Chapter 3

A Stormwater Retrofit Plan for an Urban Creek Subwatershed

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In spite of massive public investment in sewerage and drainage infrastructures, runoff pollution loading from urbanized areas continues to have a significant impact on many receiving water bodies. Trends towards the urbanization and industrialization of the Great Lakes watersheds will further stress the environment. The seriousness of these problems is evident in the Remedial Action Plan (RAP) process taking place in the Great Lakes Basin and in the issues facing municipal governments in the basin. Under the RAP program, the Canada-U.S. Great Lakes Water Quality Agreement requires both countries to clean up local water quality in each of the 42 Areas of Concern (AOC). At the seventeen Canadian AOC, urban runoff has been identified as the most important source of water pollution (Schroeter, 1993). Thus, the increased quantities of urban runoff and the corresponding increase in pollutant loadings demand that urban runoff control systems be planned and engineered to effect higher levels of runoff quantity and quality control. However, municipalities within the RAP areas must also address the following physical and financial constraints associated with runoff management in urbanized areas:

- lack of space
- integration with existing infrastructure and drainage paths
- lack of funding
- lack of proven technologies available for retrofit applications
- lack of long-term strategy development methodologies
- safety and liability issues

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These constraints are attributed to different planning principles, timing, and issues between new developments and urbanized areas as illustrated in Table 3.1. One of the many challenges that the RAP municipalities must face, in particular, is the lack of a stormwater retrofit strategy for existing urbanized areas. Stormwater retrofit can be defined as the incorporation and integration of runoff control measures into existing drainage systems.

Recognizing the lack of a stormwater retrofit strategy in the RAP areas, Environment Canada, through the Great Lakes 2000 Cleanup Fund, the Ontario Ministry of Environment and Energy, and the City of Scarborough, commissioned Ryerson Polytechnic University to build on the Stormwater Management Practices Planning and Design Manual (Marshall Macklin & Monaghan, 1994) and develop a planning strategy for stormwater retrofit in urbanized areas (Li, 1997). It is hoped that the stormwater retrofit strategy may allow the RAP co-ordinators and municipal engineers/planners to obtain a planning level estimate of the cost and potential effectiveness of stormwater quality management in their urbanized areas. Additionally, it may assist municipalities in the development of stormwater related capital works and operation programs. However, this strategy cannot answer all the RAP issues and they should be addressed separately.

Table 3.1 Planning principles, timing and issues of stormwater management.

New development Areas	Urbanized Areas
Planning principles	Planning principles
Conservation of natural resources	Rehabilitation of infrastructure
Protection of natural resources and environmental sensitive areas	Retrofit of infrastructure
Preservation of natural resources and environmental sensitive areas	Reconstruction of infrastructure
Land use planning	Redevelopment Planning
Timing	Timing
Official Plan review	Maintenance plan
Secondary Plan	Road need studies
Draft Plan	Capital budget planning
Watershed/Subwatershed planning	Environmental Assessment planning
Issues	Issues
Pre- and Post-development flow volumes, peak rates, and time to peak	Basement flooding
Baseflow impact and existing fishery protection	Baseflow augmentation and stream rehabilitation
Water quality degradation	Lack of methodology, space, natural asset, rehabilitation plan
Maximization of developable land	Spill control
Land use approval process	Environmental approval process

The stormwater retrofit strategy consists of the following steps:

1. definition of stormwater quality management goals and objectives;
2. identification of feasible retrofit stormwater management practices (RSWMPs);
3. formulation of alternative stormwater retrofit strategies using Step 2;
4. evaluation of alternative strategies; and
5. recommendation of the preferred strategy.

This chapter presents a demonstration case study using the stormwater retrofit strategy. The following sections describe each of the above steps for the Centennial Creek Subwatershed, in Scarborough, Ontario, Canada.

3.1 Description of the Study Area

One of three major watercourses in Scarborough, is Centennial Creek, indicated in Figure 3.1. It drains into Highland Creek near Lake Ontario. The drainage area is about 740 hectares and roughly bounded by Highway 401 in the north, Port Union Road in the east, Morningside Avenue and Military Trail in the west, and Lake Ontario to the south. Located within the Metro Toronto Region RAP area, runoff quality improvement in the Centennial Creek will enhance the local near-shore water quality.

The Centennial Creek Subwatershed is fully urbanized. The predominant land use is residential with some minor commercial use. No industrial land use is found in the subwatershed. The residential areas are characterized by a large number of older subdivisions with large lots and a relatively small number of high density residential subdivisions. Most of the roads and sewers are in good condition and no major capital works are planned in the next five years. (*written in 1997*).

Urbanization has altered the natural ecosystem and hydrologic cycle of the subwatershed. However, there are still some basic ecosystem functions remaining (e.g. limited wetlands, a reasonably continuous stream corridor, some resilient aquatic habitats, etc.) which give some hope of rehabilitation and enhancement (MacViro, 1995). Currently, there are no stormwater quality management facilities in the subwatershed. Through careful subwatershed and stormwater planning and the implementation of management strategies, the natural ecosystem may be partly regenerated within a reasonable time frame.

The surficial soil in the subwatershed ranges from sandy to clayey types. The hydrogeological characteristics were not known at the time of the study. However, city staff had indicated that the ground water table was quite high near the Meadowvale and Ellesmere area. As a result, it was assumed that the ground water table would be relatively high in the area bounded by Meadowvale Road, Ellesmere Road, Conlins Road, and Highway 401.

Figure 3.1 Locations of feasible RSWMPs.

The subwatershed is primarily served by separated storm sewers. There are currently two major detention facilities in the subwatershed. The first facility is located in a park while the second detention facility is an online dry pond with two storm inlets and one outlet connected to a culvert beneath a major road.

3.2 Goals and Objectives of the Stormwater Quality Management

The stormwater quality management goals adopted for the case study were:

1. Hydrologic goals:
 - rehabilitate and enhance the existing hydrologic cycle (City of Scarborough, 1995); and
 - rehabilitate and improve the existing runoff quality.

2. Economic goal:

- integrate stormwater quality management strategy with municipal capital works and operation programs; and
- minimize the cost of stormwater quality management in urbanized areas.

The hydrologic and economic goals were then defined by the following objectives:

1. reduction of the existing annual runoff volume up to 25%;
2. reduction of the existing annual total suspended solids loading up to 50%; and
3. application of proven and cost-effective retrofit stormwater management practices (RSWMPs).

The runoff volume reduction target was selected specifically for the case study while the solids loading reduction targets was established in accordance with the recommendations by the Ontario Ministry of Environment and Energy (Marshall Macklin & Monaghan 1994). It is important to recognize that the selected numerical control objectives are not based on in-stream requirements.

3.3 Identification of Feasible RSWMPs

The RSWMPs considered in the case study include: downspout disconnection, oil/grit separators, stormwater exfiltration systems, retrofit quantity ponds, and stormwater quality ponds. A brief description of each RSWMP is given below.

Downspout disconnection (Marshall Macklin & Monaghan, 1994).

Disconnection of downspout and redirection of roof runoff to lawn areas is a lot level RSWMP. By returning the roof runoff to soils through infiltration, this RSWMP reduces runoff volume and solids loadings. As storm runoff is disposed of at the lot level, it can be implemented gradually. This RSWMP is suitable for a site where the local lot grading is gentle and sufficient lawn areas are available. It is also desirable to have sandy soil and a low groundwater table on site so that the diverted runoff will not be detained on the lawn over an extended period of time. Residents generally participate in a disconnection program when a municipal bylaw is enacted. For voluntary downspout disconnection programs, public participation may be improved by education and financial subsidy.

Oil/grit separators (Marshall Macklin & Monaghan, 1994).

Traditional three chamber oil/grit separators are designed to capture spills and small runoff events. Recent designs have improved the capture of runoff by

increasing the storage capacity and providing a washout protection mechanism for large flows. Nevertheless, only rigorous field monitor programs can determine the effectiveness of these new designs. Although this RSWMP is primarily designed to control commercial and industrial parking lot runoff, there is no reason to prevent its use in residential areas. It can be installed when a road and/or sewer system is undergoing reconstruction or rehabilitation. However, if oil/grit separators are installed along local residential roads, the responsibility for maintenance will fall upon the municipalities.

Stormwater exfiltration systems

A drainage system RSWMP was proposed by the city of Etobicoke to allow stormwater exfiltration along a storm sewer system (Li and Koo, 1994 and Li et al., 1997). First flush runoff from catch basins is diverted to two 200mm perforated PVC pipes which are constructed below the storm sewers (Figure 3.2). As the perforated pipes are plugged at the downstream ends, they store the stormwater and allow it to exfiltrate to the granular stone sewer trench and subsequently to the surrounding soils. This RSWMP can be incorporated in residential road/storm sewer reconstruction and rehabilitation projects if the site

Figure 3.2 Layout of Etobicoke exfiltration systems.

characteristics are suitable. Based on a demonstration project in the city of Etobicoke, the construction cost of the perforated pipes was assumed to be about 15% of the sewer reconstruction cost. This RSWMP is not appropriate for sites where there is concern over ground water contamination by urban runoff and spills, and damage to foundations by infiltrated water. As the development of this RSWMP is fairly new, rigorous monitoring programs must be conducted to confirm its effectiveness and longevity, and determine the associated maintenance requirements.

Stormwater quantity pond retrofit

Flood control ponds may be retrofitted to provide water quality treatment functions. However, it is important to maintain the existing flood storage at the pond. For this RSWMP, there should be adequate space for the creation of a water quality cell and convenient road access for construction and regular maintenance.

Stormwater quality ponds (MOEE, 1994)

If sufficient land is available, stormwater quality ponds can be a feasible downstream control RSWMP. To be cost-effective, new stormwater quality ponds should serve a drainage area of at least five hectares. Other concerns include separate drainage system outfalls, road access for construction and maintenance, downstream fish habitats, and public acceptance.

In order to identify the feasible RSWMPs in the study area, a two-step evaluation procedure was developed for each RSWMP. The first step (Priority One) comprises the most critical screening questions which determine the physical suitability of the RSWMPs for a site of interest. All of these questions must be answered affirmatively, in order to continue to the second step. The second evaluation step (Priority Two) further examines the suitability of the RSWMPs. All questions in the second step should also be answered affirmatively, either with or without implementation of engineering measures designed to remedy the associated environmental impacts. If there are additional environmental impacts associated with the engineering remedial measures, then the RSWMP is not suitable for the site of interest. Table 3.2 illustrates the evaluation procedure for stormwater exfiltration systems. The evaluation procedure for the other RSWMPs listed above can be found in Li (1997).

The Centennial Subwatershed was first divided into 25 hydrologic catchments as shown in Figure 3.1. A series of maps was generated by the city of Scarborough which include a land use map, a lot size map, a surficial soil map, a sewer system map. Additional maps were then generated by the principal author to identify the road and sewer conditions, truck routes and the government land ownership. With the above maps and a site reconnaissance, the areas suitable for

Table 3.2 Evaluation table for stormwater exfiltration systems.

Priority One Questions	Yes/No	Information Sources
1.1 Is water supply aquifer absent at the site of interest?		Well and borehole records; in-situ measurements; MOEE Regional offices
1.2 Is the site of interest a low density residential area?		Municipal land use maps (e.g. Official and Secondary Plans); roads with truck traffic designation
1.3 Is the site of interest served by local roads?		Road and sewer maps
1.4 Is the ground water table below the invert of the exfiltration pipes?		Borehole and well records; in-situ measurements; MOEE Regional offices
Priority Two Questions		
2.1 Is sandy soil present?		Borehole records; soil maps; in-situ measurements
2.2 Are the roads and/or sewers in poor condition?		Municipal road appraisal sheets; capital works and operating schedules
2.3 Is the tree root problem absent at the site of interest?		Field observation; municipal parks and recreation departments.
2.4 Is the required maintenance equipment available at the municipality?		Municipal works departments.

each RSWMP were identified for each catchment using the two-step evaluation procedure. Figure 3.1 depicts suitable locations of RSWMPs. Based on the evaluation procedure, all RSWMPs investigated were considered to be feasible in the Centennial Subwatershed.

3.4 Formulation of Alternative Stormwater Quality Management Strategies

In the formulation of alternative stormwater quality management strategies, it was assumed that:

1. alternative strategies will be formulated with respect to quantity and quality control and three implementation phases (i.e. 5, 15, and 25 years);
2. 20% of the feasible residential areas will have downspout disconnected in the first 5 years;
3. the remaining feasible areas will have downspout disconnected over 25 years;
4. 30% of the feasible commercial areas will be retrofitted with oil/grit separators over 25 years;

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5. all the feasible roads in poor condition now will be retrofitted with stormwater exfiltration system over 15 years;
6. 20% of the feasible roads in good condition now will deteriorate over 25 years and will be retrofitted with stormwater exfiltration systems;
7. the existing quantity pond will be retrofitted with water quality functions in the first 5 years; and
8. a new water quality pond will be constructed at a city-owned land parcel in the first 5 years.

Alternative stormwater quality management strategies for the Centennial Subwatershed were developed by combining different mixes of RSWMPs. For instance, a solids loading reduction strategy for the first 5 years may be formulated by a combination of downspout disconnection (20% of the feasible area), stormwater quantity pond retrofit (all the feasible ponds), and new stormwater quality ponds (all the feasible locations).

3.5 Evaluation of Alternative Stormwater Quality Management Strategies

Alternative stormwater quality management strategies should be evaluated with respect to their achievement of ecosystem and economic objectives. Selection of appropriate models for the prediction of runoff quantity and quality and RSWMP's performance is dependent upon budget, time, required level of accuracy, and technical expertise available. Among the different types of urban drainage models (e.g. statistical models, physical models, and continuous simulation models), continuous simulation models such as STORM (HEC, 1974) and SWMM (Huber and Dickinson, 1988) are the most versatile because they can model complex processes in detail and test the system response to different types of inputs and system configurations on a continuous basis. However, they always require sophistication in their use and are time consuming for preliminary planning purposes. Analytical probabilistic models (Adams and Bontje, 1983; Li, 1991) and a multi-efficiency model (Weatherbe, 1995) were selected for this study because the required data and the level of accuracy are appropriate for the preliminary planning of RSWMPs. However, continuous simulation models such as SWMM should be used in the detailed analysis of the control performance of RSWMPs.

3.5.1 Analytical Probabilistic Models

Average annual runoff volume and solids loading can be estimated by the analytical probabilistic models given by Adams and Bontje (1983) and Li (1991). These analytical probabilistic models were developed by derived probability

distribution theory in which the probability density functions (pdf's) of input rainfall characteristics are transformed into the pdf's of runoff characteristics. The rainfall-runoff process is modeled by a simple runoff coefficient method in which initial rainfall fills the depression storage (S_d) and a portion of subsequent rainfall (ϕ) becomes runoff from the catchment. Adams et al. (1986) analyzed long-term rainfall records across Canada and found that rainfall characteristics such as rainfall event volume (v), duration (t), and interevent time (b) could be described by pdf's which are exponentially distributed. With the exponentially distributed rainfall event volume, the pdf of runoff event volume can be derived using the derived probability distribution theory. The annual runoff volume and pollution load are given by:

$$R = 10 * A * \left(\frac{\theta \phi}{\zeta} \right) e^{-\zeta S_d} \quad (3.1)$$

$$L = \frac{R * C}{1000} \quad (3.2)$$

where:

- R = average annual runoff volume in m³/yr,
- A = drainage area in hectare,
- θ = average annual number of rainfall events,
- ϕ = area-weighted average runoff coefficient,
- ζ = reciprocal of average rainfall event volume (1/mm),
- S_d = area-weighted average depression storage (mm),
- L = average annual runoff solids loading in kg/yr, and
- C = average runoff solids concentration (mg/L).

The analytical models have been compared with the continuous STORM simulation model (HEC, 1974) and the analysis results of both models were found to be in good agreement (Kauffman, 1987; Li, 1991). For planning level analysis, the analytical models offer a quick and reasonable estimate of annual runoff characteristics. The θ of a number of Canadian rain stations have been compiled by Kauffman (1987).

3.5.2 The Multi-Efficiency Model

A multi-efficiency model is used to estimate the cumulative volume (N_v) and solids loading (N_s) reduction efficiencies of a series of RSWMPs (Weatherbe, 1995):

$$N_v = \left[1 - \prod_i^n (1 - \eta_v) \right] * 100\% \quad (3.3)$$

$$N_s = \left[1 - \prod_i^n (1 - \eta_v)(1 - \eta_s) \right] * 100\% \quad (3.4)$$

where:

- i = the i^{th} RSWMP,
- n = total number of RSWMPs,
- η_v = runoff volume reduction efficiency of a RSWMP, and
- η_s = solids concentration reduction efficiency of a RSWMP.

For a RSWMP which reduces solids concentration only (e.g., oil/grit separators, ponds), η_v is zero. For a RSWMP which reduces runoff volume only (e.g., downspout disconnection, stormwater exfiltration systems), η_s is zero. It is important to recognize that the superimposition of treatment efficiencies in Equation 3.4 does not represent the solids settling mechanism of a series of runoff treatment facilities as upstream RSWMPs tend to remove coarse sediments by settling at a relatively high efficiency and downstream RSWMPs tend to remove fine solids by settling at a relatively low efficiency. However, we use it to provide a preliminary estimate of the cumulative treatment efficiency. For newly developed RSWMPs which have not been proven by rigorous field monitoring, the η_v or η_s used in Equations 3.3 and 3.4 may be based on conservative estimate of their control potential or computer model simulation.

The runoff volume and solids concentration reduction efficiencies of RSWMPs at each hydrologic catchment are determined as follows.

Downspout Disconnection

Runoff volume reduction efficiency (η_v) is given by:

$$\eta_v = \left[1 - \frac{R_s}{R_e} \right] * 100\% \quad (3.5)$$

where:

- R_s = revised average annual runoff volume (mm) after the application of downspout disconnection, and
- R_e = existing average annual runoff volume (mm).

In order to model downspout disconnection, the existing impervious area of a catchment is reduced by the equivalent disconnected roof area. The revised area-weighted runoff coefficient and depression storage are then used to calculate the revised annual runoff volume of the catchment (using Equation 3.1).

Oil/grit separators

The solids concentration reduction efficiency (η_s) is estimated by:

$$\eta_s = \eta_{sa} * \frac{R_a}{R_c} \quad (3.6)$$

where:

- η_{sa} = solids concentration reduction efficiency of oil/grit separators which is assumed to be about 30%,
 R_a = average annual runoff volume from the area served by oil/grit separators, and
 R_c = average annual runoff volume from the catchment.
 Both R_a and R_c are determined using Equation 3.1.

Stormwater exfiltration systems

The runoff volume reduction efficiency (η_v) is given by:

$$\eta_v = \eta_{va} * \frac{R_a}{R_c} \quad (3.7)$$

where:

- η_{va} = runoff volume reduction efficiency of stormwater exfiltration systems which was estimated to be 90% using the STORM model (HEC, 1974),
 R_a = average annual runoff volume from the area served by stormwater exfiltration systems, and
 R_c = average annual runoff volume from the catchment.

Quantity pond retrofit and new quality ponds

The solids loading reduction efficiency of a stormwater management pond (η_s) is given by:

$$\eta_s = \eta_{pa} * \frac{R_a}{R_c} \quad (3.8)$$

where:

- η_{pa} = solids concentration reduction efficiency of ponds which is assumed to be about 55% for retrofit ponds and 80% for new stormwater quality ponds,
 R_a = average annual runoff volume from the area served by ponds, and
 R_c = average annual runoff volume from the catchment.
 Both R_a and R_c are determined using Equation 3.1.

The average annual runoff volume (R_n) and solids loading (L_n) after the application of a series of RSWMPs is determined by:

$$R_n = R * N_v \quad (3.9)$$

$$L_n = L * N_s \quad (3.10)$$

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Table 3.3 Parameters used for the Centennial subwatershed case study.

Parameters	Values	Reference
Pervious residential areas	55%	MacViro, 95
Impervious residential areas	45%	Ditto
Pervious commercial areas	25%	Ditto
Impervious commercial areas	75%	Ditto
Runoff coefficient of pervious areas	0.15	Assumed
Runoff coefficient of impervious areas	0.85	Ditto
Depression storage of urban pervious areas	3.0 mm	CH2M Hill, 1993
Depression storage of urban impervious areas	1.3 mm	Ditto
Average concentration of total suspended solids	90 mg/L	Paul Theil & Beak, 1992
Unit cost of downspout disconnection	\$50/lot hardware and \$200/lot with labour	Assumed
Unit cost of oil and grit separators	\$20,000/ha	Li, 1997
Unit cost of retrofit stormwater exfiltration system	\$90/m	Li, 1994
Pond retrofit cost	44.2(volume) ^{0.99}	Assumed
New quality pond cost	66.4(volume) ^{0.91}	Philip Eng, 95
Runoff reduction efficiency of stormwater exfiltration systems	90%	Estimated by STORM
Solids concentration reduction efficiency of oil/grit separators	30%	Assumed
Solids concentration reduction efficiency of retrofit ponds	55%	Assumed
Solids concentration reduction efficiency of new quality ponds	80%	Assumed

Table 3.3 summarizes the parameters used to determine the cost and the runoff volume and pollutant load reduction of each RSWMP. All the cost data, which included capital, operation and maintenance costs, were estimated assuming a 25 year planning horizon and a discount rate of 7%. (*In this chapter \$ = C\$*).

In order to facilitate the evaluation of alternative strategies with respect to runoff control costs and effectiveness, a spreadsheet program, based on the analytical probabilistic models and the multi-efficiency model, was developed. Alternative strategies were evaluated with respect to their achievement of control targets, the associated total cost, and the marginal costs of RSWMPs. To achieve the runoff volume reduction target of 25%, the following mixes of RSWMPs are required:

- 80% of the feasible residential areas must have downspout disconnected ;
- all the feasible roads/sewers in poor condition now must be retrofitted with exfiltration systems; and
- 20% of the feasible roads/sewers in good condition now must be retrofitted with exfiltration systems as they deteriorate.

Figure 3.3 Marginal cost of runoff volume reduction.

Figure 3.4 Marginal cost of solids loading reduction.

However, none of the strategies can achieve the solids loading reduction target of 50%. The strategy which achieves 47% solids loading reduction assumes that:

- all the feasible residential areas will have downspout disconnected;
- 30% of the feasible commercial areas will be retrofitted with oil/grit separators;
- all the feasible roads/sewers in poor condition now will be retrofitted with exfiltration systems; and
- 20% of the feasible roads/sewers in good condition now will be retrofitted with exfiltration systems as they deteriorate;
- the existing stormwater quantity pond will be retrofitted to provide water quality treatment; and
- a new stormwater quality pond will be constructed on city property.

The cost-effectiveness of RSWMPs was investigated by comparing the marginal costs of quantity and quality controls. As indicated in Figure 3.3, the marginal cost of runoff volume reduction for stormwater exfiltration system is about one-third cheaper than that of downspout disconnection. As more roads and sewers deteriorate over time, the use of stormwater exfiltration systems becomes favourable in the Centennial Subwatershed. They should be used to substitute downspout disconnection. As indicated in Figure 3.4, the marginal costs of solids loading reduction for quantity pond retrofit and new quality ponds are generally lower than those of the other RSWMPs, while the marginal cost of solids loading reduction for oil/grit separators is the highest among all the RSWMPs. In the Centennial Subwatershed, the descending order of cost-effectiveness is (least cost-effective last):

1. new quality ponds,
2. quantity pond retrofit,
3. retrofit stormwater exfiltration systems,
4. downspout disconnection, and
5. oil/grit separators.

3.6 Recommendation of the Preferred Strategy

To achieve the runoff volume reduction target of 25%, the recommended strategy which will cost \$1.2 million assumes that:

1. First 5 years
 - 20% of the feasible residential areas will have downspouts disconnected.
2. Over 15 years
 - 50% of the feasible residential areas will have downspouts disconnected; and
 - all the feasible roads/sewers in poor condition now will be retrofitted with exfiltration systems;
3. Over 25 years
 - 80% of the feasible residential areas will have downspouts disconnected; and
 - 20% of the feasible roads/sewers in good condition now will be retrofitted with exfiltration systems as they deteriorate.

Although none of the strategies can achieve the solids loading reduction target of 50%, the recommended strategy which will cost \$2.1 million and also achieve the volumetric control target should be implemented as follows:

1. First 5 years
 - 20% of the feasible residential areas will have downspouts disconnected;

- the existing stormwater quantity pond will be retrofitted to provide water quality treatment; and
 - a new stormwater quality pond will be constructed on city property.
2. Over 15 years
 - 50% of the feasible residential areas will have downspouts disconnected;
 - 20% of the feasible commercial areas will be retrofitted with oil/grit separators;
 - all the feasible roads/sewers in poor condition now will be retrofitted with exfiltration systems; and
 - 10% of the feasible roads/sewers in good condition now will be retrofitted with exfiltration systems as they deteriorate.
 3. Over 25 years
 - All the feasible residential areas will have downspouts disconnected;
 - 30% of the feasible commercial areas will be retrofitted with oil/grit separators; and
 - 20% of the feasible roads/sewers in good condition now will be retrofitted with exfiltration systems as they deteriorate.

Operational controls such as improved street sweeping practices and increased catch basin sump maintenance and sewer flushing are also recommended to complement the strategy and make up the remaining 3%.

Currently, most of the municipal capital and operating projects, such as road and sewer reconstruction or rehabilitation, in the Centennial Subwatershed were developed without consideration for stormwater quality improvement. Examining the marginal costs in Figures 3.3 and 3.4, there is a sequence of actions that the municipality may implement:

1. A new stormwater quality pond on the city-owned site should be investigated. As land is redeveloped in the subwatershed, additional stormwater quality ponds should be considered as part of the redevelopment requirements.
2. As a capital project, the existing quantity pond should be retrofitted to provide a water quality treatment function.
3. All the feasible roads/sewers which have been currently identified to be in poor condition should be retrofitted with stormwater exfiltration systems as they are reconstructed or rehabilitated in the next 15 years. In the long term, as more roads/sewers need reconstruction, the stormwater exfiltration systems should be applied.
4. The feasible residential areas should have downspouts disconnected gradually. Ways to achieve a higher percent coverage of downspout disconnection should also be investigated, including

combinations of subsidies, regulatory measures and application of additional technologies such as rain barrels and soak-away pits.

5. All the roads in the feasible commercial areas should be retrofitted with oil/grit separators as they are reconstructed or rehabilitated. Oil/grit separators can also be considered for retrofit in additional road systems, especially in high traffic areas which there is a higher potential of spills.
6. A methodology for measuring the benefits of the RSWMPs on receiving water should be developed.
7. The recommended stormwater quality management strategy should be reviewed and updated periodically as part of the capital budget process.

3.7 Conclusions and Recommendations

The Centennial Creek Subwatershed case study demonstrated that a stormwater quality management strategy for urbanized areas should be implemented in phases and integrated with municipal capital and operation programs. Conventional RSWMPs such as downspout disconnection, quantity pond retrofit, and water quality ponds should be implemented first. It will take time to confirm the cost and effectiveness of emerging RSWMPs such as oil/grit separators and stormwater exfiltration systems. Thus, they should be implemented gradually over a long period of time.

Not all the necessary information was available at the time of this study. Thus, the study's recommendations are only preliminary and should be examined rigorously before adoption.

The efficiency of the generic planning tool was demonstrated by the Centennial Creek Subwatershed case study. The development of the stormwater quality management strategy was completed in the summer of 1995 by the principal investigator and a student at Ryerson. Most of the time was spent on the compilation of data and development of the spreadsheet program. Future applications of the generic planning tool should produce a stormwater quality management strategy in a shorter time after the compilation of data. Currently, the two-step evaluation procedure of RSWMPs is being redeveloped in a Geographic Information System environment and the spreadsheet analysis program is being redeveloped as a Visual-BASIC program. Thus, analysis of stormwater quality strategies for existing urbanized areas can be rationalized and streamlined.

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Notation

A	Drainage Area (ha)
C	Average Runoff Solids Concentration (mg/L)
i	i^{th} RSWMP
L	Average Annual Runoff Solids Loading (kg/yr)
L_n	Average Annual Runoff Solids Loading after the Application of a Series of RSWMPs
n	Total number of RSWMP
N_v	Cumulative Volume Reduction Efficiency of a Series of RSWMPs
N_s	Cumulative Solids Loading Reduction Efficiency of a Series of RSWMPs
R	Average Annual Runoff Volume (m^3/yr)
R_a	Average Annual Runoff Volume from the Area Served by a RSWMP (m^3/yr)
R_c	Average Annual Runoff Volume from the Catchment (m^3/yr)
R_e	Existing Average Annual Runoff Volume (m^3/yr)
R_n	Average Annual Runoff Volume after the Application of a Series of RSWMPs
R_s	Revised Average Annual Runoff Volume (m^3/yr)
S_d	Area-weighted average depression storage (mm)
ζ	Reciprocal of Average Rainfall Event Volume (1/mm)
η_{pa}	Solids Concentration Reduction Efficiency of Ponds
η_s	Solids Concentration Reduction Efficiency of a RSWMP
η_{sa}	Solids Concentration Reduction Efficiency of Oil/Grit Separators
η_v	Runoff Reduction Efficiency of a RSWMP
η_{va}	Runoff Reduction Efficiency of Stormwater Exfiltration Systems
θ	Average Annual Number of Rainfall Events
ϕ	Area-weighted Average Runoff Coefficient

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