RESEARCH HIGHLIGHT

October 2007

Socio-economic Series 07-013

A Plan for Rainy Days: Water Runoff and Site Planning

INTRODUCTION

In 2004, the City of Stratford (population 30,000) approved a secondary plan for a future city expansion area of 155 ha (383 acres), based on an evaluation of three plans, one of which was derived from the CMHC planning model, the Fused Grid.[1] The evaluation compared the plans against 16 criteria falling under three overarching concepts of efficiency, quality and environmental impact.

Rainwater can be an asset or a liability depending on the approach to dealing with runoff.

Since all three plans protected site watercourses and included stormwater management (SWM) ponds as a requirement, the evaluation criteria did not include rainwater runoff impacts.

Current research shows that runoff from development can be detrimental to water quality, aquatic life and the maintenance of water resources. New tools for modelling rainwater behaviour and management, such as the Water Balance Model (WBM) for Canada,[2] and new approaches for reducing runoff, have been developed and have begun to be applied. The available land use plans, the need for effective ways to protect watersheds and the new methods of modelling presented an opportunity to examine in detail what factors influence water runoff and to what extent.

The results of this research indicate that, from the perspective of sustainability, evaluations of development plans should include an additional criterion under environmental impact—rainwater management.

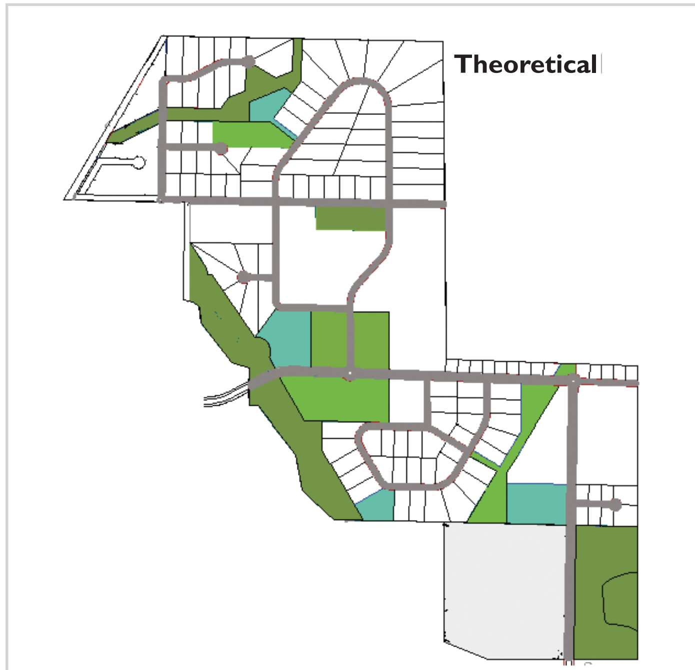

Figure 1 An experimental site plan layout using medium density forms and estate lots.

PURPOSE AND RESEARCH APPROACH

The study aims to set out the effects of site design approaches, site infrastructure methods and site development standards on the potential for reducing or eliminating water runoff from new development.

All greenfield development will invariably include impermeable surfaces big enough to cause more runoff than pre-development conditions. Most cities are expanding into surrounding greenfields and, seeing the effects of this expansion, the preservation of the pre-development, natural water balance has become a key planning issue.

[1] See CHMC Research Highlight 04-038, "Applying Fused-Grid Planning in Stratford, Ontario" at http://www.cmhc-schl.gc.ca Retrieved July, 2007, English and French

[2] See "Water Balance Model for Canada" at www.waterbalance.ca. Retrieved July, 2007, English only

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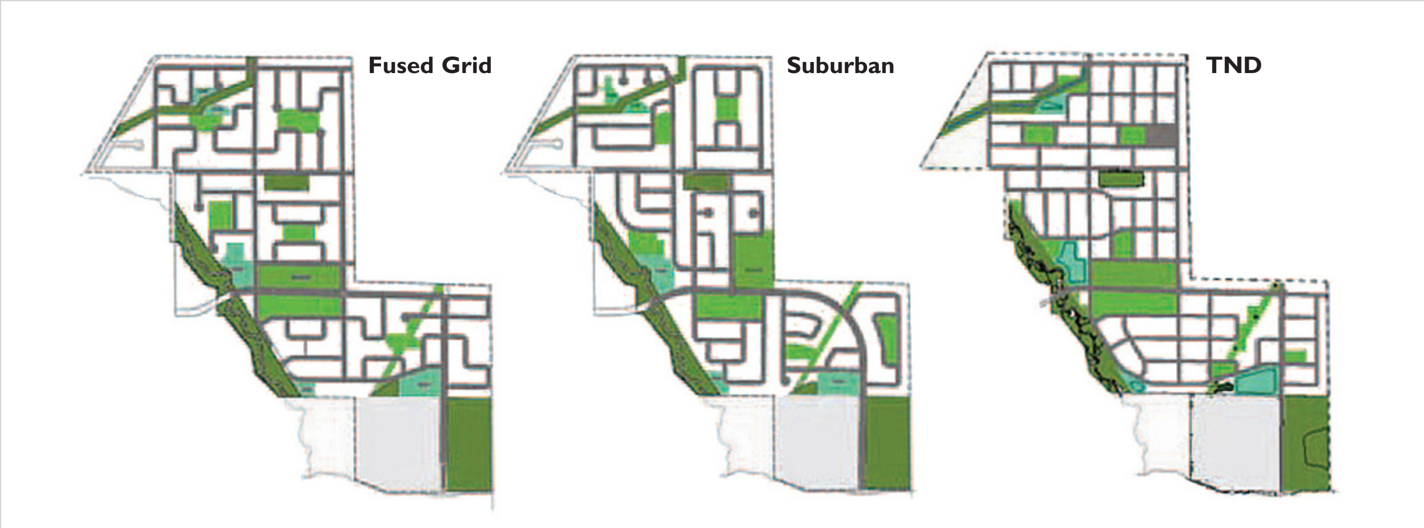

Figure 2 Site plans using alternative approaches to street layout. Left, Fused Grid; centre, conventional suburban and right, traditional neighbourhood design.

The goal in examining this is to enable planners, developers and municipal officials to make informed choices about the most effective ways to retain more water and reduce or prevent runoff, which promotes groundwater infiltration and regeneration of the water supply.

The question for this analysis was to assess to what extent street layout, amount and distribution of open space, and building form affect the post-development runoff resulting from the impermeable surfaces development creates.

The research proceeds in two steps to explore and measure development impacts.

Step One

First, the outcomes of site design approaches are tabulated and measured. Three site layouts are tested: conventional suburban, Fused Grid and traditional neighbourhood design (TND) approach. (*see* figure 2). These are juxtaposed with a theoretical site plan to examine the influence of denser building forms (*see* figure 1). This plan was drawn up to include the same number of housing units but in substantially different proportions in types than the other three.

Given the small town, slow-growth context, all plans are set to meet similar housing unit counts. Table 1 shows these counts and their distribution among housing unit types. Changing the total number of units between plans was judged to be an incidental factor for studying runoff, since all three are capable of accommodating more units by altering lot sizes, unit size and building form. Other research has established the potential of increasing density within a fixed layout.

Step Two

The Water Balance Model (WBM) was applied to measure the influence of the layout and retention techniques on total runoff. The WBM calculates annual runoff volumes under different combinations of building and hard surface coverage; soil type and depth; source controls and rainfall.

The inputs for this analysis are taken from site plan measurements (based on CAD drawings), the 1992 rainfall pattern from the closest climate station (Toronto) and the Soil Survey of Perth County (1989) for the soil types on the site.

Table 1 Distribution of lots and their sizes

Lot size (width)	Fused Grid	Suburban	TND	Theoretical
10 m (32 ft.)	203	126	263	0
12 m (39 ft.)	932	973	791	0
15 m (49 ft.)	218	291	154	0
Estate lots	0	0	0	123
Medium density—40 uph (units per hectare)	200	224	256	1296
Total lots/Units	**1,553**	**1,614**	**1,464**	**1,419**

For source controls, absorbent landscape (that is, soil depth) and "rain gardens" (that is, complete with infiltration trenches) are evaluated. The effect of each of these control techniques was estimated separately and in combination. The model produces figures for runoff, infiltration and transpiration, which together account for the entire volume of rainfall. Interestingly, in the predevelopment state, transpiration, mediated by plants, discharges about 75 per cent of the incident water (figure 4), underscoring the value of vegetation for maintaining water balance on site.

FINDINGS

Site plan approaches

Figure 3 shows the relative pervious and impervious surface areas resulting from each site planning approach.

In general, three of the four layouts produce similar proportions of impermeable areas from 34.7 per cent of the site (Fused Grid) to 35.8 per cent (suburban) and 39 per cent (TND) resulting in similar runoff volumes (*see* figure 4). The fourth, theoretical, plan shows the least impervious cover at 17 per cent of the site. These similarities and the striking difference of the fourth plan are better understood when looking at the three essential elements of a site plan – buildings, streets and natural ground in more detail.

Buildings

Buildings are the second most influential component of a site plan affecting water outflow. Their number, form and spacing affect coverage and, in turn, water runoff.

At the individual lot level, even at normal, low, building footprints of about 25 to 30 per cent of the lot area, as in this study, and with good natural soil, runoff will be about 40 to 50 per cent of total rainfall volume from a lot without treatment.

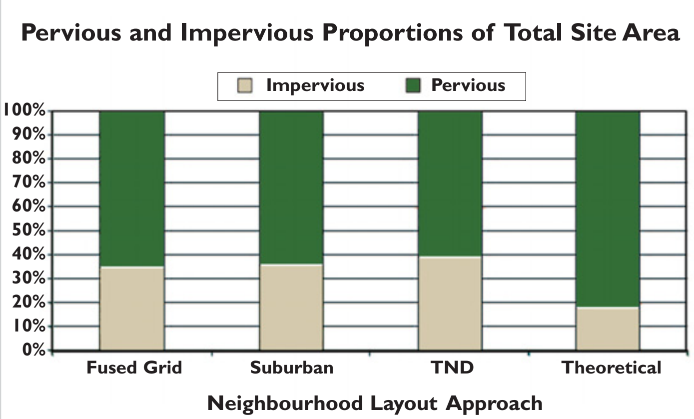

Figure 3 Ratios of pervious and impervious areas in each of the four layouts

Lowering the footprint sufficiently to reduce cover would limit building design severely and may compromise its functionality, space efficiency and esthetics. On the other hand, if the cover ratio is reduced by making the lot bigger, its size would have to more than quadruple from 550 m² (5,920 sq. ft,) to about 2,400 m² (25,824 sq. ft.) to provide sufficient area for absorption; a strategy unrealistic from price and planning perspectives.

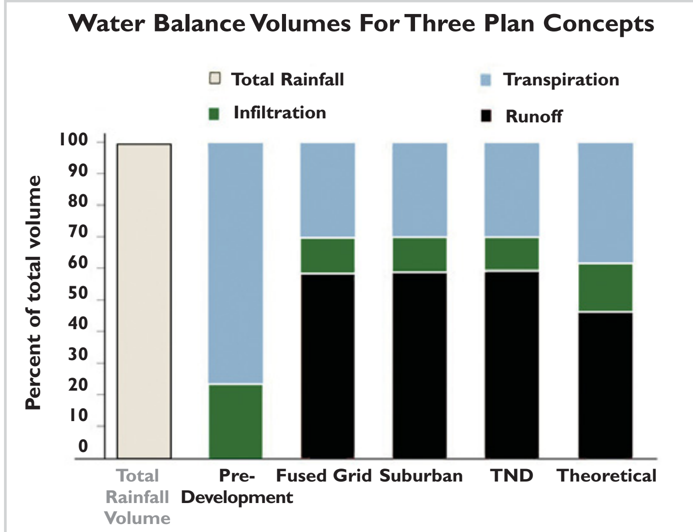

Figure 4 Relative runoff volumes of four plans

As long as building form remains low-rise and the lots stay within the customary range of 350m² to 550 m² (3,767 sq. ft. to 5,920 sq. ft.), additional absorption measures would always be necessary to limit surface runoff generation to the 10 per cent annual target volume that is often found to be characteristic of a healthy watershed.

The theoretical plan illustrates a strategy that relies on two methods for reducing impervious cover: very large estate lots that reduce the per-lot cover ratio and medium-density housing (3–4 storeys), that reduces the per-housing-unit cover ratio. This combination enables halving the road length, thus making more ground available for absorption.

To reduce impervious cover from around 35 per cent of the three plans to 18 per cent, the theoretical plan places 91 per cent of the housing units in 3–4 storeys, multi-unit structures and only nine per cent in detached houses. The analysis suggests it is theoretically possible to reduce total coverage by using mid-rise housing as the dominant type.

However, a development approach that places 9 in 10 housing units in multi-unit structures will be discordant with market trends and unlikely to succeed. Moreover, in practice, multi-storey buildings are built on location-driven sites and at coverage two or three times that of low-rise, thus nullifying their per-housing-unit footprint advantage.

Where building coverage is inevitably high, two methods can assist in reducing its impact: complementary public open space and green roofs. Public spaces offer an opportunity to introduce large infiltration facilities that act as central gathering points for adjacent lots. This becomes feasible and less costly where the open space is contiguous with the building lot and not separated by a road, as in the Fused Grid site plan.

Green roofs with extensive treatment have been shown to approximate the natural soil performance in reducing runoff.

They are a natural companion to multi-storey, high-coverage buildings, which leave less ground for absorbent techniques but can support additional weight on their roofs.

This analysis confirms that the effect of buildings on runoff cannot be masked in usual development settings by changing their form or their relationship to their lot. Since lots cannot increase in size and buildings cannot appreciably reduce their footprint, other techniques are necessary to control runoff at the building lot or lot cluster scale.

Streets

This analysis confirms that streets are the single most influential factor on the volume of water runoff. In the three layouts, they account for an impermeable surface proportion which is up to three times that of the building footprint (*see* figure 5).

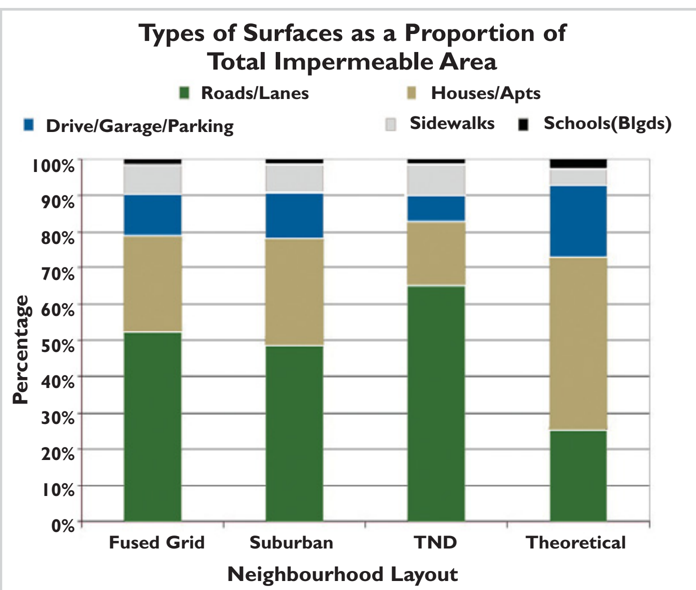

Figure 5 Contribution to impermeable site area by each land use

In addition, they invariably contain and channel all pavement water to conventional storm sewers. Moreover, they are the key source of water-borne particles and pollutants generated from daily use that require treatment in conventional, end-of-pipe stormwater facilities.

Of the total impermeable area in the three land-use plans, the portion attributable to streets ranges from 48 per cent to 65 per cent. The TND option shows the highest value. Only in the theoretical layout does the street ratio drop to 25 per cent, lower than that of the building coverage. (*see* figure 5, 4th bar)

As Figure 6 shows, after dealing with the lot-originating runoff (3rd bar), there remains about 74 per cent of the total site runoff (45/61) attributable to streets. Opportunities for introducing absorbent landscape are limited within the street right-of-way (ROW), as curbs make the adjacent boulevards inaccessible to stormwater and because boulevards are generally higher than the road. Boulevards themselves include impermeable surfaces, such as sidewalks, driveways and entry paths, which are sources of runoff requiring control.

This analysis shows streets are both large producers of runoff and most limiting in terms of opportunities to contain it. Figure 6 shows that in the case of the TND plan (with the most road surface of all three plans) that even after all the measures have been applied to both lot and street, 14 per cent of the total rainfall will flow out of the site.

Consequently, a key strategy in containing the large impact streets have on runoff would be to minimize their coverage by reducing their length and width at the site layout stage. Practical means are available to do both.

Reducing street length

This has been achieved in conventional suburban layouts, as figure 4 shows. Invariably, however, this reduction results in relatively restricted pedestrian movement (as can be seen in figure 2), a vital element of neighbourhood livability and resident satisfaction.

An alternative strategy replaces certain road segments with green open spaces, which serve as pedestrian connectors. Pedestrians do not require the full ROW of a street or its pavement for walking; paths, trails and lanes are not only adequate but are safer and pleasanter. Thus, full connectivity for pedestrians is achieved while reducing pavement and increasing landscaped areas. The Fused Grid model takes this approach to reducing street length systematically by integrating open spaces with the pedestrian network.

Though not part of the road length that serves as a circulation system, rear access lanes could add a significant amount of paved surface on a site, as can be inferred from figure 5. To maintain high permeability, lanes should be included only if deemed necessary for traffic flow.

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3 For an exaple, see figure 2 in the *Research Highlight* "Residential Street Pattern Design" at www.cmhc-schl.gc.ca/odpub/pdf/62486.pdf. Retrieved September, 2007, English and French.

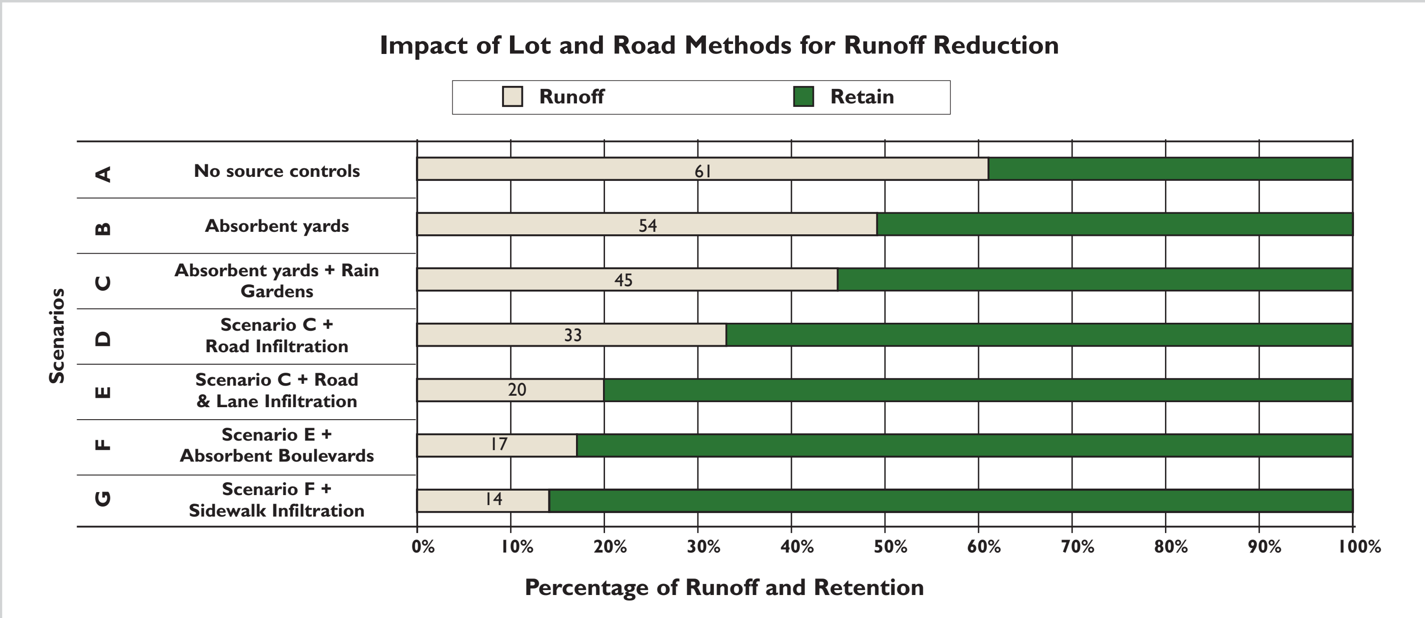

Figure 6 Relative impact of lot and street measures in reducing runoff

Street pavement width

If volume and speed of traffic are expected to be low and remain stable over time, street pavement width can be reduced.

These conditions are satisfied when a local street cannot be used for through traffic, for example the loop, double-T, and dead-end types, also a dominant characteristic of the Fused Grid and, partially, of the suburban approach.

However, road standards vary by municipality and may require adjustment to allow for type differentiation and reduction of width.

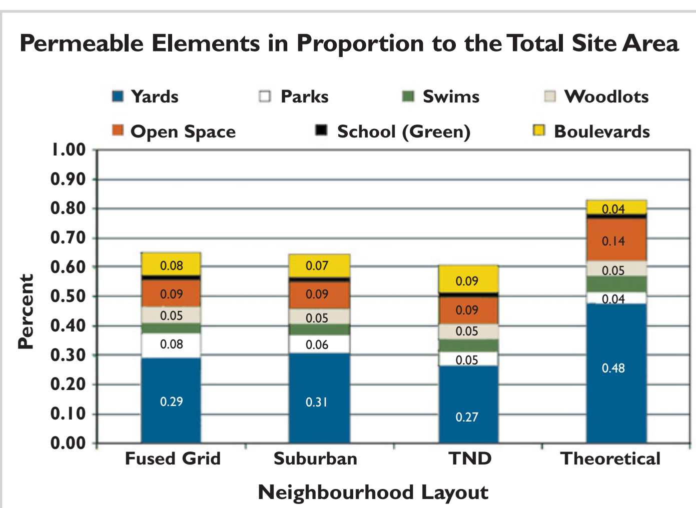

Figure 7 Relative contribution to permeability by element in four plans

A specific strategy of allowing street water to flow over to adjacent land relies on a street section design (*see* Picture from Seattle), which is a modified version of rural concession roads; no curbs or sidewalks at the sides and the pavement curves slightly to shed water to adjacent infiltration trenches.

A retrofitted residential street in Seattle, WA, includes trenches and no curbs.

Intermittent curb cuts are another variation of the same idea. This adapted design has recently been applied to suburban and exurban local streets.

The strategy depends heavily on the ROW width and the building setback; the narrower the ROW and the closer the building face to it, the lower its effectiveness. The no-curb-trench road design helps retain a significant amount of rainwater; however, more than 50 per cent of the road-generated runoff remains to be controlled with additional measures, such as the in-street absorbent drain. Collector or arterial streets that have denser forms of housing or commercial uses fronting them cannot easily accommodate this design because of the sidewalks, walkways and frequent driveway interruptions.

Streets emerge as the largest single contributor to site impermeability and, consequently, to water runoff, in normal suburban development. A site plan that reduces street length and width removes part of their negative impact at the source and reduces the extent of site treatment measures, therefore making them more cost-effective.

Open space

Open space is the critical counterbalancing factor in dealing with runoff; the more of it the easier it is to control runoff.

As the theoretical plan demonstrates, the amount of site area of a development given to open space can reduce runoff considerably by increasing both absorption and transpiration. This is also evident in the analysis of normal and maximum lot coverage, where a 16 per cent decrease in yard space causes the runoff to increase from 50 per cent to 64 per cent, an almost proportional 14 percentage point increase. (*See* table 2.)

The Stratford site includes environmentally sensitive lands and woodlots that were deemed worth preserving and all three plans reflected that requirement. These features constitute 15 per cent of the total site area; a significant portion that provides the first defence for limiting runoff, but clearly insufficient by itself to influence the overall impact of development.

Table 2 Proportion of annual rainfall volume as surface runoff for a 10 m (32 ft.) wide lot, 350m² (3,767 sq. ft.)

Scenario	Normal footprint—%	Maximum footprint—%
No source controls	50	64
Absorbent landscape only	31	51
Rain garden only	13	17
The two measures combined	2	5

An important component of open space is the area allocated to rear and front yards (*see* figure 7). In total, yards can constitute between 43 and 48 per cent of the permeable surface and, in three of the four plans, about 30 per cent of the site area.

Their importance lies in providing necessary surface where absorbent landscaping and other techniques can be used. The larger the yard area is the greater the opportunity to apply these measures. Inevitably, larger yards, usually of large lots, will reduce development density and yields, as shown in a portion of the theoretical concept plan. Yards, large or small, are subject to modifications by their owners, however, that can be detrimental to water absorption—a possibility that signals the need for greater reliance on public open space

From a site plan perspective, maintaining natural features and ensuring sizeable rear yards with appropriate site development guidelines creates a strong foundation for lot-based retention measures.

In summary, site plan design can significantly expand the opportunities for applying measures to control runoff at source by means of managing building form and density, reducing the areas allocated to streets, and balancing the amount of space that is dedicated to private and public green (yards and parks).

TECHNIQUES TO REDUCE RUNOFF AT THE SOURCE

Using the Water Balance Model, the study examines the impact of several techniques to reduce runoff. One set applies to the individual lots, such as absorbent landscape, rain gardens and pervious pavers. Another set applies to streets, such as in-street infiltration trenches, absorbent boulevards and sidewalks combined with storage underneath.

Stormwater ponds are not included in the model because they do not limit runoff volume, simply peak flow rates. In these analyses, ponds that appear on the plan are treated as natural open space.

The intent in applying these techniques is to achieve a reduction in runoff that mimics the predevelopment condition.

Absorbent landscape and rain gardens

Absorbent landscape technique

This technique increases topsoil depth from the 75 mm (2.95 in.) normally found on sites to 300 mm (12 in.). Its effect is shown in bar 3 of figure 8.

In a typical 10 m (32 ft.) wide lot, if the 165m² (1,776 sq. ft.) rear yard becomes absorbent landscape, it will reduce runoff from the expected 50 per cent to about 31 per cent, a 19 point drop. By

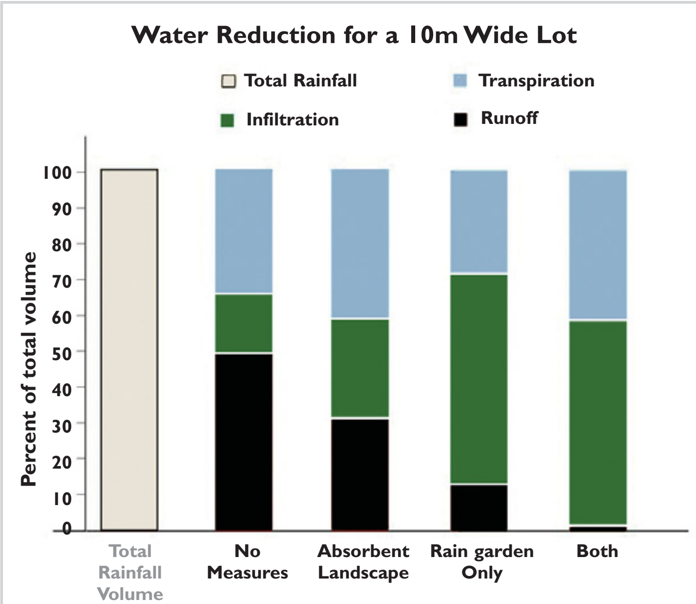

Figure 8 The impact of absorbent techniques on individual lots

comparison, a smaller yard of about 114m² (1,227 sq. ft.), resulting from a larger building footprint, will produce only a 13 point drop, to 51 per cent from 64 per cent.

Rain garden technique

This technique, an infiltration trench of 9 m² (97 sq. ft.) and 600 mm (2 ft.) deep, produces a 37 percentage point drop to 13 per cent from 50 per cent of runoff, almost twice as effective as the absorbent landscape option. When the 2 measures are combined they reduce runoff from the lot to two per cent for a normal building footprint and 5 per cent for a maximum footprint (*see* figure 8).

Increasing the size of the rain garden can assist in runoff reduction of a densely built site, such as the medium-density lots, of which half the area is impermeable. Figure 9 shows the effect of increasing the rain garden area from 50m² (538 sq. ft.) (bar 2) to 400m² (4,305 sq. ft.), a fourfold increase, (bar 5): a reduction of 52 percentage points of runoff.

In-street infiltration trench, absorbent boulevards and water-storing sidewalks

In-street infiltration systems can handle some or all of the street runoff that remains after other measures are used to retain water.

The system consists of a 1 m by 1 m (3 ft. by 3 ft.) linear trench filled with crushed stone. The trench contains the storm sewer and a drain-tile pipe. Street drainage is directed into the trench through a perforated pipe that is connected to the storm sewer system.

Figure 6 shows that the in-street system produces a 45 percentage point reduction in runoff. The remaining 30 percentage points of the total runoff that a normal street ROW generates can be handled by absorbent soil in the boulevards and water storage under the sidewalk. The absorbent soil produces a 16 percentage point reduction; the water storage under the sidewalk a 12 percentage point reduction.

This array of absorption techniques, when put in place together, can reduce the total development runoff to practically zero and render the site innocuous with respect to its effect on watercourses and watersheds.

SITE DEVELOPMENTS STANDARDS

Stratford now requires runoff water quality and quantity controls. These requirements mandate that post-development runoff be controlled to achieve pre-development rates for a 5-to-25 year storm event, with water quality controls in place to provide sediment and silt removal before release to receiving watercourses.

These practices have been established through consultations with conservation authorities and reflect the intent to provide water quality protection to receiving streams. Similar requirements are common in many Ontario municipalities, with variations based on the local rainfall patterns and soil types.

Some Ontario municipalities have imposed definitive impervious cover limits (ICLs) to promote greater infiltration for the betterment of ecosystems through groundwater recharge.

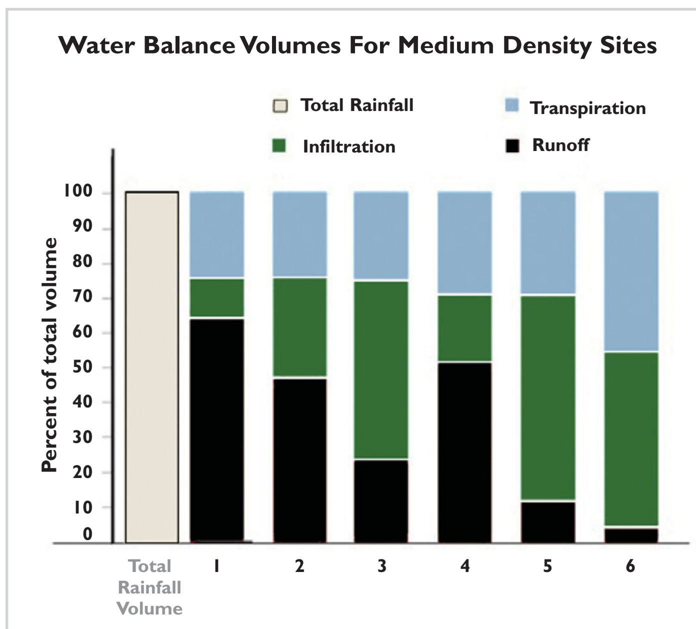

Figure 9 Effect of increasing the size of rain garden

The Grand River Conservation Authority, for example, has imposed ICLs on Cambridge and Kitchener through land use policy in official plans that restrict impervious areas to a maximum coverage of 35 to 45 per cent of the gross land area depending on soil and other characteristics of the land. The intent is to monitor existing conditions in an undeveloped state, measure groundwater flows at discharge points, then continue to monitor flows post-development at the prescribed coverage maximums to determine if pre-development infiltration can be mimicked. Ultimately, it is considered that the health of the ecosystem can be evaluated on this basis.

Surrey, B.C., requires roof leader disconnection, soil depth augmentation by absorbent landscape and infiltration systems for rainwater runoff capture. In new subdivisions, such as East Clayton, the required soil depth has been increased to 450 mm (18 in.) from 300 mm (12 in.).

CHANGE IN APPROACH

In most municipalities engineering standards that were developed in the 1970s and 1980s for dealing with water runoff assumed the commonly used "drain-and-pipe" method because, traditionally, the focus has been on protection of life and property only.

This single-objective approach resulted in unintended degradation of water quality and stream habitat. This approach incurs costs at the site, to collect the rainwater, and at the end of the pipe to treat it or stabilize receiving watercourses, or both. At the same time it deprives the local soil from desirable moisture and the watershed from the necessary recharge. Rainfall in this approach is seen as source of potential liability instead of a resource.

In contrast to the drain-and-pipe method, the source-control approach is part of a "complete solution" that achieves many objectives: it not only protects life and property, it also avoids treatment costs, lowers irrigation costs, eliminates erosion protection costs and reduces the uncertainty of potential groundwater source depletion.

The piped approach may be perfectly suited for dense urban settings, such as urban cores and central districts, where there are few or no landscaped areas for water infiltration. However, in suburban and rural settings about 30 per cent of development area is in rear yards (*see* figure 7), at least five per cent in obligatory park dedication, and together with an assortment of other open spaces, "natural" areas total almost 40 to 50 percent of the total site area. As the analysis shows, this ground surface constitutes a resource which, when combined with landscaped based techniques, could limit runoff to a tolerable quantity or eliminate it entirely.

Infiltration as an approach to reducing runoff is less widely accepted by municipalities due to lack of awareness and to concerns about the long term maintenance cost of "clogged" infiltration systems. However, awareness is steadily increasing and the concerns are gradually being addressed.

The existence of sophisticated analytical tools, such as the Water Balance Model, empowers municipalities to anticipate and expect a desired level of performance from a new development. And since the landscape approach to rainwater treatment defers infrastructure costs and maintenance, it provides negotiating room with the development industry.

COMPARATIVE COSTS

Several decades of rainwater management experience show that it costs less to intercept a problem at the source than to mitigate its impacts downstream. Furthermore, source controls are landscape-based and achieve many objectives—for example, having a tree-lined streetscape creates a more livable community; rainwater interception by the tree canopy is a spinoff benefit that reduces runoff volume that would otherwise have to be "managed" by conventional infrastructure—pipes and ponds. This multiple benefit also applies to public open spaces, which can double up as rainwater infiltration, as recreation and as connectors.

If viewed narrowly, there is an additional cost at the individual lot level for the extra soil depth and the rain garden. On the other hand, there are the "avoided costs" at the catchment and watershed scales, which can be higher in comparison than the aggregate lot costs. For example, a case study of the City of Surrey calculated that for a 1,035 ha (2,557 acre) neighbourhood plan area, implementation of rainwater capture measures at the source would eliminate the need for $6 million in development cost charges for construction of detention ponds. In the same development, a rain garden for one house lot costs about $5,000.

In addition to rainwater capture on individual lots, the landscape-based strategy includes the creation of contiguous, large-scale green corridors through the watershed.

The City of Surrey has concluded that the corridors can result in cost savings for developers and municipal governments as their effectiveness at controlling rainfall volumes makes the traditional detention pond redundant, and therefore high land acquisition and construction costs (often in the range of $1 to 2 million) as well as long-term operation and maintenance costs are unnecessary.

At a minimum, a green corridor can be cost-neutral compared to the costs associated with a detention pond facility.

CONCLUSIONS

Rainwater can be an asset or a liability. It is an asset when it becomes "irrigation" and groundwater "recharge." It is a liability when it is gathered and piped and requires treatment or when it runs off and pollutes or erodes, or both, natural watercourses.

The study finds that all plans for new suburban development at normal densities, as in the Stratford example:

- Create an impermeable cover between 30 and 40 per cent of the total site area and the one-third variation between the three planning approaches is attributable mainly to the road pattern;
- Release about 60 per cent of the rainwater in runoff that can either be kept on site or piped to a central location;
- Generate about 40 to 50 per cent of the total permeable surface through rear and front yards and accessory open spaces

Applying known methods for filtering water can reduce runoff to practically zero. Increasing density or intensity throughout the site increases runoff and reduces the area where source control methods can be applied.

The difference in cost between the old drain-and-pipe and new hold-and-filter methods is small or, in some cases, nil, but the benefits of hold-and-filter methods are by far greater.

On the basis of these findings and from the perspective of managing runoff generated by new development, site plans for new subdivisions should:

- retain sensitive natural areas and allocate at least 50 per cent of the gross site area in permeable surfaces in the form of yards, parks, greenways and playfields;
- consider reducing road length to an optimum for motorized traffic (about 27 per cent in ROW area) and complement it with a soft network of paths for full pedestrian circulation;
- reduce all paved surfaces to a minimum or specify porous alternatives where applicable;
- propose building forms that reduce a structure's footprint—two-storey houses versus bungalows; three-storey schools versus one-storey;
- use analytical tools, such as the Water Balance Model, to calculate the potential for runoff generation and to assess the appropriate combination of methods to reduce it or eliminate it;
- analyse the respective full costs of different runoff handling methods to ground the case for on site control.

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