challenge posed by the 'unfunded infrastructure liability'. It is increasing year after year due to the legacy cost resulting from renewal and/or replacement of road, water and sewer systems. An increasing local government 'infrastructure deficit' means that there will be even more competition for available funding. Thus, a driver for the *ISMP Course Correction* is to demonstrate how to 'do more with less' by placing emphasis on what really matters and being outcome-oriented.

Connecting the dots between watershed health and infrastructure type has emerged as an important piece in 'sustainable drainage infrastructure', both fiscally and ecologically.

Infrastructure Asset Management

Asset management usually commences after something is built. The challenge is to think about what asset management entails BEFORE the asset is built. This paradigm-shift starts with land use and watershed-based planning, to determine what services can be provided sustainably. The linkage to asset management is a way to re-focus ISMPs on outcomes.

Tackling the unfunded infrastructure liability has led to a life-cycle way of thinking about infrastructure needs, in particular how to pay for those needs over time. The Province is branding this holistic approach as *Sustainable Service Delivery*.

Sustainable Service Delivery: Level-of-service is the integrator for everything that local governments do. Everyone will have to make level-of-service choices. Thus, a guiding principle for a Watershed Blueprint is framed this way: *Establish the level-of-service that is fiscally sustainable AND protects watershed health.*

The financial burden and environmental impacts associated with 'pipe-and-convey' infrastructure contrast with the benefits of 'green' infrastructure at a watershed scale: *natural landscape-based assets reduce runoff volumes, have lower life-cycle costs, decrease stresses applied to creeks, and enhance urban liveability*.

Life-Cycle Analysis

Everyone needs to be thinking in terms of life-cycle costs, especially future recapitalization of the investment. Historically this has not been considered as significant in traditional infrastructure decision-making.

While developers and new home purchasers pay the initial capital cost of municipal infrastructure under either greenfield or redevelopment scenarios, it is local government that assumes responsibility for the long-term cost associated with operation, maintenance and replacement of infrastructure assets.

A rule-of-thumb is that the initial capital cost is about 20% of the life-cycle cost. The other 80% represents an unfunded liability.

Reassess Existing Practices: The process of establishing an acceptable *'Level-of-Service'* will require local governments to reassess the rationale for existing practices and standards; and determine whether and what changes may be necessary in future to achieve a balance between cost, affordability and community willingness to pay.

If, for example, application of new standards that accommodate climate change would trigger a costly upgrade of existing drainage infrastructure to provide greater system capacity, one should question whether the perceived benefit would justify the cost - particularly if there is no extensive history of widespread flooding and damage resulting from rainfall or storms. One could then ask whether different criteria might result in a lower cost solution.

Drainage Infrastructure Screening Tool: A shift to a ***'Level-of-Service'*** approach is a more rational way of providing community infrastructure with acceptable levels of service and cost. The level-of-service concept could, for example, lead a municipality to revise a design standard to a uniform drainage capacity rather than one subject to changing design frequency and intensity.

Section 4 presents a pipe capacity screening tool for assessing drainage level-of-service.

5. Drainage Infrastructure Screening Tool

A typical situation faced by local governments is this: an existing storm sewer system; some problem areas; limited funding available for system upgrades; and the need to provide flood protection while being fiscally responsible. To address this 'typical situation', a web-based *Drainage Infrastructure Screening Tool* is under development by the Partnership. It will help local governments achieve more with less. It will be incorporated as a Water Balance Model module.

Decision Framework

The goal in developing a web-based tool is to help local governments answer four questions. These provide a framework for decision-making:

1. What is the existing level of drainage service within the community?
2. What will be the effect of climate change?
3. What will be the effect of redevelopment?
4. What will be the effect of climate change on redevelopment?

To accomplish more with less, the objective is to enable local governments to undertake drainage system capacity analysis without the need for intensive and expensive modelling of the storm sewer system.

Guiding Principle: Many drainage systems operate without serious problems for many years. Furthermore, the vast majority of the time, the system capacity is only partially utilized for conveyance. These reality-checks lead to this guiding principle:

> *Provide a uniform Level-of-Service (LOS) for both drainage and flood prevention, one that is based on a uniform area discharge rate.*

This would provide an equal level of service or access to the drainage system for all properties within the watershed.

Universal Relationships

Figure 4 illustrate relationships that underpin the Drainage Infrastructure Screening Tool.

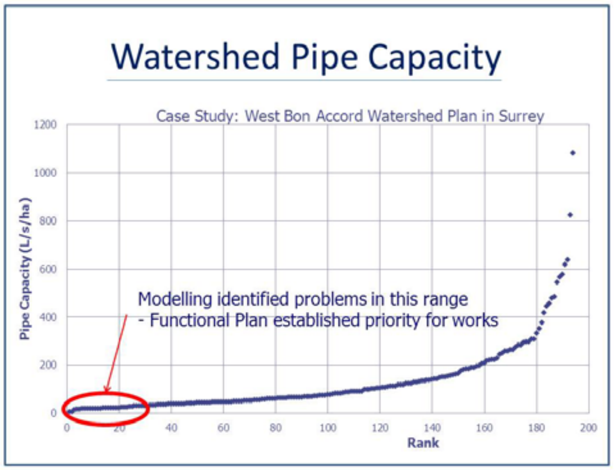
Watershed Pipe Capacity: Figure "A" shows the ranking of every section of storm sewer pipe within a watershed area. This illustrates the relationship between tributary drainage area and installed pipe capacity per hectare. In this case, detailed modelling established that 'problems' fall within a narrow range. The lesson learned is that one need not model every section of pipe.

Typical Design Discharges: Figures "B" and "C" show that standard practice for pipe sizing results in a narrow range of values when design discharges are expressed as unit discharges. The lesson learned is that unit discharge rates for various return periods can be reasonably established and applied to establish the LOS provided by each section of pipe.

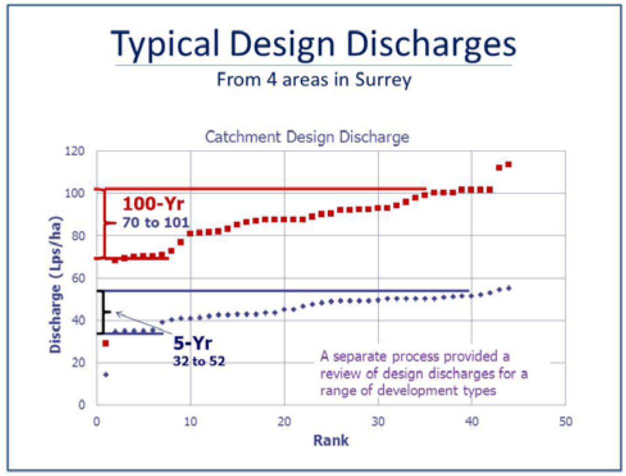
Setting Priorities: Figure "D" shows application of the lessons learned to establish priorities and make decisions. This LOS approach serves as an inexpensive screening tool. It provides relevant information for capital planning; and it does this without the need for detailed and expensive computer simulation of the drainage system. The process establishes existing system capacity and then identifies those parts that do not meet this standard. These can then be prioritized and entered into a capital plan.

Summary of the Methodology to "Achieve More with less"

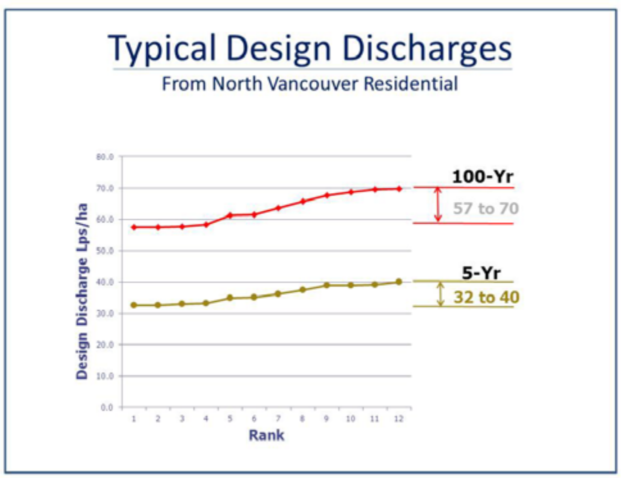
- Identify design discharge (Lps/ha) or required (desired) Level-of-Service
- For each section of pipe estimate:
  - ✓Catchment area and capacity (Lps/ha)
  - ✓Actual Level of Service
- Compare design discharge to installed pipe capacity
- Identify problem areas ($Q_{capacity} < Q_{design}$)
- Modelling is optional



(A)



(B)



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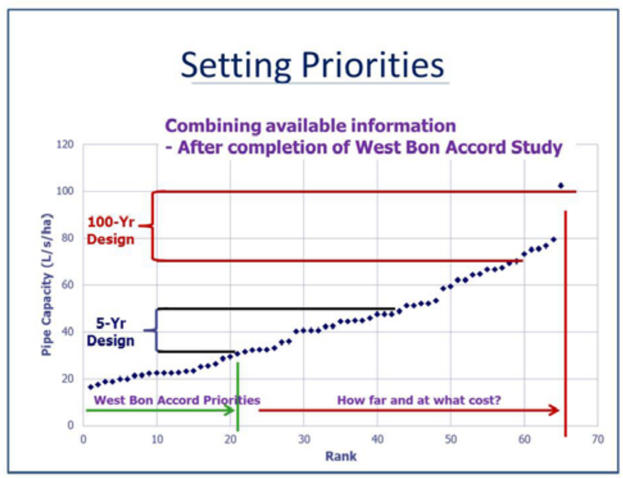


(D)

Application of Drainage Infrastructure Screening Tool

Figure 4

6. Drainage Modelling in the 21st Century

Developed as an extension of the Guidebook, the Water Balance Model (WBM) bridges planning and engineering; links development sites to the stream and watershed; and enables science-based performance targets to be established. It is a scenario comparison and decision support tool. The 'WBM powered by QUALHYMO' differs from other drainage modelling tools in three fundamental ways:

- it is web-based;
- development is driven by the community of users; and
- it can help create a vision of the future watershed.

"All three are powerful in their own rights. There is no other comparable web-based tool," states Dr. Charles Rowney, WBM Scientific Authority and creator of the QUALHYMO calculation engine

The WBM is Unique

The WBM demonstrates how to achieve a lighter 'water footprint'. This helps planners and designers wrap their minds around how to implement 'design with nature' solutions on-the-ground. The stream health methodology embedded in the WBM enables a watershed target to be established. It also enables the user to assess how to meet the watershed target at the site scale.

A key message is that the WBM is a unique 'scenario comparison tool'. Because there is no restriction on the scenarios, this allows users to create an understanding of the past and present and compare it to many possible futures. This capability allows communities to assess how watersheds can be altered, for good or bad. Then they can create a vision of where they would like to go, and how the watersheds can meet their vision.

What Drives a Successful Model?

At the 2011 WBM Partners Forum, Dr. Charles Rowney reviewed the implications of computing technology decisions.

Impediments to Success: "Figure 5 is a distillation and synthesis of conversations with several hundred people from all around the world who are experienced modellers. Within this group are individuals who I consider to be the premier people in their field. When we discussed the question **- what are the major issues? -** seven themes emerged," stated Dr. Rowney. In order of priority, they are:

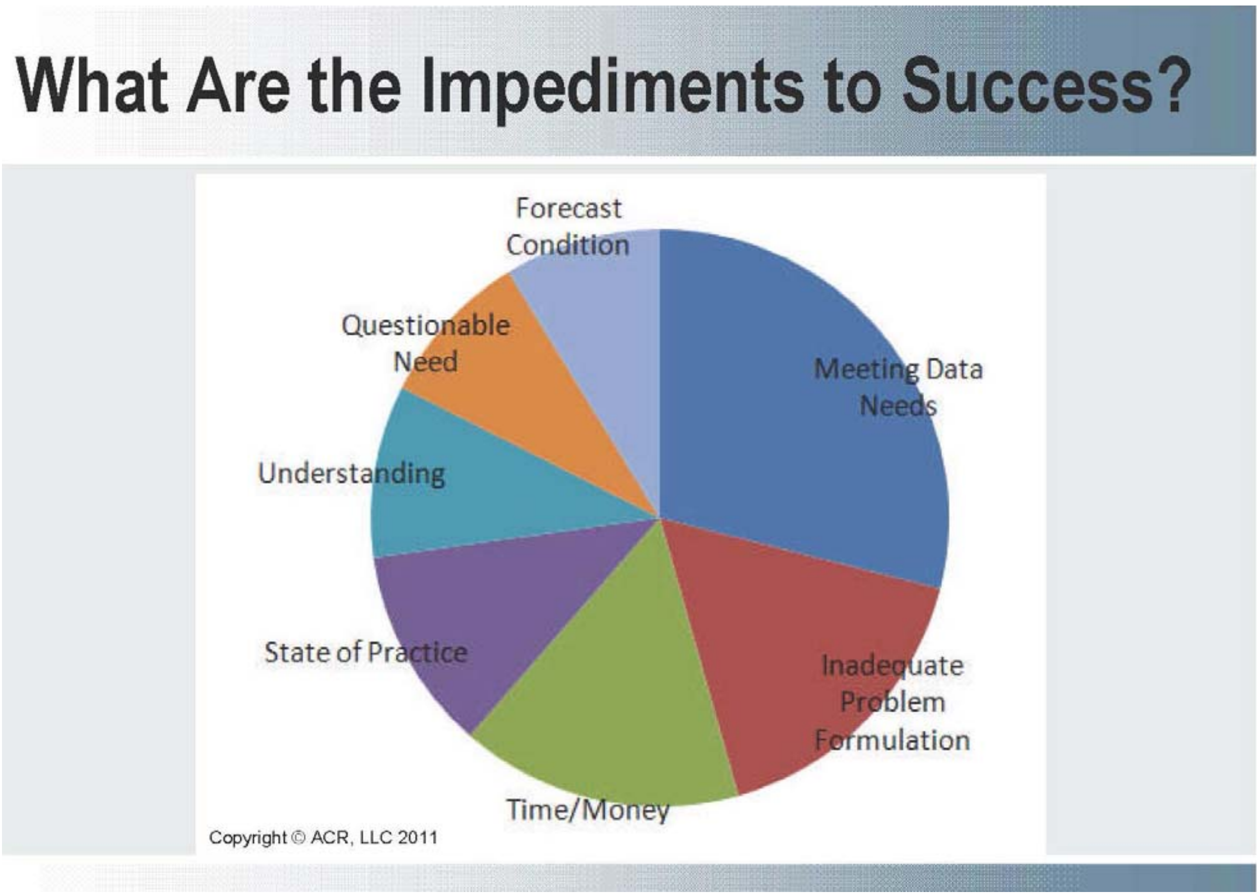
1. Meeting Data Needs
2. Inadequate Problem Formulation
3. Time / Money
4. State of Practice
5. Understanding
6. Questionable Need
7. Forecast Condition

"What is interesting about this synthesis of an engine as compared with the framework that is the WBM is that these seven impediments are tackled head-on."

Meeting Data Needs: "The number one point of pain is meeting data needs. We have all heard the stories about a model such as HSPF with 30 or 40 parameters to adjust, and the best curve-fitting engine in the world, but we can't find the data. We can't make it work."

"If we take what we as a community know is required, the data needs to get to the end-point within the WBM are just minimal. **They are no less than is needed; but they are no more than is needed**. When you think about what is happening with this Water Balance tool in terms of consistency, and in terms of what you might call a consensus standard and agreed approach, it is formulating the problem in a way that is technically defendable...and that is workable."

"What we doing with the WBM is exciting. It is a direct attack on what it takes to get the answers. We are evolving the state of practice. BC is the only place I know of where there is a link between the applied practice and climate change, and what are we going to do to make this a routine part of our analysis," summarized Dr. Rowney.



Drainage Modelling: Seven Impediments to Success

Figure 5

The Uncertainty Cascade

Figure 6 is a synthesis that comprises eleven steps that cascade down from a theory to interpretation of results. Dr. Rowney has coined this mind-map as the *Uncertainty Cascade*:

1. Theory
2. Conceptual Model
3. Mathematical Model
4. Solution Algorithm
5. Code
6. Adjusted Algorithm
7. Executable
8. Site Representation
9. Calibration
10. Case Representation
11. Interpretation

“There is a preoccupation with theory, but the heavy lifting takes place in the last four steps. We need to keep our focus on SOLUTIONS on the ground," emphasized Dr. Rowney.

From Theory to Interpretation: "We start with a theory, we develop a conceptual model of that theory and how things work. Next, we come up with a mathematical model that describes that concept, and we create a solution algorithm. We write some computer code, we adjust that because the code never really does what we want it to, and we come up with an executable.”

"Then we start to represent the site and start putting all our data together. We calibrate and adjust our model with the data. Then we start to think about how we will look at our future case. And finally we start to interpret our results."

"Much of the discussion and arguments are about the theory and model. You will hear these kinds of statements: *I have a model that does this or does that; I can do a pipe this big or that big; I can do this kind of thing, I can do that kind of thing*. Yet the heavy lifting is at the other end."

"The real problems and solutions come together when you look at the site and the data you have to represent what you have. How do you compare the future condition that is very undefined with a calibrated tool that is very well defined? There is much that we do that has a place and purpose, BUT sometimes what we do is questionable."

Focus on Solutions: "We have learned that we really need to look at things from the point of view of the solution. As we have been working on the WBM, we have been orienting it to THE SOLUTION. We are keeping it as simple as possible, but no simpler. The tool has to be consistent, inexpensive, and workable with limited data. It has to fit the local context, and it has to evolve as we learn.

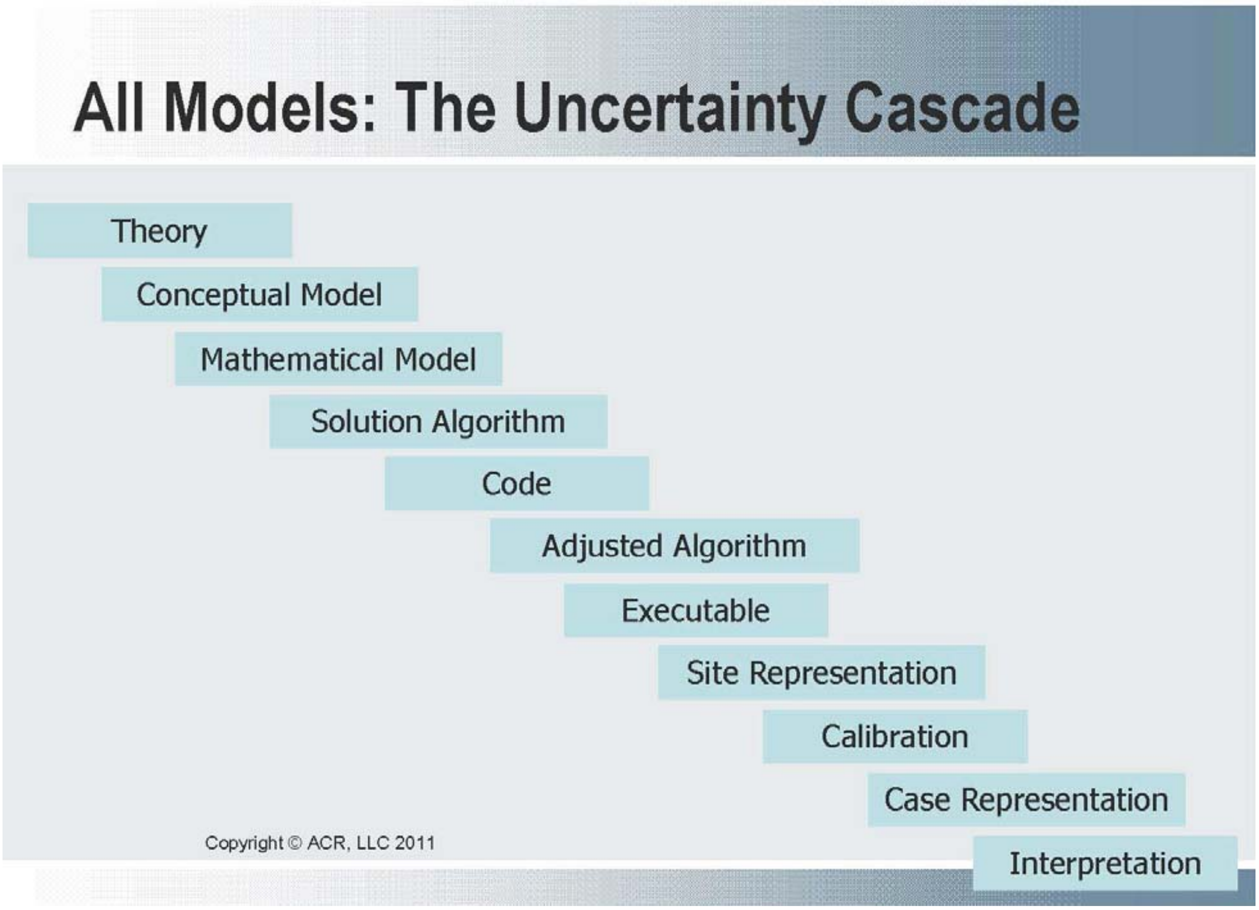
"What is it that we really want to solve? Where are we driving this? We have ample horsepower to pick just about any theory we want and put it inside the WBM. But what we really need to focus on is: *what are the solutions that are really necessary*. Once we have figured out the solution that we need, we need to come up with tools that do that and no more and no less.”

"An outcome that we are pushing for is the ability to interpret results, and the ability to represent the cases that we are actually trying to solve.”

Bridge between Scales of Need: "There are two levels of thinking. At one level is the broad scale of planning where we look at how and where we might wish to go tomorrow - for example, how should we view the watershed and what might we do to protect receiving waters. And at the other level is the need to eventually put something on or in the ground."

"We need to bridge those two kinds of needs. With the WBM, we have a tool on a platform that is designed to do just that. As we go forward with model development, we need to know more and more about that polarity. At one end, it is about where are we going to take this tool. At the other end, lot by lot by lot, it is about how we put things in the ground to ensure they work."

"What we have learned is that we really need to take a look at this from the point of view of the solution. As we have been working on the WBM, we only go as complicated as is necessary. We strive to make the tool as simple as possible, but no simpler. It has to be consistent, cheap and workable with limited data. It has to fit the local context; and it has to evolve because we are not at the end point today. The WBM will continue to grow and adapt over time," concluded Dr. Rowney.



Drainage Modelling: From Theory to Interpretation

Figure 6

7. Water Balance Model powered by QUALHYMO

The web-based *Water Balance Model for British Columbia* (found at www.waterbalance.ca) is the embodiment of the building blocks described in the foregoing sections. This scenario comparison and decision support tool was developed by an inter-governmental partnership to meet the needs of local government. Launched in 2003, it has since gone through two platform conversions as technology has evolved.

The Water Balance Model (WBM) comprises two distinct components: the web-based user interface; and the QUALHYMO calculation engine (Figure 7). The latter was developed in the 1980s with funding provided by the Ontario Ministry of Environment. The strength of QUALHYMO resides in the 'flow exceedance analysis' which is key to correlating streamflow with impacts on stream health.

Bridging Policy and Practice

A driver for development of the WBM was the need to bridge the gap between high-level policy objectives and site design practices. The QUALHYMO calculation engine provides the ability to quantify and assess hydrologic effectiveness of 'green' infrastructure. This then enables setting of achievable performance targets for reduction of rainwater runoff volume and stream erosion.

The WBM outreach and training program supports the Province's Living Water Smart (2008) and Green Communities (2008) initiatives. Program goals include:

- facilitate an understanding of the rainfall-runoff process;
- enable land development and infrastructure professionals to implement 'design with nature' designs; and
- soften the 'water footprint' of development.

In 2009, the WBM received a *Premier's Award for Innovation and Excellence*.

How to Address Runoff Quality

Integrated rainwater management includes attention to both runoff quantity and quality. The QUALHYMO engine can simulate water quality and can add sediments and dissolved constituents to the analysis process. Because we can calculate how much energy is available in a stream, we can then compare scenarios to determine the most effective combination of rainfall capture measures on development sites.

Sediment Build-Up and Wash-Off: Normal sediment loading from a stable urban watershed is in the range of ~0.1 to ~0.6 tonnes per year per hectare of watershed. It is therefore normal and expected that a stream will carry some sediment on a regular basis. Because sediment transport is a natural process, it should not be disrupted without anticipating some consequences.

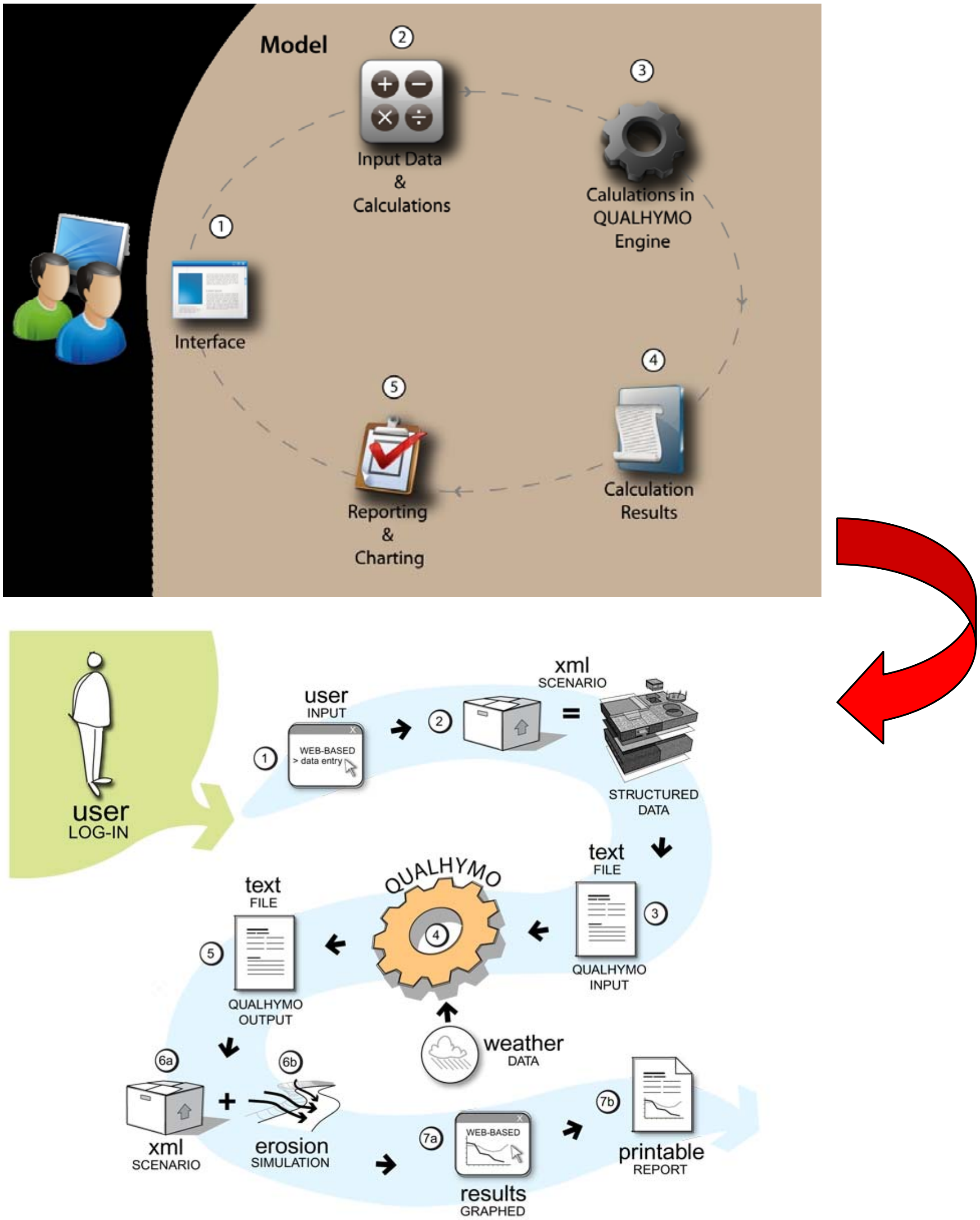
So, when simulating the build-up and wash-off of sediment and first-order decay contaminants from a watershed, the general objective is to identify what combination of rainfall capture measures will maintain a natural level of annual suspended sediment loading.

"Everyone has a different concept of water quality and how to model it. It is not easy. So we need a surrogate. Sediment meets that need; and this is what is unique about QUALHYMO," states Dr. Charles Rowney.

How to Set Performance Targets

The WBM enables the user to establish performance targets for rainfall capture and runoff control at the site, neighbourhood and watershed scales. Appendix B presents the "how to do it" steps in applying the methodology.

The WBM is accessible to multiple levels of users who have a wide range of technical backgrounds, from hydrology experts to stewardship groups.



Water Balance Model
powered by QUALHYMO

Figure 7

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Appendix A:

Water Balance Model Methodology