INNOVATIVE STORMWATER MANAGEMENT:
TRANSLATING SCIENCE INTO ACTIONS

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CANADIAN WATER NETWORK
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BACKGROUND:

More than 3 billion people will move into cities over the next 30 years and to accommodate them all will require increased densification that dramatically changes the urban landscape. This built up landscape is dominated by impervious surfaces which no longer allow the rainfall to infiltrate into the soil and will instead result in increased overland flow that contributes to more widespread flooding. At the same time climatic variability is increasing and the combination of urban densification and climate change will result in increasing runoff events that will result in increased flood risk. When we change land use we change the way the water is distributed in the hydrological cycle. As shown in Figure 1, a portion of the precipitation can either be evapotranspired, converted into surface runoff, stored in the soils or percolated into groundwater. When we convert a forested watershed into a paved urban landscape a much larger portion of the rainfall becomes surface runoff, which in traditional management is then conveyed directly into urban streams though an elaborate system of stormwater pipes. It is becoming increasingly apparent that conventional stormwater drainage systems are ill prepared to deal with increasing rain events and a drastically changed land surface.

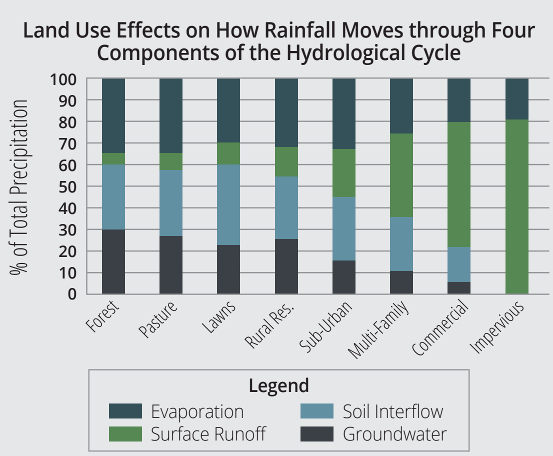

Figure 1. Land use impacts on the distribution of precipitation within the hydrological cycle.

Most municipalities base their stormwater design on the 100 or 200 year storm return period that uses the maximum historic rainfall event as a basis and then develops the return period graph that is known as the rainfall intensity-duration-frequency curve (IDF). If long term streamflow data is available this can be converted into storm runoff return graph, which shows to probability of a storm flow of a certain magnitude to reoccur over a different time period (Figure 2). However, such graphs are no longer valid because the land use and the climate have changed over recent times and no longer represent the historic conditions. This means that a

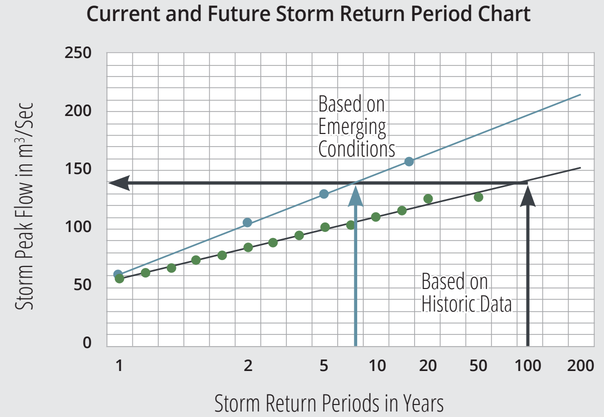

Figure 2. Historic and emerging stormflow return period due to increased climatic variability and increased impervious surfaces. The historic line formed the basis for designing stormwater and flood protection infrastructure (In this example a 100 year historic storm would now likely occur every 7 years – based on blue line).

previously expected one in one hundred rainfall or stream discharge event is now occurring at a much more frequent rate. With these new environmental conditions, we anticipate that much larger rainfall events will occur in the near future and the frequency of flooding events over the past few years already show and increasing trend. The questions that needs to be asked is how can we deal with this new reality and how do we change the traditional stormwater management system to cope with more frequent and higher flood events?

TRADITIONAL STORMWATER MANAGEMENT

The traditional approach in stormwater management has been to convey the surface runoff directly into urban streams, without any consideration of contaminants that accumulate on urban surfaces from land use activities, transportation and spills. This management scheme has been very successful in removing water from roads and parking lots but has resulted in a stream flow regime that became flashier, increased stream bank erosion and generated increased sediment transport. To cope with these new problems many urban streams were channelized using protective walls and protective structures, which pushed the water through the stream more efficiently. As a result more water ended up in the lowland portion of the watershed, which then required floodplain protective structures and land use regulations in the flood zone. As land became scarce in many cities the pressure on development within the flood zone increased, which then required improved flood proofing of the new infrastructure.

If we hope to create greener and more environmentally friendly cities we now need to address not only the increased flood risk but also the neglected urban pollution problem which resulted in deteriorating conditions in most urban streams.

THE NEED FOR INNOVATIONS

As part of the Canadian Water Network (CWN) research initiative a number of workshops were held in Vancouver, Calgary and Toronto to discuss the current problems in urban stormwater management, and to learn from case studies how the increasing flood risks can be reduced, and how best to address the non-point sources of pollution. Based on this cross-city experience it became evident that a number of new initiatives are under way to radically change the way we manage urban stormwater. Three key issues emerged from these workshops:

1. How effective are many of the new innovations and is there enough scientific evidence to show that the innovative approaches are more effective than the traditional measures;
2. How can these innovations be incorporated into mainstream urban development to reduce the risk of flooding and contamination; and
3. What are the most appropriate combinations of innovative approaches that work at all scales of watershed management and different environmental settings?

A wide range of innovative measures were identified and examined and it became clear that not all of the proposed innovative solutions are appropriate in all cities because each urban watershed differs in geology, surface conditions, climate and land use. To document the effectiveness of some of the proposed innovative measures a number of research projects were initiated with CWN support to address the above mentioned issues. We are now confident that many of the proposed changes are effective not only from the environmental point of view but also in terms of costs, particularly if they are introduced into new expanding urban areas. A major effort is now needed to promote these innovations so that they can become the main adaptive measures taken to cope with the increased risk of flooding and stream contamination.

THE NEW STORMWATER MANAGEMENT PARADIGM

When people move into cities they assume that the city engineers will provide them with all the key services related to water management including safe drinking water, sewage treatment, stormwater removal and flood protection. Given these new issues of densification and climate change it is now apparent that the sole reliance on the engineering structural approach is no longer sufficient and the property owner will now have to be part of the solution in solving the emerging stormwater problems.

The fundamental changes that are required in order to cope with the new rainfall/runoff regime are to shift from draining and removing water from sites, to storing, detaining and infiltrating rainwater and by enhancing the natural processes that provide these functions. At the same time these innovative approaches need to address both the hydrological processes as well as the impacts from non-point sources of pollution. Enhancing soils, wetlands and plant cover in the watershed and within riparian buffer zones is essential in order to provide sufficient capacity to absorb, convert and immobilize many of the contaminants from different land use activities.

As the water moves from the property to the neighborhood and into the watershed, the processes change and so do the contaminants. At the property scale it has been the norm to drain all water away from the housing structure and into stormwater pipes. Pollutants from gardening, spills and household activities are all removed through storm drains. At the neighborhood scale we have to deal with roads, parking lots and commercial facilities and many of the transport related activities create a wide range of new contaminants such as hydrocarbons, oils, grease metals and industrial chemicals. Again these contaminants are directly released into the storm sewer system. At the end of the pipe all of the runoff and contaminants end up in the urban stream and we hope that nature will provide sufficient remediation and dilution so as not to harm the ecosystem. To reduce the hydrological and pollution impact on urban streams requires a new approach, shown in Table 1, and this differs significantly from what has traditionally been done.

Table 1. Differences between the traditional approach versus the new innovative approach at the three spatial scales.

	TRADITIONAL APPROACH	INNOVATIVE APPROACH
PROPERTY SCALE	Drain and remove rain & runoff	Retain rain on site, slow release of water though infiltration systems
NEIGHBORHOOD SCALE	Drain and remove rain & runoff	Store and delay runoff using detention and filter systems
WATERSHED SCALE	Store water in ponds, develop protective structures (dams & dykes), channelize streams Land use restriction in flood plain	Delay runoff in wide buffer zone and naturalized stream channels, improve flood storage within the watershed.

INNOVATIVE ACTIONS AT DIFFERENT SPATIAL SCALES

As shown in Table 2, there are a wide range of innovative approaches that need to be adapted in order to reduce the flooding and pollution risks. No single action will be able to address all issues but a combination of actions at the different spatial scales will be the best recipe for success. Not all of the listed actions in Table 2 will succeed in all areas due to the differences in climatic and site conditions. However, there is now sufficient evidence that using a combination of options can go a long way in reducing the risk of flooding and the amount of contaminants reaching the urban streams.

Table 2. Innovative approaches to reduce stormwater runoff and contamination

PROPERTY SCALE	NEIGHBORHOOD SCALE	WATERSHED SCALE
Rainwater harvesting from roofs and impervious surfaces for re-use during dry periods	Minimize the size of roads, parking lots and impervious surfaces	Create large, continuous riparian buffer zones along streams and lakes
Green roofs to reduce and delay runoff	Create infiltration swales to direct road and impervious surface runoff into swales	Diversify stream channels into meandering and side stream systems (naturalize drainage)
Improve soil conditions to maximize infiltration and water storage	Create and incorporate wetlands into neighborhoods	Build wetlands and detention systems in the buffer zones
Minimize imperious surface and soil compaction	Provide temporary water storage in the form of ponds and detention systems	Select appropriate topographic areas for deliberate temporary water storage
Plant trees to reduce runoff where possible		Enforce land use zoning in the floodplain

THE PROPERTY SCALE:

For the first time individual land owners in the urban environment need to be part of the integrated solution to reduce the flood risk. Rainwater collection is one of the most effective ways to store water that can then be used either for outdoor purposes or for toilet flushing. A CWN sponsored student project (Maurer 2005) showed that up to 48% of the bacterial free treated domestic water is used for watering lawns in the urban areas in B.C. Collecting roofwater for outdoor use can dramatically reduce the use of domestic water depending on the size of the rainwater storage tank. If roofwater is used for toilet flushing then the domestic water can be reduced by an additional 30 %.

Green roofs are another way to slow down and reduce rainfall runoff and to filter out airborne contaminants that are deposited on roof surfaces. Another student project by Asadian (2010) tested how much rainwater is intercepted and evapotranspired by urban trees. Most research has shown that between 25-35% of all rainfall is evapotranspired by forests. In forests temperatures are usually cool and wind movement is restricted, but urban trees are more in the open, with the wind easily moving through them leading to higher temperatures and more evapotranspiration. A one year monitoring study was initiated by measuring rainfall interception and evapotranspiration on 54 urban trees and the results showed that Douglas Fir and Red Cedar trees were able to evapotranspire up to 40-55% of the rainfall. Since the remaining rain has to move through the canopy the throughfall is delayed and energy is dissipated. What this shows is that urban trees planted on individual properties are not only useful for absorbing CO2 but they are extremely useful for reducing the amount of rainfall that ends up as runoff. Another important factor is the maintenance of topsoil. If we require a 30cm layer of organic rich topsoil to be added to each new property before planting turf, then the soils can store large amounts of rainwater that is filtered and very slowly released as subsurface flow. This will not only result in water storage but the lawn will require up to 30% less irrigation water in the summer, thus saving additional

Figure 3. Rain-garden in Surrey, B.C. that allows the surface runoff to infiltrate into the soil

domestic water. Another effective way is to disconnect roof drains from the stormwater pipes and divert water from impervious patios and driveways into rain-gardens (Figure 3) and swales that allow the water to infiltrate and be stored temporarily. This will allow the microbial population in the soil to convert and reduce the contaminants which will eventually reach the urban stream.

Driveways can also be changed to either reduce the paved surface or by using many different materials and designs that allow the water to infiltrate into the sub-soil.

THE NEIGHBORHOOD SCALE

At this enlarged scale we need to consider transportation corridors, parking lots and commercial facilities that require drainage and that contribute many new contaminants to the runoff. These contaminants are usually different from the property scale in that they contain hydrocarbons, oil, grease, metals and sediments. Making the roads smaller, removing curbs and gutters and allowing the road runoff to flow into swales filled with sand and gravel are very effective ways to temporarily store water, filter out the sediments and reduce the contaminants by microbial processes and plant uptake.

Swales are also replacing drainage pipes in parking lots and are designed to detain water and reduce the contamination before the water seeps into local streams. An example of an effective parking lot runoff design is provided in Figure 4.

Figure 4. An Innovative parking lot in North Vancouver where runoff is infiltrated into a sand and gravel filter

Minimizing impervious surfaces and developing parking surfaces that allow water to infiltrate is not only effective in reducing the flood peak and the pollution problem but is also more cost effective and more appealing than conventional paved parking lots.

The key option for dealing with storm events is to develop detention ponds and wetlands that function as water storage devices and water filtering systems. Sediment which absorbs many metals can be collected in a forebay before the water enters the wetland systems. The organic matter helps to retain water and the vegetation and the microbial community is useful to uptake, dilute and convert many of the contaminants before the water is slowly released below the wetlands. Constructed urban wetlands are proving to be very effective water storage and filter systems.

Many urbanites are apprehensive about having wetlands in their neighbourhood because of the concern about mosquitos and West Nile virus issues. As part of the research it was shown that the mosquito problem can be reduced significantly by designing the wetland so as to always maintain slowly moving surface water, to minimize the development of blue-green algae (minimize eutrophication), to plant a wide range of wetland plants, to make sure there is open space between the plants for UV light penetration and by introducing fish, like stickleback, that eat larvae and can survive in somewhat degraded water quality conditions.

THE WATERSHED SCALE

At the watershed scale the focus has to be on maintaining wide vegetated riparian buffer zones that allow natural stream channels to be maintained. Buffer zones have many functions, as shown in Figure 5, and if we leave a sufficiently wide corridor before urban development takes place we can incorporate wetlands and detention structures that delay and moderate peak flow, allowing the vegetation and soils to retain sediments and the plants to take up excess nutrients. These wide and protected buffer zones can also be used for recreational purposes because they attract significant populations of birds and wildlife, promote biodiversity and are a major food source for aquatic organisms.

It is also essential to no longer put stream channels into concrete structures but rather allow the channel to meander and follow a natural pathway because significant amounts of water can then flow laterally in order to dissipate energy and help recharge groundwater, and store and delay water in back-channels and oxbow lakes in the lowland.

Rather than building more protective structures in the form of dykes and protective walls in the floodplain a major effort needs to be made to search for topographically appropriate sections within the watershed where water during very high storm events can be stored on a temporary basis. These can be areas in parks, playgrounds and agricultural areas

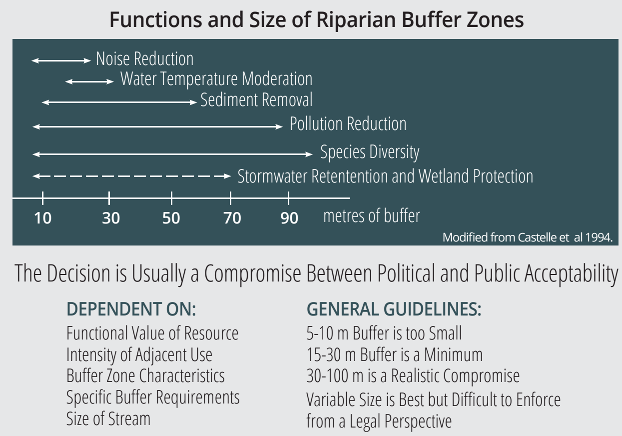

Figure 5. The appropriate size of the riparian buffer zones to accommodate all effective functions.

and this can significantly reduce flooding in the lowland. The damage caused by large storms in these temporary storage areas is small and it is a much cheaper and effective solution than building and maintaining protective structures and flood proofing properties in the lowland. Of course restricting land use activities in the floodplain needs continuous enforcement.

Each watershed has multiple uses and this makes evaluations complex. The most important functions are to protect the water sources and to ensure that all environmental services are fully functioning. This means that each watershed will have slightly different sensitivities and a different range of adaptive measures will be needed.

CONCLUSION

Emerging changes in land use and climate show that conventional stormwater management systems in urban watersheds are no longer adequate to deal with increased runoff and flooding events. The conventional approach focuses on rapid drainage and removal of stormwater runoff from all urban surfaces without addressing the problem of contaminants from urban land use activities. The CWN research has shown that a major shift is needed to address these new conditions by focusing on runoff detention, temporary storage and infiltration of runoff water which also reduces the contamination problem. To accomplish this and to reduce the flooding and contamination risk a wide range of innovations are required to deal with the emerging runoff, flooding and pollution problems at three different spatial scales.

For the first time the property owners need to participate in retaining precipitation and delaying the runoff from their properties. This can be accomplished by using green roofs, harvesting roofwater for outdoor and indoor use, improving soil conditions, reducing impervious surfaces, planting urban trees and establishing rain-gardens. The concept is source control that addesses both the quality and the quantity of water.

The next level of innovation is at the neighbourhood scale where runoff from impervious surfaces and contaminants from transportation are more intense. This can be accomplished by re-designing roads and parking lots so that the runoff water is directed into swales, sand filters, detention ponds and wetlands.

Ultimately all runoff and pollution ends in the watershed and in the lowland floodplain. The key innovative solutions at this scale are to establish wide riparian buffer zones that allow the river to establish a natural channel which acts as a filter and storage systems for sediment and water and allows contaminants to be contained before they reach the river. This also requires a new approach for how to deal with extreme flooding events. Designating temporary storage areas in topographically appropriate sites within the watershed can help reduce the flood risk problem dramatically.

None of the individually proposed innovations will be sufficient to solve all problems but it is proposed that a combination of these approaches will help reduce the flood risk and for the first time will help to reduce contaminant input into urban streams. Not all of these innovations are appropriate in all urban watersheds because the local site and climatic conditions vary from city to city. This requires that an adaptive management approach is needed to select innovations that are best suited for the local conditions.

The research identified a new and innovative path to address a major urban problem and offers solutions that are capable of not only reduce the flooding risks but also significantly improving the environment of urban streams. The first step is to initiate all the above options in new urban developments where these measures are most cost effective and can reduce potential problems in a significant way.

A number of cities have taken the lead in using these innovative ideas to reduce the urban stormwater problems and some of the innovations that are in place in the Vancouver area are featured in a new video accessible on the CWN website. The remaining challenge is how these innovations can become the main tools for any new urban expansion and how the knowledge generated by research can be translated into widespread action.

FOR FURTHER INFORMATION PLEASE SEE HTTP://MLWS.LANDFOOD.UBC.CA/VIDEOS/

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