BURNABY MOUNTAIN SUSTAINABLE COMMUNITY: OVERCOMING FEAR AND DOUBT, AND MANAGING STORMWATER AT THE SOURCE

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ABSTRACT

Burnaby Mountain is located about 15 kilometres due east from Downtown Vancouver, and is situated in the City of Burnaby on the West Coast of Canada. With a population of 180,000 people, Burnaby is the third largest municipality in the Province of British Columbia. Located at the top of Burnaby Mountain is Simon Fraser University (SFU).

The mountainside below the university is in a natural state. The mountain is a green oasis within a 'big city' urban environment. It is often described as the 'crown jewel' of Burnaby.

The 'SFU vision' is to develop a complete urban community at the top of Burnaby Mountain that demonstrates principles of sustainable development through a *balanced approach,* one that builds a compact community while protecting natural systems. One of the underpinning principles is to manage watercourses and stormwater flows to protect aquatic habitat in affected watersheds.

This new community will be highly urban – with densities ranging from townhouse up to ten storey towers. It will include a main-street commercial area, new university buildings, and extensive underground parking. This density of development will involve extensive modification to the land, including the realignment of several intermittent and disturbed headwater streams, as well as daylighting of existing piped watercourses.

The paper compares traditional stormwater management approaches to urban development with the approach applied at Burnaby Mountain. It discusses how project planning included science-based rainfall capture criteria that clarified stormwater objectives for the development.

The paper shows how the proposed system balances storage on private development parcels, on-street storage and downstream detention using a full range of best management practices, ranging from in-building cisterns, to absorptive landscape soils, to constructed wetlands.

The paper explains how the concept of 'functional equivalency' was applied to the development plan, and how the design for the site assesses the contribution that each existing ditch and small tributary makes to the watershed to ensure that an equal or better equivalent is provided in the final development.

KEYWORDS

Sustainable development, stormwater management, rainfall capture

INTRODUCTION

With a campus population of over 25,000, Simon Fraser University (SFU) at the top of Burnaby Mountain is sometimes described as a city within a city. The campus is bounded by a Ring Road.

In 1995, SFU transferred 773 acres below the Ring Road to the City of Burnaby to create the Burnaby Mountain Conservation Area. The City and SFU then agreed to an Official Community Plan that also established high-density zoning within the Ring Road for a new community of approximately 10,000 people on the remaining 160 acres.

The land exchange created, in effect, a density transfer. Instead of creating the possibility of a single family housing development that would cover a large area of Burnaby Mountain, the density transfer accommodates about the same number of units on 20% of the land area, saving 80% of the land for conservation purposes.

SFU has established the Burnaby Mountain Community Corporation (BMCC) to manage the development for the University. The University '*intends to design and develop a model community integrating residential, commercial and academic uses in a manner that will bring international acclaim, both to the University and the City of Burnaby'*.

The density transfer is the first environmental achievement of the project – rather than creating single-family housing development that would cover the entire hillside, the density transfer accommodates about the same number of units on 20% of the land area, saving 80% of the land for conservation purposes.

The project's second environmental achievement is to create a compact and complete community, integrated with the university campus, that will be walking and transit oriented. A reduction of up to 40% in car trips is projected, compared with a more traditional single-family development.

The project's third environmental achievement is the plan for performance monitoring and adaptive management. The Burnaby Mountain Community will be implemented in stages over about a 25-year period. This will create opportunities for constant improvement in successive phases of the stormwater and watercourse management plan.

OFFICIAL COMMUNITY PLAN REQUIREMENTS

The Official Community Plan (OCP) for Burnaby Mountain outlines the requirements for watercourse and stormwater management. It states that "the *Watercourse and Stormwater Management Plan* is intended to allow development in accordance with this Plan to proceed within the Ring Road while protecting the environmental resource values of the downstream watercourses; i.e. Stoney Creek, Eagle Creek and Silver Creek". It then goes on to list the "issues to be addressed" (i.e. the *OCP Issues Framework*):

Issue	OCP Policy Statement
1	Maintaining pre-development stormwater runoff rates, volumes and seasonal variations to maintain existing downstream hydrologic patterns
2	Maintaining pre-development water quality to ensure downstream aquatic life is not adversely affected
3	Potential development of a detention ponds system within the Ring Road on University property that effectively addresses runoff rates and quality
4	A strategy for management of the existing watercourses within the Ring Road, including the identification of watercourses which are to be enhanced or improved, as well as any minor watercourses for which diversion, culverting or enclosure is proposed
5	Impacts originating from the University's lands on the north face drainage area (re: fisheries impacts and slope stability)
6	All relevant environmental issues discussed in Section 3.0 of the OCP. This section states that subdivision, servicing, site planning and design for development within the Ring Road is to be sensitive to the existing natural environment including topography, watercourses, significant trees and wildlife habitat.
7	Ownership and responsibility for proposed stormwater facilities

These OCP issues are categorised into the following specific areas of concern:

- ☐ Ecological Function of Watercourses
- ☐ Increase in Runoff Volume
- ☐ Frequency and Magnitude of Runoff Events
- ☐ Incremental Increases in Peak Flows
- ☐ Long-Term Impacts to Water Quality
- ☐ Sediment Control during Construction
- ☐ Long term maintenance and operation

THE CHALLENGES

Land development alters the natural water balance. When natural vegetation and soils are replaced with roads and buildings, less rainfall infiltrates into the ground, less gets taken up by vegetation, and more becomes surface runoff. The biggest increments of change occur when forested land is first cleared, then ditched, and finally paved or roofed over.

This change in the water balance is the root cause of drainage-related problems in an urban watershed. Changing the water balance triggers watercourse erosion and sedimentation processes that then degrade or eliminate aquatic and/or riparian habitat.

The Burnaby Mountain project is an opportunity to demonstrate how a new, sustainable community can integrate stormwater and watercourse management with urban design, starting where the rainfall lands.

The high expectations for the project are not just held by the university community. The lands fall within the area of two watershed management pilot projects – the Brunette Basin Plan and the Stoney Creek Watershed Plan:

- The **Brunette Plan** was the result of an inter-agency and inter-municipal pilot process for consensus-based watershed planning in the Greater Vancouver Region.

- The **Stoney Creek** sub-watershed strategy was then the 'pilot within a pilot'. Its purpose was to test the principles of a *watershed-based approach* to integrating stormwater and riparian corridor management. The Stoney Creek process resulted in a philosophy and in hydrologic criteria for watershed restoration over a 50-year timeline. The same philosophy and criteria are to be applied to all Burnaby Mountain sub-watersheds.

These plans established demanding objectives for integrated stormwater management – requiring a level of protection far more demanding than that of prevailing standards, and requiring that the performance of this high-density community mimic that of the existing site, which is more than 75% forested. These high expectations are supported by senior government agencies and local streamkeeper groups.

The Burnaby Mountain Community applies the vision, objectives and guiding principles of the Brunette and Stoney plans. Early in the project planning, the Burnaby Mountain design team created ten sustainability principles under four themes – sustainability in environment, economics, equity and education. Details of these principles can be seen at http://www.sfu.ca/bmcp/.

Adding to these challenges, the project site is unique – a mountaintop sitting high above the surrounding city. The elevation of the campus site is high enough to create a local microclimate – with slightly higher annual rainfall than surrounding areas, but also more freezing weather and snow than below.

SOLVING CHALLENGES BY STARTING AT THE SOURCE

Traditional stormwater management approaches treats runoff once it has accumulated – at the end of the pipe. For the Burnaby Mountain project, stormwater management starts at the source – where rainfall lands.

Water Balance Approach to Stormwater Management

In view of the consequences of changes to the water balance, the strategy for Burnaby Mountain is to maintain as close as possible the water balance for existing land uses within the Ring Road. The key objectives of this strategy are:

- ☐ **Flow Volume -** Reduce surface runoff volume to prevent erosion and support seasonal baseflow

- ☐ **Flow Rate -** Slow down the rate of surface runoff to prevent erosion and flooding

These volume and rate objectives form the basis for a *water balance approach to stormwater management.* The approach has two distinct components:

- ☐ **Rainfall Capture -** Capture the low intensity, frequent rainfall events (small storms) at the source and return volumes to more natural hydrologic pathways (i.e. volume reduction). This means that the small events would be infiltrated into the ground.

- ☐ **Runoff Control -** Detain surface runoff from higher intensity, infrequent events (large storms) and release it under controlled conditions (i.e. rate control). The rate of release must meet the criteria established for the Stoney Creek watershed.

Understanding Runoff Control versus Rainfall Capture

Runoff control *without* rainfall capture is the conventional detention-based approach to stormwater management. Evidence shows that this approach does not protect downstream fish habitat which are sustained under natural levels of erosion, sedimentation, and baseflows in watercourses.

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

Rainfall capture requires *storage at the source*, where water is stored and infiltrated into the ground rather than released directly to surface drainage systems. This reduces runoff volume and supports stream baseflow by partially restoring the natural water balance.

Stoney Creek Criteria for Watershed Protection

The *runoff control component* of the water balance strategy is based on implementing the criteria for detention storage sizing as established in the Stoney Creek Plan:

Parameter	Parameter Value
Input Hydrograph	5-Year Rainfall Event (R_5), and the runoff pattern associated with the watershed response for the post-development land use condition
Release Rate	50% of the 2-Year Event (Q_2) peak flow associated with the watershed response for the pre-development land use conditio*n*

The *rainfall capture component* of the strategy is based on maintaining the existing Effective Impervious Area (EIA) for the watershed. This can be accomplished by minimizing the number of times per year that rooftops and paved areas contribute runoff by providing opportunity for storage and infiltration of runoff generated from these surfaces during small rainfall events.

Adaptive Methodology for Implementing Stoney Creek Criteria

The Stoney Creek Watershed Plan developed a philosophy and hydrologic criteria. The Burnaby Mountain Plan translated those criteria into conservative design values for *both* rainfall capture and runoff control. Table 1 summarizes the 6-step adaptive methodology for implementing 'detention plus infiltration'.

The operational foundation of an adaptive approach is periodic environmental assessment, using modelling to predict outcomes, and monitoring to test predictions.

The Role of Site-Specific Rainfall and Streamflow Data

Two rainfall stations have been operational at SFU since 1965 and 1974, respectively. Having long-term data has enabled a science-based approach to determine preliminary design values for runoff control, and to establish a storage concept that integrates rainfall capture.

Three streamflow stations were put into operation in August 2000. The rainfall plus streamflow data has enabled characterization of the existing watershed response to rainfall, modelling of the impact of changes in land use, and validation of the design values for rainfall capture and runoff control for the Burnaby Mountain Community.

Ongoing rainfall and runoff data collection is an integral part of the adaptive approach described earlier. Having data provides a feedback loop so that the assumptions underlying the design criteria can be confirmed and/or refined over time.

Table 1 – Adaptive Methodology for Implementing Stoney CreekCriteria at Burnaby Mountain

- ☐ **STEP #1 - Establish preliminary design values for runoff control** – Using Burnaby Mountain-specific rainfall and flow data, establish conservative values for storage volume and release rate (i.e. maximise volume and minimise the release rate) that correspond to the Stoney Creek criteria.

- ☐ **STEP #2 - Integrate rainfall capture into the storage concept** – Establish the right combination of storage at the source and community detention storage. Build in redundancy to provide a safety factor that ensures detention performance will remain effective under historical rainfall conditions.

- ☐ **STEP #3 - Validate the preliminary design values and storage concept** – Using site-specific development plans, rainfall and streamflow data, perform continuous simulation modelling to validate the performance of the design values for rainfall capture and runoff control.

- ☐ **STEP #4 - Develop an integrated strategy to manage the complete spectrum of rainfall events** – Integrate a risk management component for flood control (to manage very large storms) with the rainfall capture and runoff control components (that manage the smaller storms).

- ☐ **STEP #5 - Monitor detention and infiltration system performance over time -** Assess how well the design criteria and site development actions are controlling runoff and restoring the natural water balance. This will be accomplished through continued monitoring, modelling, research and evaluation.

- ☐ **STEP #6 - Refine the design values for rainfall capture and runoff control -**. Based on the ongoing assessment process (Step #5), optimize the design and operation of detention and infiltration systems to meet stormwater management objectives.

The Importance of Interflow

The water balance comprises four components: evapo-transpiration, surface runoff, interflow, and deep groundwater. Figure 1 below illustrates the approximate balance for the existing mixed land use condition in the two Burnaby Mountain neighbourhoods.

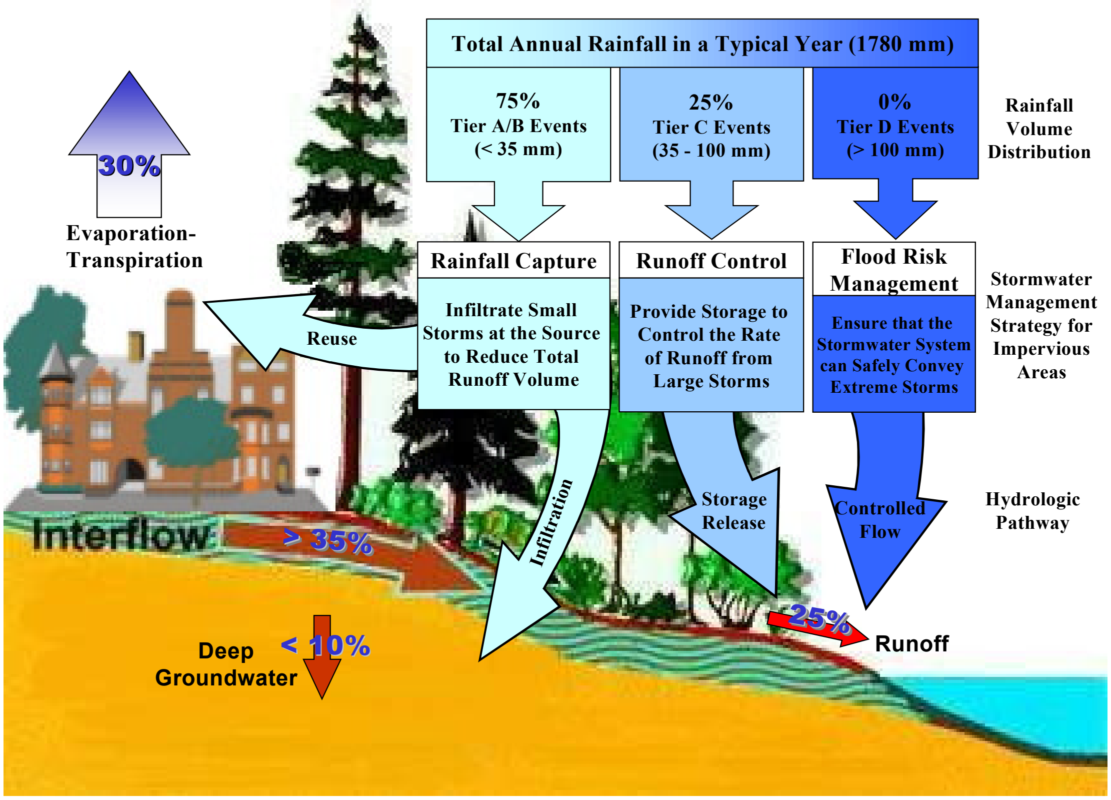


Figure 1 – Science-Based Strategy for Managing the Complete Rainfall Spectrum

Interflow is that portion of rainfall that infiltrates into the soil and moves laterally until intercepted by a stream or channel. For a fully forested area, there is virtually no surface runoff. The flow that we observe in streams is actually interflow.

Since the hydrology of a natural watershed is governed by interflow, it is a key parameter for *both* rainfall capture and runoff control:

- **Runoff Control** – storage release rate is based on matching the streamflow rate resulting from natural interflow.
- **Rainfall Capture** – the focus is on restoring the interflow component of the natural water balance.

Both existing areas for the East Neighbourhood and the South Neighbourhood represent a partially developed land use condition. This means that there *is* surface runoff. The Burnaby Mountain Plan is based on the objective to infiltrate and/or release flow at a rate comparable to the existing forested condition.

Tiered Approach to Stormwater Management

Table 2 summarizes the tiered approach that has been developed for stormwater management at Burnaby Mountain. The tiers are cross-referenced to the Stoney Creek storage and release criteria, and define three categories of rainfall capture and runoff storage elements, namely*: on-parcel, along roads, and off-parcel*.

Defining tiers is the key to the rainfall analysis. It enables a systematic approach to data processing and identification of rainfall patterns, distributions and frequencies. The tiers become the building blocks in managing the full spectrum of rainfall events, from the smallest to the most extreme.

Rainfall Distribution Pattern

The first emphasis in the stormwater management planning was to gain a clear understanding of the local microclimate. The 25 years of rainfall data were analyzed to determine distribution patterns and identify normal and peak storms. Figure 1 illustrates the results of this analysis:

- In a typical year, total annual rainfall is 1,780 mm (70-inches)
- 75% of this rainfall arrives in events that are less than 35mm (24-hr rainfall)
- 25% of the rainfall arrives in events that exceed 35mm
- The 5-year design storm is a rainfall of 100mm over a 24-hour period
- There are no rainfall events exceeding 100 mm in most years

Once the rainfall characteristics were understood, the second step involved interpreting how the rainfall interacted with the receiving environment on the site.

Initial work has focused on the East Neighbourhood of the campus, which currently has about 25% impervious parking area, with the balance of the site in second growth forest. The existing water balance is illustrated on Figure 1, and is approximately as follows:

- About 30% of rainfall returns to the atmosphere as evapotranspiration.
- Greater than 35% of rainfall moves into shallow ground – the interflow zone of organic matter and surface soils.
- Less than 10% of the rainfall enters deep groundwater.
- About 25% of the rainfall generates surface runoff.

As additional data are collected, a calibrated computer model is being used to validate and/or refine the above assumptions. In the meantime, the historical rainfall data have provided a scientific basis on which to generate initial water balance estimates.

The key innovation that will allow this project to meet its challenges is **Rainfall Capture** at the source. Figure 1 shows the target water balance that captures the small events (<35mm), and provides detention and runoff control for larger rainfalls.

Table 2 - Tiered Approach to Rainfall Capture and Runoff Control

Tier	Description	Synopsis of Management Strategy
A	**Source Control** *(up to 35mm per day)*	**Target the "<$0.5R_2$" category.** Focus is on the 160 rainfall events per year that result in up to 35mm (which equals 50% of a rainfall event having a 2-year recurrence interval). Disperse localized runoff in a natural way. Capture rainfall for beneficial re-uses and/or interflow recharge. Incorporate 'hydraulic disconnects' so that impervious areas are discontinuous. Grade sites to prevent nuisance water accumulation.
B	**Road Drainage** *(up to 35mm per day)*	**Target the "<$0.5R_2$" category.** Focus is on the same 160 events. Construct roadways to minimize pavement widths. Shed road runoff to 'green swales' for bio-retention and infiltration in 'constructed soils'. Integrate escape routes that connect to downstream drainage outlets. Where possible, self-mitigate by incorporating storage to accommodate R_5
C	**Detention Storage** *(from 35mm to 100mm)*	**Target the "between $0.5R_2$ and R_5" category.** Focus is on the 8 events per year that result in 35mm to 70mm, plus the one event that results in between 70mm (R_2) and 100mm (R_5). Provide a combination of on-parcel and off-parcel storage to mitigate runoff from impervious areas. Store and release in accordance with the Stoney Creek watershed criteria.
D	**Overland Flow** *(greater than 100mm)*	**Target the ">R_5" category.** Focus is on the two events per decade that exceed 100mm, up to the 170mm storm-of-record. For these large storms that occur infrequently, apply the 'dual drainage concept' and integrate 'escape routes' for directing excess runoff overland to drainage outlets.

Note:

R_2 is defined as a rainfall volume (70-mm) having a 2-year frequency of occurrence

R_5 is defined as a rainfall volume (100-mm) having a 5-year frequency of occurrence

Rainfall Capture Component of the Integrated Strategy

Figure 1 illustrates the integrated strategy for managing the complete spectrum of rainfall events. The Rainfall Capture component for the small Tier A/B events has several key advantages over traditional end-of-pipe-detention-only approaches:

- **Volume Reduction:** Achieves "zero runoff" for 160 events that account for 75% of annual rainfall volume.

- **Rate Control:** Reduces number of "runoff events" to less than 10 per year.

- **Water Quality Protection:** Achieves dramatic increases in water quality protection, in such elements as total suspended solids due to moderated instream flows, as well as in-soil treatment of stormwater to reduce sediments, nutrients, hydrocarbons, high water temperatures and other potential pollutants.

- **Groundwater Recharge:** Maximizes opportunities for stormwater to return to interflow and deep groundwater.

Once the first 35mm of rainfall is captured, it will be released at a rate of 15mm/day (0.625mm/hour). This very low release rate mimics the flow from a natural forested condition. Such a low release rate also is more realistic for groundwater interflow recharge than more traditional high release rates.

Runoff Control Component of the Integrated Strategy

The Runoff Control component for the Tier C events mitigates the impacts of storms greater than 35mm. For events up to 100mm, 35mm will be captured on development parcels and released at 15mm/day, and the remaining 70mm is accommodated in downstream community detention ponds and released at the same rate. A Controlled Flow pathway is provided for the Tier D events larger than 100mm.

Of note, the methodology does not rely on evapotranspiration (ET) for volume reduction, as the stormwater design is for an extreme winter event when ET is low.

STORMWATER MANAGEMENT PLAN FOR EAST NEIGHBOURHOOD

Figure 2 shows the layout and the elements of the watercourse and stormwater management plan for the East Neighbourhood. The combination of the elements provides volume reduction through infiltration, water quality protection through infiltration and riparian channels, and runoff control through detention and controlled release.

Figure 3, the Environmental Synthesis, summarizes the existing biophysical conditions in the East Neighbourhood. It shows the approximate locations of existing watercourses. All are headwater streams. They are important for their food, nutrient and biofiltration functions, and in providing a consistent flow of high-quality water for downstream uses.

RAINFALL CAPTURE IN HIGH DENSITY DEVELOPMENT

Relying on infiltration of rainfall into the ground is a controversial topic in any development. But how could rainfall be captured on high-density development parcels?

At Burnaby Mountain, the density transfer has created zoning that allows a Floor Site Ratio (FSR) of 1.7 in the East Neighbourhood to create a vibrant walking community that will support local commercial services. This translates into buildings of up to 10 storey height, density of 40 to 80 units per acre, and potential site impervious area of 70% or higher.

To further increase the challenge, various social objectives led the design towards low-rise development, including some two and three storey townhomes. Impervious area for this ground-oriented development can be greater than for point towers. Finally, valuable land and the site plans allowed no space on most parcels for stormwater detention ponds.

Key to stormwater success was the decision to locate all parking underground. With properly designed absorbent landscape over the parking garages, this reduces the effective impervious area to the 40% range. This alone, however, would not be enough to meet the target of capturing the first 35mm of rainfall right on the development parcels.

The final strategy uses a range of Best Management Practices (BMPs). Most important, the BMPs are designed as a **Treatment Chain**. Water flows from one BMP into another, and each BMP supplements the role of the others in the chain.

Absorbent soils are a key link in the treatment chain at Burnaby Mountain. The role of soils in moderating the flow and quality of stormwater is of increasing interest. The ‘Soils for Salmon’ initiative in the Pacific Northwest has recognized the significance of soils and organic matter in storing water, cleansing it, and releasing it slowly to streams.

Table 3 provides comparisons of hydraulic properties for different landscape soils. All of the soils in the table meet the specifications for a Level 1 landscape in the British Columbia Landscape Standard, which would be the type of landscape soil installed to developments at Burnaby Mountain.

Table 3 - Hydraulic Properties of Landscape Soils

	Lightest Soil	Heaviest Soil	Design Soil
Texture	Sand 90% Silt/Clay 5% Organic Matter 5%	Sand 55% Silt/Clay 25% Organic Matter 20%	Sand 75% Silt/Clay 15% Organic Matter 10%
Saturated Hydraulic Conductivity	79 mm/hr	4.4 mm/hr	13.1 mm/hr
Winter Water Storage (% volume)	23% water	22% water	23% water
Winter Water Storage in 300mm depth of soil	69mm	66mm	69mm

(Adapted from Soil Texture Triangle: Hydraulic Properties Calculator, Washington State University, USDA/ARS, Dr K.E. Saxton)

How can soils over parking and in landscape areas be designed for stormwater purposes?

The percentage of sand versus clay in the landscape soil (soil texture) has a dramatic effect on its infiltration rate, or *saturated hydraulic conductivity*. Soils within the range allowed under the BC Landscape Standard (Table 3) might exhibit saturated hydraulic conductivity from 4.4mm/hr to 79mm/hr, with the design soil providing 13 mm/hr. The design soil would infiltrate 35mm of rainfall off the surface within 2- 3 hours (i.e. absorbing the rain as it falls). However, using the design soil the 35mm of rainfall would take about 1 day to drain completely through a 300mm layer of the soil.

All of the soils in Table 3 store soil water in the range of 23% of their volume in a winter condition, and greater than this percentage in summer. For the design soil, a 300mm layer would store about 70mm of rainfall, which provides a Factor of Safety of approximately 2 for the Rainfall Capture Storm.

However, the proposed release rate to receiving waters is 15mm per day. The design soil is releasing 35mm or more per day. An additional measure of storage is therefore required. See below for the discussion on how this need has led to design of the next BMP in the Treatment Chain.

TREATMENT CHAINS

Table 4 illustrates several Treatment Chains planned for Burnaby Mountain. For example, the Treatment Chain for rainfall landing on absorbent soils over a parking garage includes the following elements.

1. Initial rainfall treatment and storage is provided by a 300mm layer of controlled-texture landscape soil. The infiltration rate of this soil is maintained by either grass or mulch on the surface to keep pores open, by inclusion of organic matter in the surface layer to encourage burrowing earthworms and other insects, and by normal landscape maintenance practices such as lawn aeration, weeding, mulch replenishment, etc.

2. A carefully specified geotextile separates the landscape soil from a drainage layer. The drainage layer may a be 100mm depth of drain rock, which at 35% void would store the 35mm captured rainfall. As an alternate to save weight, depth and provide more free flow of water to drains, new recycled plastic products can provide a 98% void, allowing the 35mm of water storage in a 40mm drainage layer.

3. Flow control rings at drainage outlets in the parking garage lid will be designed to release the 35mm captured rainfall at a rate of 15mm/day, while at the same time bypassing larger storms to the drainpipe from the parking deck. Inspection boxes over the control ring and drain allow for maintenance. At key points in the landscape would be surface drain inlets and sumps, with outfalls to the drainage layer. These provide a backup to catch surface drainage when the soil layer is frozen or locally plugged.

Table 4 - Stormwater Management Treatment Chains in the Stoney Creek Watershed at the Burnaby Mountain Community

Treatment Stage	Rainfall on Parking Garage	Rainfall on Building Roof	Rainfall on Road Pavement
1	300mm absorbent landscape soil (or localized / pervious paving) to store and filter 35mm rainfall.	Collect to screened rain water leader	Sheet drain to pervious pavement or grass swale (w/overflow) on the Crescent.
2	Filter cloth and drainage layer to store 35mm rainfall with 15mm/day release rate	Cistern to contain 35mm rainfall with 15mm/day release rate	Sand filter in swale (600 mm depth)
3	Flow control device (w/ overflow) to pipe	Flow control device (w/ overflow) to pipe	Perforated underdrain with cleanouts
4	Infiltration gallery to groundwater interflow (w/overflow)	Infiltration gallery to groundwater interflow (w/overflow)	Catch Basins for overflow and to Storm Drainage piped system
5	Stormwater Pond sediment forebay	Stormwater Pond sediment forebay	Stormwater Pond sediment forebay
6	Constructed wetland vegetation and micropools	Constructed wetland vegetation and micropools	Constructed wetland vegetation and micropools
7	Control structure with 15mm / day release rate and overflow	Control structure with 15mm / day release rate and overflow	Control structure with 15mm / day release rate and overflow
8	Constructed stream riffles	Constructed stream riffles	Constructed stream riffles
9	Constructed stream pools	Constructed stream pools	Constructed stream pools
10	Monitoring station	Monitoring station	Monitoring station
	Receiving waters	Receiving waters	Receiving waters

4. Drainage from the parking garage lid would be piped to an infiltration gallery below the building site. Using ‘Infiltrator’ half pipes, the controlled low flows will be allowed to enter the groundwater interflow zone, passing through native soils before entering stormwater ponds below. A high volume overflow pipe will pass flows that cannot infiltrate directly to the stormwater ponds. When space and site terrain does not provide space for the infiltration galleries, the parking lid drainage would outfall direct to detention ponds.

5. The stormwater ponds vary in size depending on the contributing catchment area. For the Stoney Creek catchment area, the treatment chain continues with a sediment trap at the pond entry, constructed wetland terraces and micropools to provide both water treatment and habitat.

6. Below the stormwater ponds, a portion of existing piped stream and ditch is being daylighted to a new constructed surface stream. The new stream will have a complex variety of pools, riffles, runs, as well as extensive in-stream habitat complexing and restored riparian areas to provides shade, food and insect inputs. The complexity of the constructed stream provides additional water storage and treatment, with each riffle adding oxygen, and each pool acting as a sediment trap.

7. Finally, at the end of the Treatment Chain, the water is returned to the existing receiving stream. It flows in a conserved riparian area. Before it exits the site to the Conservation Area, the stream flow and water quality is monitored by a computerized monitoring station.

Similar Treatment Chains are shown for drainage from building roofs and roadways.

In the case of drainage from roof areas, it is to be collected and piped to cisterns in the building parkade. A study of a townhouse site indicated that to store the 35mm storm would require a vault about the size of three parking spaces, at a cost of approximately $500 per dwelling unit. Costs per dwelling unit for higher buildings would be less. Release rates from the vaults will be 15mm/day, with the release piped to either infiltration gallery or detention pond as the site allows.

For drainage from roads, several different BMPs are being used.

- For the Main Street and University Boulevard, which are a small portion of the site area, a traditional storm drainage system uses minimum lengths of pipe flowing to a created stream with pools and riffles. The created stream outfalls to a detention pond and the treatment chain below.

- For the Crescent – the main residential road – a combination of pervious pavement under parking, reservoir base courses, dry swales, sand filters, and perforated underdrain will store and treat the runoff from the 6m asphalt traveled lanes. Runoff from the roads also is directed to the stormwater ponds and constructed stream for further treatment.

All of this attention to water storage and quality is for small headwater streams that are hundreds of metres away from fish-bearing streams. The focus of the stormwater strategy is to ensure that the water quantity and quality meets or exceeds the existing water produced on the site. Net Gain for fish habitat is the objective, with a 50-year vision that the hydrology of the watershed will be improved after this development compared to the existing condition.

OPTIMIZE FACILITY DESIGN THROUGH ADAPTIVE MANAGEMENT

The preliminary performance targets and site design criteria, as developed via the 6-Step Adaptive Methodology presented in Table 1, provide a *starting point* for the design of stormwater systems on Burnaby Mountain.

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

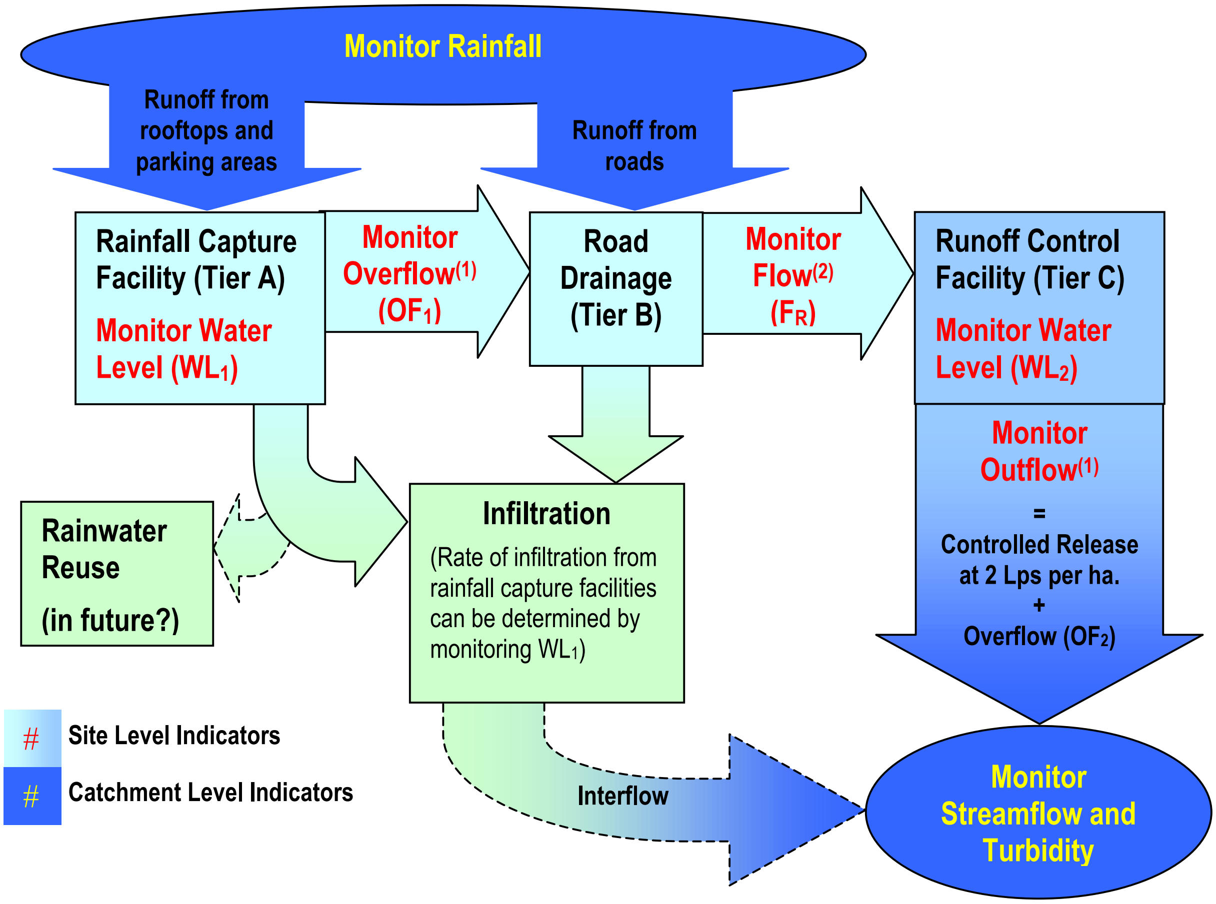
Performance Evaluation at the Site Level

Monitoring and evaluating the performance of d*emonstration projects at the site level* is the primary basis for optimizing the design of stormwater systems. Figure 4 shows the indicators that must be monitored to enable a good evaluation of stormwater system performance.

A continuous record of water levels/flows in rainfall capture and runoff control facilities (including road drainage flows) over an extended time period, combined with continuous rainfall data over the same time period will provide an accurate picture of how water moves through the stormwater system. This will answer the following key question relating to stormwater system performance:

For Rainfall Capture Facilities:	**For Runoff Control Facilities**:	**For Road Drainage**:
• What is the frequency and volume of overflow? • Are targets for runoff volume reduction achieved? • How often does water accumulate? • How fast does water level drop under saturated soil conditions? • What would be the effect of increasing/decreasing infiltration area? • What would be the effect of decreasing storage volume?	• What is the frequency and volume of overflow? • Are targets for runoff rate control achieved? • Do detention facilities empty prior to large rainfall events? • What would be the effect of decreasing storage volume? • Does the outflow hydrograph from detention facilities resemble the hydrographs observed at the streamflow monitoring stations in undeveloped catchments?	• Where does road runoff go? - How enters the underdrain pipe? - How enters storm sewers? - How much infiltrates? • How fast does road runoff and overflow from rainfall capture facilities enter the road drainage system? • Are the targets for runoff volume reduction and rate control achieved?

Figure 4 - Hydrologic Performance Monitoring



(1) Compound weir outlet structures will enable overflow from rainfall capture facilities and outflow from runoff control to be correlated with water levels (WL$_1$ and WL$_2$, respectively). Overflow from runoff control facilities (OF$_2$) can be determined by subtracting controlled release (a known parameter) from outflow.

(2) There will likely be more than one road drainage pathway to monitor (e.g. an underdrain pipe in an infiltration trench plus an overflow catch basin connected to a storm sewer). The amount of road runoff that infiltrates can be determined by subtracting F$_R$ from total road runoff (and accounting for OF$_1$).

Indicator	OF$_1$	OF$_2$	Road Drainage(3)	Streamflow
Performance Targets	➢ **Total overflow volume** should not be more than 25% of total runoff volume. ➢ **The frequency of overflows** should be about 6 to 8 times per year, on average**.**	➢ **Total overflow volume** should be about 2% of the total runoff volume. ➢ **The frequency of overflows** should be about once per year, on average.	➢ **Flow into the storm sewer system** should meet the volume and frequency targets for OF$_2$ ➢ **Underdrain pipe flow** should meet the volume target for OF$_1$	➢ **The pre-development hydrograph** should be maintained in downstream watercourses**.**

(3) The design objective is to make roads 'self-mitigating' (i.e. provide rainfall capture *and* runoff control).

Deciding Which Facilities to Monitor

In order to properly evaluate the performance of the East Neighbourhood stormwater management system, the comprehensive monitoring program will *define the water balance of the development site.* This means that the monitoring information must answer the following question: **Where does the rainfall that falls on the site end up?**

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

- **On-lot rainfall capture monitoring** – Monitor water levels and overflow from at least one on-lot rainfall capture facility.

- **Road drainage monitoring** – Monitor the drainage from at least one section of 'self mitigating' road (including underdrain pipe flow and catch basin flow)

- **Community detention pond monitoring** – Monitor water levels and outflow from detention ponds.

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

Testing Conservative Assumptions

The preliminary rainfall capture and runoff control criteria are based on conservative assumptions. Storage volumes are conservative because they are based on long duration rainfall events (24 hr) and do not account for release rate.

Performance monitoring should confirm that initial assumptions are conservative and provide the certainty needed to reduce the size of future facilities.

Hydrologic Performance Evaluation at the Catchment Level

Performance evaluation *at the site level* is the primary basis for optimizing the design of stormwater systems. Performance evaluation *at the catchment level* is also important to ensure that overall objectives for protecting aquatic habitat and receiving water quality are being achieved.

A key hydrologic performance objective at the catchment level is to maintain the characteristics of the pre-development hydrograph, including: total flow volume; peak flow rates; baseflow rates (i.e. interflow); and hydrograph shape.

ARE WE MANAGING WATERCOURSES OR THE WATERSHED?

The emphasis of the stormwater and watercourse management plan has been on layering the stormwater functions of a natural forest over the reality of a high-density development. Contrasted to suburban development, this density of development involves extensive modification to the land.

To meet the compact and complete community objectives, the development proposes the realignment of several man-made headwater streams. Most of the watercourses being replaced are ditches along roadsides with intermittent flow and compromised riparian areas. A localized portion of a perennial stream will also be relocated to avoid sterilized the land use from a significant part of the property. Given recent focus on protecting watercourses and streamside leave areas under the British Columbia Fish Protection Act, these concepts were subject to serious scrutiny from approving authorities.

A key part of the watercourse management strategy is the concept of 'functional equivalency'. The design for the site assesses the contribution that each existing ditch and small tributary makes to the watershed. The design ensures that equal or better equivalent is provided in the final development. Creating 'functional equivalency' is not to be taken lightly. It is difficult to replicate existing watercourses – even small non-fish-bearing ones. Doing so requires not only capital investment and design skill, but the time required for nature to 'grow a new stream', with effective riparian shade, food supply and other functions provided by an established aquatic ecosystem.

Decisions on which stream reaches could be relocated, and what riparian setbacks should be left or restored, were based on the following factors:

- ☐ State of receiving watershed
- ☐ Nature of water source
- ☐ Current instream features
- ☐ Current water quantity and quality
- ☐ Nature of normal annual flow
- ☐ State of riparian / upland habitat
- ☐ Benefits of effective restoration
- ☐ Development considerations

To satisfy the agencies and the design team, the proposed stream relocation needed to meet the spirit of the British Columbia Fish Protection Act, as well as the *No Net Loss – Net Gain* Management Guiding Principle.

The key to successful resolution of the watercourse management issues was a round-table atmosphere of respect and active listening, leading to understanding of objectives and concerns, and eventually building trust. Once trust was established, the interagency group was able to jointly find innovative solutions that created win-win results. In the end, the decisions considered what were the best solutions for the watershed in general, rather than a focus exclusively on individual stream segments.

Contractor Awareness Training

To respect this trust, it is the responsibility of the Burnaby Mountain Community Corporation and its consultants to ensure that the environmental strategy is realized during development. To this end, in addition to detailed guidelines and specifications, all site and landscape contractors that will work at this development will be given a training course on watershed awareness.

The course will explain the special BMPs that are involved on the site, the reasons for their use, and will highlight common mistakes that can make a BMP fail (e.g. siltation of pervious paving, or using the wrong landscape soil texture). It is anticipated that such contractors will be given a designation (such as **SFU Certified**) that recognizes their watershed and environmental awareness.

STAKEHOLDER CONSENSUS

A critical success factor in Plan development was the process by which issues were resolved and consensus reached among stakeholders at many levels. To both inform and balance the many perspectives at the table involved two 'tracks' of effort: *Track #1* was the technical analysis; *Track #2* was the stakeholder involvement process.

Working Sessions

To advance the regulatory review and approval process for land development within the Ring Road, and to facilitate knowledge-transfer, a series of working sessions were conducted. These sessions provided a forum for testing of approaches and concepts, and for obtaining feedback and direction on what may or may not be acceptable.

	Scope
Stormwater Charrette	Present an approach, design guidelines, and plan elements. Reach initial alignment and consensus regarding a shared vision that will drive a concept design
Environmental Principles & Watercourse Management	Develop regional and local sustainability principles. Determine how to meet the requirements of *No Net Loss* and strive to achieve a *Net Gain* in fish habitat.
Hydrology Sessions	Provide supporting analyses. Build confidence in the design guidelines, methodologies, and the resulting parameter values that will drive the detailed design
Green Infrastructure Sessions	Focus on practical and appropriate detailed design tools for use at the development parcel level. Select appropriate BMPs to achieve impervious area objectives

Overcoming Fear and Doubt

Competing expectations created a number of barriers. The #1 barrier was the lack of trust that a sustainable, compact and complete community could be achieved while protecting the environment. Overcoming this barrier meant earning trust through a process:

1. Interdisciplinary teamwork
2. Introductory forum
3. Stakeholder roundtables
4. Technical sessions
5. Assured delivery

Bumps along the way included shortcuts that did not work, uncovering people's worst fears, imperfect personality matches that resulted in conflict, difficulty finding built precedents, and accepting some risk.

CONCLUSION

Stormwater management at Burnaby Mountain is undertaking several innovations that are new to British Columbia. However, most of the BMPs involved have been applied elsewhere in the world. What is unique to this project is the application of so many state-of –the-art approaches in a high-density development, to meet stormwater management objectives and criteria that exceeds prevailing practices and standards.

The challenge of the Burnaby Mountain Community project is fundamental – how can we resolve the competing objectives of:

- ☐ Higher density development, to avoid sprawl and meet transportation, global warming and air quality objectives, versus
- ☐ Watershed objectives, which emphasize maximum forest cover and riparian zones, with minimum impervious area.

The approaches outlined in this paper show great promise at resolving these conflicting objectives. The project will be the subject of long-term monitoring. Results will allow the stormwater management program to take an adaptive approach to ensure that objectives are being met.

The Burnaby Mountain Community project is a rare opportunity to demonstrate how a new, sustainable community can truly integrate stormwater management into urban design, starting where the rainfall lands.

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Name	Organization	Position/Role/Contribution
Michael Geller	Burnaby Mtn Community Corp	President
Eric Emery	Burnaby Mtn Community Corp	Project Manager
Joost Bakker	Hotson-Bakker Architects	Neighbourhood Concept Plan
Kim Stephens	CH2M HILL	Stormwater Management Strategy
Fernando Pasquel	CH2M HILL	Rainfall Capture Peer Review
Colin Kristiansen.	CH2M HILL	Hydrotechnical Engineering
Philip Cheung	CH2M HILL	Computer Modelling
Patrick Graham	CH2M HILL	Rainfall Research/Analysis/Strategy
David Reid	Lanarc Consultants Ltd	Environmental Planning/Design
Patrick Harrison	Lanarc Consultants Ltd	Forestry Management
Ron Kistritz	R.U. Kistritz Consultants Ltd	Aquatic Ecology & Equivalency
Glenn Stewart	ENKON Consultants Ltd	Fisheries Biology
Bob Worden	Ramsay Worden Architects	Housing Typologies
Declan Rooney	Hunter Laird Engineering Ltd	Civil Engineering Design
Patrick Condon	University of British Columbia	Environmental Principles
Sebastian Moffatt	The Sheltair Group	Sustainability Framework

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- British Columbia Ministry of Environment (Erin Stoddard),
- Greater Vancouver Regional District (Mark Wellman),
- Brunette Basin Stewardship Program (John Saremba and Diane Ramage), and
- Stoney Creek Environmental Committee (Jennifer Atchison).

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