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A Genetic Algorithm for the Minimum Cost Design of a Stormwater System

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Optimization methodology for design of stormwater systems is developed. The methodology uses a Genetic Algorithm Cost Minimization tool (GA-CM) to evaluate stormwater drainage system project costs. Also used are design capacity and water quality controls, real-world design standards, cost analysis, PCSWMM and version 4.4HGUX of the US-EPA SWMM program. It was successfully applied to a realistic but hypothetical stormwater system to select a near-optimal (minimum cost) set of design parameters.

The GA-CM considered standard design practices from (i) the Ministry of the Environment of Ontario 2003 Stormwater Management Practices Planning and Design Manual and (ii) design information collected from interviews with consultants. The detail provided in the GA-CM is perhaps beyond what consultants feel that they need today. Interviews with consultants emphasized the need to address sizing of significant design parameters (e.g. depth of storage facility). This was the focus of the optimization methodology developed.

Genetic algorithm routines are a powerful tool for the selection of the best combination of stormwater system design parameters. Semi-automatic optimization of urban drainage systems and associated costs will lead to improved urban drainage design practices and improve stormwater quality discharges to downstream receiving waters.

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2.1 Introduction

The Stormwater Management Planning Practices and Design Manual released by the Ministry of the Environment of Ontario (MOE) in 2003 provides technical guidance for the planning, design, and review of stormwater management designs. It is not intended to provide guidance for optimum design of a stormwater system.

The purpose of the present research was therefore to develop design methodology to fill this need. The optimization methodology developed in this study integrates four elements: a genetic algorithm (GA), PCSWMM, real-world design standards and cost analysis. It was successfully applied to selection of an optimal (minimum cost) set of design parameters for a hypothetical stormwater drainage system in Guelph, Ontario.

2.2 Scope of Study and Approach

The proposed method starts by building a realistic test dataset, in this case for a typical but hypothetical stormwater design problem in Guelph, Ontario. Interviews were conducted with several engineering consultants in Southwestern Ontario. During these interviews, the design process, most significant design parameters, relevant project unit costs and water quantity and quality objectives were discussed. A list of questions posed during the interviews is provided in the appendix at the end of this chapter.

Design and cost templates were developed, based on recommended provincial guidelines and interviews with consultants. A cost objective function and design capacity evaluation functions (e.g. sewer capacity and flood control) were developed for use with the GA optimization procedure. These functions are based on input and output from the SWMM model, using PCSWMM (CHI, 2000).

Optimization procedures were then developed to compute minimum cost stormwater systems that meet water quality and quantity constraints. Design parameters such as sewer diameters and maximum depth of storage in wet ponds were considered. These parameters are selected by considering construction, material, operational and maintenance costs as described by Behera et al. (1999).

The designs are based on the Runoff, Transport and Storage modules in PCSWMM. In the final stage of analysis, spreadsheets were used to evaluate associated tangible costs and to implement a genetic algorithm.

2.2.1 Interviews with Consultants

Minimum cost design that satisfies water quantity and quality constraints is the objective for most urban drainage projects, but no technique is generally available. To develop an effective method, cost estimation practices by various consultants were reviewed. Intangible costs were not covered.

The following companies in the Guelph area were interviewed: Gamsby and Mannerow Ltd., Braun Consulting Engineers, Stantec Consulting, Schaeffer & Associates Ltd. and R.J. Burnside Consulting.

The interview format consisted of a 1 hour question-and-answer period at the firm's office. The interview questions were designed to promote discussion of practical engineering design practices.

2.2.2 Development of Optimization Tool

The present authors have developed a semi-automatic optimization method, called the Genetic Algorithm Cost Minimization Tool (GA-CM). It uses water quantity and quality constraints and detailed cost estimation for a stormwater system. The GA-CM uses the MOE (2003) and the MEA (1987) Guidelines (referred to as 'the Guidelines' here) as a basis for design.

The main worksheet is the spreadsheet that links the iterative results from the input and cost spreadsheets for optimization. It allows output from PCSWMM to be reported as shown in Table 2.1, excerpted from the main worksheet.

Table 2.1 Objectives and constraints in GA-CM (main worksheet).

	Estimated cost	Constraints		
		Pre-dev cond. met?	Sewer cap.?	> 80% sed removed
Child 1	\$281,494.47	yes	yes	82.05
Child 2	\$351,027.78	yes	yes	77.81
Child 3	\$344,817.78	yes	yes	77.92
Child 4	\$302,171.86	yes	yes	81.64
Child 5	\$331,943.47	yes	yes	77.12
Child 6	\$309,623.86	yes	yes	81.63

Design parameters, unit costs and material descriptions are inputted into the GA-CM. The input parameter worksheet is outlined in more detail later in this chapter. A genetic algorithm is used to size the design parameters. When the

objective(s) are reached within a defined tolerance, the GA-CM reports the optimal design selected. Output from the GA-CM describing the stormwater system is then inserted into PCSWMM.

The Runoff, Transport, Combine and Storage modules were run in PCSWMM to evaluate the design objectives and constraints. These modules used data from the Guelph area (e.g. rainfall time-series, street dust and dirt distribution) in the test dataset (TD) as described below.

2.2.3 PCSWMM Test Dataset Used For Guelph, Ontario Catchment

The boundaries for the urban drainage system in Guelph identified as Site A are shown in Figure 2.1, and are defined by the Speed River, College Avenue, Edinburgh Road and Gordon Street. Land data (e.g. land use, size of catchment area, size of lots and percent imperviousness) were evaluated using GIS maps and aerial photographs provided by the City of Guelph.

Design storm selection

The Guidelines suggest that whenever practical, a series of real design storms should be used (MEA, 1987, Section 4.3, Para 3). Meteorological records provided by the Grand River Conservation Authority (GRCA) for a combination of five stations: the old Guelph OAC, Blue Springs IHD, Guelph Arboretum, Guelph Turfgrass, and GRCA Guelph Dam were used. The 1 in 5 y frequency selection procedure was applied to a continuous, 5 y time. This procedure was used to determine the storm to be used for sizing a wet pond. In this paper the storm selected is referred to as the *5 y causative storm* and is shown in Figure 2.2. The term *causative* is chosen because it is the storm that causes the runoff requiring the greatest storage volume to meet predevelopment runoff requirements.

The 5 y/6 h causative storm with 2-minute time steps was required for accuracy. (Note that a 5 y causative storm occurred on September 11th, 1984). The 5 y causative storm was used for the design and testing of water quantity and quality constraints (e.g. pre-post storage, % sediment removal).

The volume required for the storage pond for the pre-post analysis is determined using the time series utility in PCSWMM. Figures 2.3 and 2.4 show the rainfall time-series and the pre-post analysis hydrograph for the peak rainfall event (September 11th, 1984), determined to be the 5 y causative storm.

Figure 2.1 Discretization of Site A in Guelph, Ontario.

Figure 2.2 5 y causative storm.

Figure 2.3 Wet pond sizing used in PCSWMM

Figure 2.4 Continuous hyetograph displayed in PCSWMM

2.3 Development of the Design Tool Template

A Microsoft Excel input worksheet was developed using design templates provided by consultants. The user enters significant design parameters, unit costs and other information relevant to the project design. The worksheet consists of three sections: Basic Input, Unit Costs and Derived Parameters. The GA is repeated for all parents (e.g. Parent 1, Parent 2) for each of the three sections of the input worksheet for various parameter sizing alternatives as shown in Figure 2.5.

Design parameters

The first section provides a template for input of the physical dimensions of the drainage and is entitled *Basic Input*. The sizes are used in the cost worksheet for hard services, soft services and O&M.

Design constraints: Project cost and water quantity and quality controls

Unit Costs is the second section of the input worksheet. Unit costs for hard e.g. excavation/m³, plants/m² (shoreline fringe and flood fringe vegetation) and soft (e.g. engineering design, contingency) services along with O&M (e.g. sediment removal/m³) are user input. Unit costs are then used in the tender spreadsheet to estimate the overall project cost. The estimated total project cost is then linked back to the main worksheet.

Figure 2.5 Input worksheets showing iterations.

Cut and fill volume calculations for various aspects of the stormwater system (e.g. wet pond, storm sewer trench, and spillway) are also evaluated. The water quality and quantity controls selected for the test dataset in Guelph are evaluated in the main worksheet as shown in Table 2.2.

Table 2.2 Water quality constraints in GA-CM.

	Pre-dev cond. met	Sewer cap.?	% sediment removed (> 80)?
Pot. Parent 1	Yes	Yes	4.92
Pot. Parent 2	Yes	Yes	81.64
Pot. Parent 3	Yes	Yes	77.26
Pot. Parent 4	Yes	Yes	70.88
Pot. Parent 5	Yes	Yes	65.39
Pot. Parent 6	Yes	Yes	0.09

Pre-development Conditions

The pre-development downstream runoff ($Q_{out - pre}$) for Site A in Guelph was computed using the Runoff module in PCSWMM. The post-development design scenario engaged several modules (e.g. Runoff, Transport, Storage, and Combine) in PCSWMM to model the Site A treated outflow from the wet pond ($Q_{out - post}$).

In order for the constraint to be satisfied, post-development flow needs to be less than or equal to pre-development flow:

$$Q_{out - post} \leq Q_{out - pre} \quad (2.1)$$

A sample comparison is shown in Figure 2.6.

Figure 2.6 Hydrographs for 1. pre-development, 2. post-development and 3. post-development with wet pond.

Sewer Capacity

A sewer capacity analysis is performed using PCSWMM for each post-development design created in the GA-CM worksheet. The Transport module output file is reviewed to determine whether or not surcharging occurred.

% Sediment Removed

The wet pond designs derived in the input worksheets for the various GA-CM iterations are transferred into the corresponding Storage modules in PCSWMM. The particle settling velocity equation in SWMM is based on Stokes' Law:

$$v_s = \sqrt{\frac{4 \cdot g \cdot D}{3 \cdot C_D}} (S_p - 1)$$

where:

- v_s = terminal velocity of particle, m/s
- C_D = drag coefficient
- S_p = specific gravity of particle
- D = diameter of particle
- g = 9.8 m/s^2 , gravitational constant

Detention Time

In this study detention time has not been covered. The modeling results from SWMM did not provide an accurate measure for detention time due to the simplification of the wet pond design in the Storage module.

Modeling: SWMM and PCSWMM

Runoff, Transport, Storage/Treatment and Combine are the SWMM modules used within PCSWMM in this study to evaluate constraints. For details of these modules see James and James (2000).

Stage 3: Development of GA optimization tool (GA-CM)

The Genetic Algorithm Cost Minimization (GA-CM) tool developed potential and derivative parent populations. GA-CM consists of two worksheets and one interpolation graph for each stormwater system design considered (The GA-CM considers six designs per iteration with 3 strata and 2 parents). For this case study, one hundred worksheets were developed. Information is only input into the main worksheet. The main worksheet acts as the central hub for all other worksheets in the tool, interacting with the other worksheets to determine the optimal design using as objective functions, the minimum cost, and whether constraints are met (storage capacity, sewer capacity, % sediment removal) within a tolerance defined by the user.

The tool was developed from the study and reworking of stormwater system design templates, the design recommendations in the Guidelines and

other supplementary guidelines (e.g. ASCE for storm sewers) and the selection of an appropriate objective and constraints for a stormwater system.

Cost minimization objective function

The GA-CM worksheet computes the total estimated cost using (MOE, 2003):

$$C_{\text{tot}} = \sum_{i=1}^{i=N} C_{\text{unit } i} \cdot [L]_i + \sum_{j=1}^{j=n} \sum_t C_{OM \ j} \cdot (1+r)^{-t} + C_{\text{Eng.}} + C_{\text{Contin.}}$$

where:

- C_{tot} = total tangible costs, [\$]
- i = specific type of construction/material unit price for the generic best management practice (BMP) design, user selected
- N = total number of specific types of construction/material required for generic BMP design, user defined
- j = specific type of operation/maintenance unit price for the generic BMP design, user selected
- n = total number of specific types of operation/maintenance required for generic BMP design, user defined
- C_{unit} = Capital unit cost for construction/material, [\$]
- $[L]$ = dimension(s) of the unit required to determine overall cost of the unit, $[m, m^2, \dots \text{etc.}]$
- C_{OM} = operation/maintenance cost that is required to be performed every t years, [\$]
- r = annual inflation-free interest rate
- t = the interval between maintenance activities in years
- T = service life of the selected generic BMP operation
- $C_{\text{Eng.}}$ = engineering cost that is required to be performed every t years, [\$]
- $C_{\text{Contin.}}$ = contingency cost that is required to be performed every t years, [\$]

Tangible costs such as unit costs, O&M costs, and engineering cost were included in the objective function due to their relative certainty. Other intangible costs such as environmental costs and electricity costs in construction were not included due to their relative uncertainty.

The cost worksheet (corresponding to each set of stormwater system project sizes, e.g. Cost P1, Cost IP4, Cost IVP2) applies the above objective function (N.B. P1 refers to the first stormwater system design in the initial population generated by the GA-CM, IP4 refers to the fourth stormwater system design in the first iteration generated by the GA-CM). This estimate for total stormwater system project cost is then transferred back to the GA-CM worksheet.

Table 2.4 GA-CM objective function assessment for various stormwater system design sizing scenarios.

Step 1. Initial population (potential parent population)					
	Upstream Transport Module GEOM1 dia	Storage Module Dmax	Storage Module BREADTH	Downstream Transport Module GEOM1 (dia)	Objective function Est cost
Pot. Parent 1	0.738	3.2	2	0.414	\$278,888.70
Pot. Parent 2	0.438	2.7	1	0.78	\$298,465.87
Pot. Parent 3	0.63	3.6	8	0.708	\$329,429.02
Pot. Parent 4	0.9	2.8	4	0.675	\$261,363.51
Pot. Parent 5	0.804	3.4	16	0.786	<i>\$429,771.79</i>
Pot. Parent 6	0.711	3.1	32	0.9	<i>\$716,875.44</i>

The estimated costs in italics in Table 2.4 are greater than the maximum allowable project cost (i.e. \$425,000), defined by the user in the input worksheet. The two potential parent project designs (Pot. Parent 1 and Pot. Parent 4) have the designs that meet all of the constraints and the lowest estimated costs. All objective functions and constraints need to be met in order for a set of design sizes to be selected for the next iteration in the GA-CM tool.

Initial population in GA-CM: The main worksheet considers an initial, potential population of parent solutions to start the GA procedure. The initial population is randomly generated using a worksheet that applies a routine to generate random numbers within defined limits for each parameter (i.e. $0 \text{ m} \leq \text{depth of pond} \leq 5 \text{ m}$) as shown in Table 2.4.

Crossover procedure in GA-CM: A number of strata need to be defined at the start of the crossover procedure. The GA-CM tool uses three strata throughout the optimization process. The strata assigned for each sizing (e.g. GEOM1,

Breadth) is randomly generated using the Random Number Generator worksheet as shown in Table 2.5.

Table 2.5 Crossover operation in GA-CM.

Step 2. Crossover operation				
Strata		3		
Crossover probability:		25%, 50%, 25%		
Maximum possible children:		6		
Notes:				
Parent 1	Is from the initial parent pool and is the best parent: E.F.s (min. cost, 80 % TSS removed)			
Parent 2	Is from the initial parent pool and is the second-best parent: E.F.s (min. cost, 80 % TSS removed)			
<i>Strata Assignment</i>				
	Upstream Transport Module GEOM1(dia.)	Storage Module Dmax	Storage Module BREADTH	Downstream Transport Module GEOM1(dia.)
	1	2	2	3
	GEOM1(dia.)	Dmax	BREADTH	GEOM1(dia.)
Parent 1	0.738	3.2	2	0.414
Parent 4	0.9	2.8	4	0.675
Child 1	0.738	3.2	2	0.675
Child 2	0.9	2.8	4	0.414
Child 3	0.738	2.8	4	0.414
Child 4	0.9	3.2	2	0.675
Child 5	0.9	2.8	4	0.675
Child 6	0.738	3.2	2	0.414

The three strata for both parents are then crossed over to generate a number of children (or chromosomes). The number of children generated is based on the number of strata (Wan and James, 2001):

$$\text{Total Maximum Possible Children} = 2^n - N_{\text{parent}} \quad (2.4)$$

where

$$\begin{aligned} n &= \text{total number of strata} \\ N_{\text{parent}} &= \text{total number of parent} \end{aligned}$$

Mutation procedure in GA-CM: A random mutation that is a multiple of 5% (plus and minus) is selected for each iteration in the GA-CM tool using the Random Number Generator worksheet. Each child is assigned a positive and negative mutation. The Random Number Generator worksheet generates the mutations according to the order of the sizing capacity determined by the strata assignment as shown in Table 2.6.

Table 2.6 Mutation operation in GA-CM excerpted from GA-CM.

Step 3. Mutation operation				
Iteration 1	Mutation +/- 5%			
Mutation Order	5%	-5%		
P1	1	2		
P2	1	2		
P3	4	2		
P4	1	0		
P5	2	3		
P6	4	0		
	Upstream Transport Module GEOM1(dia)	Upstream Storage Module Dmax	Upstream Storage Module BREADTH	Downstream Transport Module GEOM1(dia.)
Child 1	0.7749	3.04	2	0.675
Child 2	0.945	2.66	4	0.414
Child 3	0.738	2.66	4	0.4347
Child 4	0.945	3.2	2	0.675
Child 5	0.9	2.94	3.8	0.675
Child 6	0.738	3.2	2	0.4347

Notes: Randomly selected mutation values +/- percentage values (e.g. +/- 0 % mutation range).

The mutated parameters are then randomly selected within the mutation value range specified. This mutation process continues for a set number of iterations defined by the user. The performance evaluation occurs after each iteration to select the next. Kalman, 2001 demonstrates a similar strategy along with providing detailed background into the genetic algorithm terminology and application.

The values of sizing capacities for every child are then modified if a mutation assignment occurs. The values of sizing capacities are considered

the genes and the entire stormwater system design is considered the chromosome in the GA procedure. The chromosome may also be considered the child, offspring or the parent of the next iteration (if selected by the fitness evaluation).

Selection of new parents: Cost objective function and constraints evaluation

The two children that are selected as the fittest to be parents in the next generation have the best results as shown in Table 2.4.

The tolerance defined by the user in the main worksheet considers the best estimated cost result as shown in Table 2.7.

Table 2.7 Tolerance evaluation excerpted from GA-CM.

Cost minimization tolerance (+/- %):	1.5
Comments:	
Child 5 = parent 1, iteration 3	
Child 6 = parent 2, iteration 3	
Cost minimization tolerance (%):	-1.51
Tolerance met ?	no
Continue optimization ?	yes

The last estimated cost result is compared with the next minimum result. If the difference is less than the tolerance defined, the GA-CM stops. If the difference is greater than the tolerance, the GA procedures continue in the main worksheet.

Output from GA-CM

A final recommendation of four sizing parameters may be reached as shown in Table 2.8. The complete recommendation includes a tolerance evaluation.

Table 2.8 Final design recommendation excerpted from GA-CM.

Final design recommendation (iteration 4, child 2)				
	Upstream Transport Module GEOM1(dia.)	Upstream Storage Module Dmax	Upstream Storage Module BREADTH	Downstream Transport Module GEOM1(dia.)
Ga-cm	0.5	2.7945	0.9	0.406
Final	0.45	2.75	0.9	0.375

This output should not be considered to be the best design. It is however a design of significantly lesser cost which meets water quantity and quality constraints.

2.4 Results

The results from the interviews and the application of the semi-automatic optimization methodology are discussed in this section of the chapter.

2.4.1 Results from interviews with consultants

All consultants interviewed agreed that, for detailed design, cost estimation procedures are needed and should address site-specific criteria, which implies detailed cost estimation methods. However, most consultants emphasized that, for initial planning, cost estimation of the overall cost of an urban drainage project, using a simple price per area (e.g. \$/ha) would be sufficient.

Post-to-pre storage design is consistently used by all of the consulting firms interviewed. This design methodology is recommended by both the MOEE (1994) and the Municipal Engineers Association (MEA) (1987), and is mandated by most regulatory bodies (i.e. municipalities and conservation authorities).

The depth and the amount of excavation were highlighted consistently as design parameters that affect cost.

Different consulting firms use different cost estimation techniques – there was no preferred methodology between those interviewed. Consultants agreed that using a database with more cost information, e.g. one that records and stores recent detailed unit price information (prices associated with individual contractors for specific times of the year) rather than a typical tender spreadsheet, would be ideal. The MOEE 1994 Stormwater Management Practices Planning and Design Manual is used consistently by all consultants interviewed. The MOE 2003 manual is referenced throughout this chapter but was not available to consultants at the time of these interviews.

2.4.2 Step 4: Analysis of GA-CM results from the test dataset

The Site A stormwater system project GA optimization demonstrates a significant reduction in estimated project cost as shown in Figure 2.7 and iterates until achieving a near-optimal value.

Water quantity and quality constraints were met for the final design selected. Although the output provided by the models and techniques (i.e. SWMM, pre-post analysis) used to evaluate these constraints is sensitive to input data, complexity of the model and other uncertainties (James, 2002), the results are useful for the development of the method. The models and techniques used to evaluate constraints are consistent with acceptable

engineering practice by engineering consultants interviewed and the Guidelines.

Figure 2.7 Cost minimization result: Total SW BMPs and sewer systems project cost, Site A –Guelph, Ontario.

The user may adjust the tolerance of the GA-CM to consider more or less detailed design. Since the worksheet is easily manipulated, a new layout can be considered with relative ease (e.g. incorporating other BMPs such as permeable pavement, or swales).

GA-CM should be regarded as a first step automatic optimization tool.

2.5 Conclusions and Improvements for GA-CM

The information provided through interviews with consultants and the application of the semi-automatic optimization methodology both demonstrate the need for an improved optimization procedure for a stormwater system.

2.5.1 Conclusions from interviews

All consulting firms acknowledge the use of the Guidelines throughout the design process and admit to adhering to standard designs for different types of

BMPs. A new design approach that allows engineers to consider multiple design parameter sizing solutions while adhering to constraints in the Guidelines would contribute to innovative design in the consulting practice.

2.5.2 Conclusions from the GA-CM optimization

Optimization estimated results for the test dataset design demonstrated the ability of the GA-CM tool to reduce the cost of a stormwater system. The initial estimated project cost was reduced from approximately \$298,000 to a final cost of \$238,000 (20% reduction).

The GA-CM optimization methodology reviewed in this paper is a preliminary study for urban drainage system design optimization. Much work remains to be explored in future research to improve the GA-CM.

2.6 Overall Conclusions

A GA optimization tool called GA-CM has been developed to investigate whether such a tool could assist stormwater engineers.

The methodology used in the GA-CM discussed in this paper is a preliminary study for urban drainage system design optimization. Much work remains to be explored in future research to improve the GA-CM.

2.6.1 Limitations of methodology

This study has a number of limitations as follows. The study was applied to a hypothetical drainage system in Guelph, Ontario and not an existing design. The stormwater system in the downtown area that the hypothetical system is modeled after is too complex for the purpose of developing a first step in a GA method. Optimization *per se* has not been studied; rather, only one optimization method (GA) has been employed. BMP guidelines for the province of Ontario only (i.e. not for other jurisdictions) have been reviewed. No attempt was made to conduct a comparative study of various stormwater management guidelines. Only sewer sizing and pond sizing have been considered; other variables (e.g. materials) were not investigated. Water quality is considered (sediment removal) but detention time is not. Sediments were collected in the Guelph area for mechanical analysis to produce an appropriate distribution curve for modeling. However, it must be acknowledged that there were limitations with the collection technique for finer sediment particles. Automation of the design process has not been attempted.

A more effective sediment collection process as well as the programming necessary to automate the GA methodology developed were not performed and will be encompassed in future research.

2.6.2 Recommendations

Suggested possible directions for future research include:

1. Programming to automate GA-CM completely to handle larger urban drainage networks.
2. Multi-objective functions may be incorporated into the optimization methodology. Velocity of downstream rivers, concentration of pollutants downstream and receiving water temperature may all be future objectives to explore.
3. Linking the GA-CM tool to an on-line database (e.g. RS Means database) may improve the accuracy and resolution of the cost estimation routines.
4. Incorporating different water quantity and quality models or improving the SWMM model can reduce uncertainty.
5. Using more effective water quality data (e.g. pollutographs from wash off tests performed at sites in Guelph area) would improve the validity of the water quality results.
6. Incorporate the 24 h detention time constraint into the fitness evaluation in the GA for future development work.
7. The relationship between the uncertainty of models used for optimization and the appropriateness of GA-CM project design selection may be explored.
8. Real observed data and user input files should be applied.
9. A greater number of design parameter sizings should be optimized.

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Appendix

1. a) How are construction, operations and maintenance costs for a planning or preliminary design estimated ?
b) How are construction, operations and maintenance costs for the final design estimated ?
2. a) How do you assess long term maintenance and operational costs for a project ?
b) Does your firm endorse paying O & M costs up-front to the municipality for constructed BMPs ?
3. What kind of cost analysis does your firm perform when selecting urban drainage designs?
4. a) Do you currently use a model to assess a preliminary BMP design (e.g. detention pond) ?
b) If so, what model(s) ?
c) When designing a BMP, what design storms do you use ?
5. What, if any, water quality/quantity objectives are typically incorporated into a design?

6. Do you have any BMP design rules-of-thumb that are used for SWM projects (e.g. stage relationship used for detention and/or retention ponds) ?
7. What improvements to minimum-cost design do you think would be useful for urban drainage design ?
8. What are your typical engineering and contingency fees (%) for a SWM project ?

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