Overview of the Theme Issue

Innovation in Stormwater Management in Canada: The Way Forward

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Rapid urban expansion, increased traffic, ageing infrastructure, greater climatic variability, and the need for enhanced sustainability of urban water resources pose significant challenges to conventional stormwater management. Innovative approaches are needed in order to mitigate the risk of flooding, pollution, and aquatic ecosystem degradation, and enhance beneficial uses of urban waters. To examine such approaches, a series of three regional conferences on innovative stormwater management were held in Vancouver, Calgary, and Toronto during 2007 to 2008 under the sponsorship of the Canadian Water Network (CWN) and the Canadian Mortgage and Housing Corporation (CMHC). Authors of selected conference papers providing information on innovative approaches to mitigating the risk of flooding and reducing pollution impacts at the property, neighbourhood, and watershed scales were then invited to submit journal papers, and those accepted in the review process were included in this Special Issue of the *Water Quality Research Journal of Canada*.

An overview of the selected papers indicates that no single innovative measure is adequate under all circumstances, and a multibarrier approach is deemed to be most effective. Examples of innovations at the property level include harvesting roof runoff and reusing water, managing rainwater by infiltration in swales and into soils in bioretention areas, minimizing impervious surfaces, and using pervious pavement. At the neighbourhood level, runoff impacts are mitigated by designing roads without curbs, gutters, and drain pipes, and diverting runoff into infiltration channels, swales, and wetlands. Creating roads and parking lots with pervious pavement and draining runoff from such surfaces into infiltration basins is also discussed. Among stormwater quality source controls, potential effects of street sweeping on runoff quality enhancement were assessed. New innovations at the watershed scale include: (a) the creation of wide riparian buffer zones that can detain water, remove sediments, and mitigate nutrient export and other pollutant effects, (b) the minimization of channelization of streams and rivers, and (c) the designation of floodwater storage areas. A new water balance model that is linked to a global information system (GIS) and works at all the three scales offers the best option to conceptualize stormwater problems, and their mitigation, in urban watersheds. Finally, the aim of this Special Issue is to promote examples of successful innovative approaches to improving stormwater management in Canadian cities, hoping that other practitioners will build on this experience and bring stormwater management practice to the next higher level.

Introduction

Rapid urban expansion leads to increased traffic and greater imperviousness which result in flashier stormwater runoff and greater generation of pollution from urban nonpoint sources (Marsalek et al. 2008). There is also clear evidence that, as a result of global climate change, we are experiencing greater climatic variability (IPCC 2007). The combined effect of rapid land use changes and increased climatic variability point to the problem that conventional stormwater management systems that were designed to remove runoff via piped conveyance systems are no longer adequate to deal with larger and more intense storm events and the associated pollution. Considerable research efforts have been invested in developing alternative approaches to conventional stormwater management focusing on rainwater management, infiltration of rainfall on site, and detention of runoff during large storm events, rather than piping it directly into urban streams (U.S. EPA 2000; Stephens et al. 2002; U.S. Department of Defense 2004).

Unfortunately, many of the innovative approaches

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have not been sufficiently promoted and have so far not been widely incorporated in new urban developments. To remedy this situation, The Canadian Water Network (CWN-NCE) and the Canadian Mortgage and Housing Corporation (CMHC) sponsored in 2006 a two-year knowledge translation project that aimed to highlight successful innovative approaches to stormwater management across Canada, and to present case studies to practitioners and developers in Vancouver, Calgary, and Toronto during 2007 and 2008. The specific aims were to promote innovations across Canada, to identify which approaches work best under different climatic conditions, and to examine innovations in a comprehensive manner with a focus on using a multibarrier approach that is capable of reducing the anthropogenic and environmental impacts of flooding and pollution. Quite deliberately, the leaders of this project, Hans Schreier and Jiri Marsalek, decided to use the term "innovative stormwater management" rather than adopting one of the more trendy expressions like "low impact development," "water sensitive urban design," or "sustainable urban drainage systems," because they felt that the first term reflects better the historical context and evolution of managing rainwater and surface runoff in urban areas, and the newer terms are somewhat ambiguous with respect to the qualifying adjectives, "low," "water sensitive," and "sustainable."

There has been a shift from blue water management to green water management thinking in urban watershed management (Novotny and Brown 2007). Blue water is the proportion of rainfall that runs off the land surface into lakes and rivers and recharges groundwater. In the past, the rapid removal of surface runoff has been given the majority of attention in urban stormwater management. The new approach is to focus on the green water component of the hydrological cycle, which aims at intercepting, infiltrating, detaining, and evapotranspiring as much of the rainfall as possible rather than conveying surface runoff into pipes and streams (Ellis 2008). This approach can also be described as preserving the local onsite water balance (U.S. Department of Defense 2004). This not only reduces the amount of stormwater available for runoff, but also reduces the pollution from urban nonpoint sources that enters local streams. In this new approach the focus is primarily on smaller rain events which represent, in most cases, 70 to 85% of all annual rainfall events, and possibly a slightly higher percentage of the annual runoff volume (Urbonas and Roesner 1993). Note however that in spite of this shifting emphasis, the stormwater management infrastructure still has to deliver on all design objectives, which can generally be listed as local water balance maintenance, flood protection (i.e., for large events), erosion and sediment control, stormwater quality enhancement, and beneficial use of stormwater (MOE 2003).

Innovative stormwater management and its planning should begin with rainwater management at the site or individual property level. The next consideration is to link these activities to the neighbourhood level, and then to scale them up to the watershed level.

Innovative Stormwater Management at the Property Scale

The dominant trend in property development has been to build larger houses with double garages and paved driveways, patios, and walkways on urban lots which, over the years, have been becoming smaller. This resulted in an increased extent of impervious surfaces, with less infiltration and much greater surface runoff. Runoff from such properties was traditionally drained into a dense system of urban stormwater pipes that conveyed the runoff into local drainage systems and streams. With increased urbanization and climatic variability, new approaches are needed to mitigate these problems. The innovative approaches that need to be considered at the site or property scale level are summarized in Table 1 and consist of a wide range of collection and infiltration systems that in the best cases result in zero surface runoff from the properties.

TABLE 1. Innovative approaches to rainwater management at the property level

Traditional Approach	*Innovative Approach*
1. Roof runoff is directly conveyed to storm sewers	1. Install green roofs that detain rainfall, allow some evapotranspiration, and reduce and delay storm runoff
2. Collect roof rainwater and discharge it into storm sewers	2. Connect roofwater downspouts to rainbarrels or a storage tank and use the water for indoor or outdoor uses
3. Pave driveways and walkways	3. Minimize impervious surfaces, use pervious pavement, and infiltrate runoff in swales
4. Strip topsoil, allow soil compaction during house construction and roll out thin turf layer after construction	4. Prevent soil compaction, or restore soil porosity after construction, and specify at least 30 cm of topsoil before planting lawn
5. Use piped drinking water for watering lawns and gardens	5. Use collected roof water to water lawns and gardens or develop xeriscapes
6. Remove large trees because of risk of house damage during storms	6. Plant and maintain trees on property for stormwater generation reduction and carbon credit

The first type of innovation is to collect roofwater in rainbarrels and use the collected water for gardening and lawn watering, or use the water indoors to flush toilets and wash cloth. The need for this approach, and its practical implementation, at both single-family residential and commercial scales, is described in a paper by Farahbakhsh et al. (2009) on *Developing Capacity for Large-Scale Rainwater Harvesting in Canada*.Green roofs have been heavily promoted in Europe, not only to detain and reduce runoff but also to assist in reducing energy needs within the building. The effectiveness and challenges in developing functional green roofs in different climatic conditions is discussed by Van der Linden and Stone (2009) in a paper entitled *Wet Weather Performance of a Green Roof in Waterloo, Ontario*, and by Van Seters et al. (2009) in a paper on *Green Roof Runoff Quantity, Runoff Quality, and Growing Media*.

Trees planted on individual properties can have a significant favourable impact not only on moderating air temperatures and sequestering carbon, but also on intercepting rainfall and reducing and delaying runoff. The effectiveness of trees in enhancing the local hydrological abstractions (and potentially reducing runoff) is described by Asadian and Weiler (2009) in their paper on *A New Approach in Measuring Rainfall Interception by Urban Trees in Coastal British Columbia*.

Building pervious driveways allowing rainwater or stormwater to infiltrate into the underlying soils represents another approach that can be used both at the property and neighbourhood scales. Pervious pavements serve not only to reduce surface runoff, but also to improve its quality, e.g., by removing sediment and suspended solids. Performance of an innovative permeable pavement in sediment removal is discussed in a paper by Brown et al. (2009) on *Characteristics of Sediment Removal in two Permeable Pavements*.

Another approach to managing the onsite water balance, described at the project conferences but not covered in this issue, is soil moisture retention by keeping the topsoil layer on residential lots at least 30-cm thick. This is one of the most effective measures at the property level for minimizing runoff generation, storing significant quantities of water in soils, and reducing the irrigation requirements by at least 1/3, depending on location.

Any additional stormwater that cannot be controlled by these suggested measures can be infiltrated by building rock pits (infiltration wells) on the property and connecting them with infiltrations systems (swales, rain-gardens, French drains, etc.). Most of these measures can deal with 75 to 85% of the rainfall events, but provisions still need to be made for extreme storms which will likely generate runoff that needs to be transported to neighbourhood- or watershed-scale stormwater systems.

Innovative Stormwater Management at the Neighbourhood Scale.

The innovative approaches to dealing with stormwater management within neighbourhoods are summarized in Table 2 and focus on street and parking lot runoff management.

Conventional streets in single family neighbourhoods are usually excessively wide and consist of curb and gutter systems that direct runoff into storm sewer pipes. In innovative approaches, curbs are removed and the street runoff is allowed to drain into swales incorporating sand filters. These swales are connected to detention ponds and wetlands in order to detain water from large storm events and to allow sediments and pollutants to settle in ponds; alternatively, runoff is allowed to infiltrate into the ground, where soil organisms and plants are capable of reducing the pollution effects. Wetlands are the most effective storage and filtration systems, but there are many safety and health concerns associated with developing constructed wetlands in the city.

The issues of stormwater quality enhancement at the neighbourhood level were addressed in four papers dealing with street sweeping, stormwater detention in stormwater management ponds, and stormwater biofiltration by compost filters.

The effectiveness of street cleaning as a source control measure reducing stormwater pollution is described in detail by Rochfort et al. (2009) in a paper entitled *Street Sweeping as a Method of Source Control for Urban Stormwater Pollution*.

The effectiveness of detention systems in reducing

TABLE 2. Innovative approaches to stormwater management at the neighbourhood level.

Traditional Approach	*Innovative Approach*
1. Pave all roads and sidewalks and direct runoff into storm sewers using a curb and gutter system	1. Minimize the width (area) of roads, remove all curbs and gutters and direct runoff into road-side infiltration swales, use pervious pavement (as much as possible)
2. Build a network of storm sewers and direct stormwater runoff into local streams	2. Build stormwater detention ponds and wetlands for large storms to detain runoff and reduce pollutant and sediment loads that enter streams
3. Build parking lots that are impervious and direct the runoff into storm sewers	3. Build parking lots with pervious pavement materials or direct runoff away from storm sewers into detention systems, swales and constructed wetlands
4. Allow contaminants to accumulate on street surface and be washed off by runoff into stormwater conveyance systems	4. Apply source controls by minimizing the use of polluting chemicals, and practicing street sweeping, contaminant retention, and rehabilitation of contaminated areas.

contaminants that can enter urban streams is described in a paper by Brydon et al. (2009) on *Evaluation of Mitigation Methods to Manage Contaminant Transfer in Urban Watersheds*. Detention systems promote stormwater settling, and the resulting sediment deposits need to be assessed, removed, and properly disposed of. The underlying environmental considerations for such maintenance operations are discussed by Westerbeek-Vopicka (2009) in her paper on *Sediment Assessment of Stormwater Retention Ponds within the Urban Environment of Calgary, Canada*.

Another method of enhancing runoff quality is by filtration through various media. The treatment of construction site runoff, with high concentrations of suspended solids, by compost filters was assessed by Taleban et al. (2009), as described in their paper on *Stormwater Runoff Treatment Using Compost Biofilters*.

One of the key public health concerns about stormwater ponds and constructed wetlands serving to detain and absorb contaminants is the problem of mosquitoes and the spread of West Nile virus. While the insect risk cannot be completely eliminated, the problem can be significantly reduced by a number of measures described in the paper by Jackson et al. (2009) entitled *Culex Mosquitoes, West Nile Virus, and the Application of Innovative Management in the Design and Management of Stormwater Retention Ponds in Canada*.

Another emerging stormwater management problem not discussed in this issue is the use of road salt in winter road maintenance and the resulting impacts on the environment. Road salts may interfere with operation of stormwater management facilities (e.g., by accumulation of chloride in stormwater ponds at toxic levels, release of chemicals from bottom sediments, impeded vertical mixing) and environmental impacts of road salts may be exacerbated by stormwater infiltration facilities diverting salt-laden stormwater into groundwater aquifers (Marsalek 2003). Warmer winters of recent years contributed to more fluctuation around the freezing point, and possibly a greater use of salt in road maintenance. Chloride saturated road runoff and chloride release from snow storage areas can have significant impacts on the aquatic ecosystem (Exall et al. 2008).

Innovation at the Watershed Scale

The individual stormwater management systems developed at the neighbourhood scale need to be integrated into a comprehensive drainage system within the watershed. A summary of the watershed-scale innovations that minimize drainage impacts is provided in Table 3.

Of foremost importance is the creation of a wide riparian buffer zone, also referred to as an ecological buffer (Day et al. 2008). In order to ensure effective functioning of buffer zones, it is required to design them sufficiently wide (a minimum width of 50 to 60 m) and with a good vegetative cover so that they uptake excess nutrients and provide sufficient space for absorbing and detaining sediments and pollutants, and for storing and detaining excess water during storm events. In many cities, the current buffer zone regulations require zone widths of 30 m, which is not sufficient to deal with all the impacts and the anticipated increases in storm event rainfalls and intensities. Ideally, a variable width buffer zone, depending on the local topography, surficial materials, and the hydrological regime, should be considered.

The second important aspect is to avoid channelization of urban stream and river beds. Hardened constructed channels may allow faster drainage of stormwater and prevent local bank erosion, but they often increase the risk of flooding in downstream areas because of restrictions imposed on lateral flows and storage outside of the stream channel. Maintaining natural channels should be given priority in all new urban developments, and conversion of constructed channels into more natural channels should be an important rehabilitation activity in old and established urban areas.

TABLE 3. Innovative stormwater management at the watershed scale

Traditional Approach	*Innovative Approach*
1. Stormwater is conveyed through pipes, passes through riparian buffer zones and is released into local streams	1. Create wide riparian buffer zones and create constructed wetlands within these zones to store excess stormwater, retain sediments and pollutants, and filter the water. Minimize or eliminate all stormwater outfalls discharging directly into streams
2. Channelizing urban streams and rivers to increase flow capacity, minimize bank erosion and speed up drainage	2. Maintaining natural river channels to allow lateral flow and storage of stormwater within the riparian zone
3. Floodplain is designated and flood management (protective) structures are built	3. Designate areas within the floodplain and the riparian buffer zone to serve for temporal storage of stormwater during flood events
4. All stormwater systems are connected and their outlets become point sources of pollution discharged into local streams	4. Avoid cumulative effects that increase flow and pollution loads by directing all stormwater drainage to pass through infiltration and detention systems

Floodplain management should also be changed because in the past most efforts have gone into building flood management (protective) structures (dikes, dams) and regulating land use activities. In view of increasing variability of climate, it is anticipated that flood events in cities will become more frequent and as a result, certain low-lying areas should be reserved for deliberate flooding. The land use should be such that activities can readily be restored after the floodwater has receded. Parks, wetlands and riparian buffer zones are the most appropriate sites for such considerations.

Finally, having many storm sewers conveying runoff directly into local urban streams results in concentration of flows as well as pollution. Retaining and infiltrating as much of the rainwater as possible, preventing generation of surface runoff, and detaining storm event runoff in ponds and wetlands within the watershed is the best strategy for adaptation to the increasing storm events and the increasing pollution from increased traffic and urban activities. No single measure will be sufficient to fully manage the aforementioned risks, but having a combination of these innovative measures in place should reduce the risk of flooding and the pollution associated with urban activities.

Integration and Effectiveness of Innovative Approaches

Using single innovation methods in isolation is only marginally effective, but to successfully reduce the anticipated increased risks of flooding and pollution requires a combination of innovative measures. Innovative initiatives also need to be linked within the watershed. The (Canadian) Water Balance Model (WBM) which was developed by an interprovincial body of experts (British Columbia Inter-Governmental Partnership 2003) is a first step towards facilitating integration of innovative stormwater management measures. It allows property owners to calculate runoff from impervious surfaces on their property and to determine the fraction of the rainfall depth that needs to be managed on site to maintain the onsite water balance. Once this is determined, a range of innovative options serving to detain and infiltrate the calculated rainfall/runoff can be identified.

Like any other hydrological model, WBM also has some limitations. The groundwater component and water table fluctuations are not sufficiently considered in the model. However, as a first approximation this WBM-based approach has a significant potential. Once the hydrological property assessment is completed, then there is a need to link the hydrology of the property to that of the neighbourhood and of the watershed. This can now be accomplished by using the QUALHYMO engine (Rowney and McRae 1991a, b) that was recently added to the WBM. As expected, the complexity of scaling the model results from the site to the watershed is challenging and examples of such attempts are not yet fully available. However, the basic idea of using spatially based models that can link the hydrological dynamics at the property scale with the cumulative effects over the neighbourhood and the watershed is a direction that has significant merit.

Some of the innovations discussed in this issue have been introduced in other countries, but have not been rigorously tested in different environmental regions of Canada. Many individual detention and infiltration systems have been constructed, but few are monitored to determine how effective they are in minimizing floods and reducing pollutants. A significant effort is needed to provide sound short- and long-term monitoring data so that one can calibrate the effectiveness of these measures. Only then we can recommend with confidence the use of the innovative methods elsewhere in new urban developments.

More efforts are also needed to determine the cost of constructing and maintaining innovative systems. Such a cost analysis should include comparison between conventional and innovative systems. This information is urgently needed in order to persuade developers to adapt these techniques. It is generally agreed that many of the innovative approaches are less expensive to build than conventional systems, but many of the long-term comparisons of maintenance costs of conventional and innovative systems are still lacking. In other words, comparisons of life-cycle costs between conventional and innovative stormwater management approaches are still missing. While it is possible to calculate flood damage costs, valorization of environmental benefits, such as improved aquatic ecosystem health, is most challenging.

Finally, given the widespread evidence that increased climatic variability and increased densification of urban areas are taking place simultaneously, it is evident that adoption of new approaches to stormwater management is urgently needed. Since we cannot anticipate what some of these cumulative effects will be and where the resilience and threshold levels are within the systems, it is prudent to use a multibarrier approach that includes a range of options that will likely differ from city to city depending on the topographic, geological, climatic, land use, and environmental conditions. At the same time, there are many obstacles to innovation in stormwater management, including the prevailing legal environment that focuses on litigation, and the many overlapping fragmented jurisdictions that make approvals of development permits complex and time consuming. Often, the additional requirements associated with moving from the conventional to the innovative approach are excessive and discourage the innovation. What is needed are incentives to facilitate and speed up the approval process and to provide experimental permits that allow developers to experiment. The key is to promote well documented case studies demonstrating innovative stormwater management that is effective in reducing the risk of flooding and pollution, and at the same time is more cost effective, than the conventional approaches, over the long run.

Conclusions

This special journal issue on innovative stormwater management brought together a wide range of Canadian experts who specialize in all aspects of urban stormwater management in various parts of Canada. The focus of the featured papers is on introducing innovative approaches that range from rainwater retention, reuse, and infiltration at the property level, to detention and infiltration of runoff at the neighbourhood scale. All such efforts should take into account the linkages to the urban watershed by managing large riparian buffer zones, refraining from channelization of streams and rivers, and designating areas in floodplains for temporary storage of stormwater during storm events. Roof-water harvesting, minimization of impervious surface areas, diversion of runoff into detention and wetland systems, use of pervious pavements, and directing road and parking lot runoff into filter systems are all approaches that are well documented in different parts of Canada. Increasing health concerns about insects and the spread of disease in areas adjacent to urban ponds and wetlands, and impacts of road salts on streams, as well as economic considerations, are all addressed in this introduction. The recommended approach emphasizes the use of a wide range of combinations of innovative measures, rather than focusing on single innovations, in order to hedge against uncertainties and to integrate individual efforts between the site, neighbourhood, and watershed levels.

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