Life Cycle Costing Tool (version 2.0)

Sensitivity Analysis

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PUBLICATION INFORMATION

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

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1.0 INTRODUCTION

To test the 2019 update to the STEP Life-Cycle Costing Tool (LCCT) for accuracy, we took designs from 6 completed projects (4 bioretention, 1 permeable interlocking paver, 1 infiltration trench), ran them through the tool, and compared the construction costing results from the LCCT to actual construction costs for the projects. The accuracy target set for the tool was plus-or-minus 30% of actual construction costs.

For the first three cases (Kenollie PS, Glendale PS., County Court Boulevard) the approach to testing the tool was to use it as a tool: rather than inputting the specific design variations, we only altered the site and design information cells to match the actual designs. This is to approximate how a user would employ it in the early stages of project planning. Figure 1 shows the input requirements for this approach for bioretention facilities in particular. Any further efforts would be "cheating", since one purpose of the tool is to generate reasonably accurate, realistic costs, with minimal imputs at early stages in the planning process.

Site and Design Information

USER INPUTS			
Drainage area (DA)		2000	m^2
Native soil infiltration rate		15	mm/hr
Design type [1]		Partial Infiltration	Unitless
Drainage period		48	hours
BR surface area length to width ratio		1	Unitless
Project land value classification		None	Unitless
DESIGN DEFAULTS	defaults	***(values in col G can be changed)***	
Maximum drainage area to surface area ratio	20	20	Unitless
Water Quality Volume Requirement	45	45	m^3/ha
Filter Media Depth	0.75	0.75	m
Ponding depth	0.2	0.2	m
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Mulch depth	0.075	0.075	m
DESIGN CALCULATIONS			
Pea gravel depth		0.10	m
Filter media depth		0.75	m
Gravel storage layer depth		0.92	m
Total depth [2]		1.85	m
Underdrain diameter		0.20	m
Surface area (SA)		100.0	m^2
Length		10.0	m
Width		10.0	m
Maximum duration of ponding		33.3	hours
Water storage volume [3]		73.8	m^3
Maximum rainfall captured		36.9	mm

Figure 1: site and design information for the bioretention design sheet

For other projects, we were more specific to the tenders, removing costs from tenders for which the tool does not provide outputs (e.g. driveway removal and reconstruction) and raising, lowering or removing costs when the actual project designs differed substantially from the model designs used by the tool. This is to approximate how a user would employ the tool further on in the planning and design process, or in more complicated retrofit cases, where construction work beyond just building an LID facility is required for project completion.

We hope to complete more tests in the near future on projects for the other BMPs for which the tool is functional, when time and resources permit.

2.0 KENOLLIE PUBLIC SCHOOL

Built in 2015, this CVC-led project resulted in a bioretention rain garden in Mississauga, Ontario which cost $35,949 dollars to construct. Table 1 shows the site and design information inputs into the tool; Table 2 shows the results compared to actual construction costs. Note that the drainage-area-to-surface area ratio for this project is much higher than STEP guidance suggests. This is because the LCCT assumes drainage areas to be 100% impervious, which the drainage area for this particular rain garden is not. For costing out individual designs, the critical element is getting the surface area of the facility correct.

For changes to the design defaults, we lowerd the amount of filter media from .75 m to .38 metres. We also had to lower the gravel storage layer depth calculated by the tool to .57 metres, since the .92 given by the tool did not match the actual design.

Table 1: inputs into the tool for Kenollie Public School

Site and Design Information

USER INPUTS			
Drainage area (DA)		3294	m^2
Native soil infiltration rate		10.5	mm/hr
Design type [1]		Partial Infiltration	Unitless
Drainage period		48	hours
BR surface area length to width ratio		1	Unitless
Project land value classification		None	Unitless
DESIGN DEFAULTS	defaults	***(values in col G can be changed)***	
Maximum drainage area to surface area ratio	20	44	Unitless
Water Quality Volume Requirement	45	45	m^3/ha
Filter Media Depth	0.75	0.38	m
Ponding depth	0.2	0.15	m
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Mulch depth	0.075	0.075	m
DESIGN CALCULATIONS			
Pea gravel depth		0.10	m
Filter media depth		0.38	m
Gravel storage layer depth		0.57	m
Total depth [2]		1.13	m
Underdrain diameter		0.20	m
Surface area (SA)		74.9	m^2
Length		8.7	m
Width		8.7	m
Maximum duration of ponding		35.7	hours
Water storage volume [3]		33.7	m^3
Maximum rainfall captured		10.2	mm

Table 2: tool results for Kenollie public school.

Construction cost (2019 Canadian dollars)	**LCCT result**	**LCCT result (without 10% overhead)**
$35,949	$32,281	$29,346
Per cent difference from construction cost	-10%	-18%

Table 2 (and the following result tables) shows two LCCT results: one which includes the 10% overhead which the tool includes by default, and one which doesn't. The 10% overhead is meant to cover items such as construction management and contingency, which were not included in the construction costs for this project. Therefore, the result without the overhead is the better test of the tool's accuracy regarding construction costs. However, small projects like the Kenollie rain garden often come at premium when compared with larger projects. This might make sense of why the tool undershoots construction costs in this case.

3.0 GLENDALE PUBLIC SCHOOL

Built in 2019, this CVC-led project resulted in a bioretention rain garden in Brampton, Ontario which cost $156,711 to construct. Table 3 shows the site and design information inputs into the tool; Table 4 shows the LCCT outputs compared to actual construction costs, and Table 5 shows the outputs compared to the average of all construction bids for the project.

The designs for this bioretention facility differed substantially from STEP guidance. While the site soils were found to have a 20mm per hour infiltration rate, the chosen design most closely matched the partial infiltration model design used by the tool to generate costs, as it includes an underdrain. However, the final design did not have a gravel storage layer, so the relevant cell in the design calculations table (see Table 3 below) was set to zero. Moreover, while the partial infiltration model design includes curb-and-gutter with curb inlets, this facility has no curbs or curb inlets and instead takes flows from three swales. While the curb-and-gutter is a significant cost, this project's designs include a series of pathways and an outdoor education area which separate the facility's three cells. We assumed that the cost of construting these pathways, the education area and the swales would offset the lack of curb-and-gutter with inlets, i.e. that the tool would be accurate enough for early-stage project planning purposes when features like these are still hypothetical or under discussion.

Finally, the site's final design did not include filter media. Instead, the on-site soils were amended with manure and backfilled into the gardens. Again, we assumed that the costs for amending the soil and backfilling would account for the filter media costs used by the tool.

Table 3: inputs into the LCCT for Glendale Public School

Site and Design Information

USER INPUTS			
Drainage area (DA)		19415	m^2
Native soil infiltration rate		20	mm/hr
Design type [1]		Partial Infiltration	Unitless
Drainage period		24	hours
BR surface area length to width ratio		1.6	Unitless
Project land value classification		None	Unitless
DESIGN DEFAULTS	defaults	***(values in col G can be changed)***	
Maximum drainage area to surface area ratio	20	19.45	Unitless
Water Quality Volume Requirement	45	45	m^3/ha
Filter Media Depth	0.75	0.58	m
Ponding depth	0.2	0.15	m
Safety factor	2.5	2	Unitless
Void ratio	40	40	%
Mulch depth	0.075	0.1	m
DESIGN CALCULATIONS			
Pea gravel depth		0.00	m
Filter media depth		0.58	m
Gravel storage layer depth		0	m
Total depth [2]		0.68	m
Underdrain diameter		0.20	m
Surface area (SA)		998.2	m^2
Length		40.0	m
Width		25.0	m
Maximum duration of ponding		15.0	hours
Water storage volume [3]		271.5	m^3
Maximum rainfall captured		14.0	mm

For this project we also compared the LCCT outputs against the construction cost and the average of all bids recieved. For the comparison with acutal construction costs, the LCCT results were 22% over the construction costs with the 10% overhead included, but only 10% higher with the overhead removed. Because we are only evaluating the construction cost in this case, the latter number is the better test of the tool's accuracy. For the comparison with the average of all bids on the project, the LCCT results were 16% and 5% over, respectively.

Table 4: results for Glendale Public School compared with the construction cost.

Construction cost	LCCT result	LCCT result (without 10% overhead)
$156,711	$190,419	$173,108
Per cent difference from construction cost	22%	10%

Table 5: results for Glendald Public School compared with the average of all bids.

Average of all bids	LCCT result	LCCT result (without 10% overhead)
$164,707	$190,419	$173,108
Per cent difference from construction cost	16%	5%

4.0 BRAMPTON – COUNTY COURT BOULEVARD

Built in 2014, this TRCA-led project resulted in two no-infiltration bioswales being constructed along an collector road in Brampton, Ontario. It cost $130,356 (adjusted for inflation to 2019 dollars) to construct. Table 6 shows the site and design information inputs into the tool, and Table 7 compares the LCCT's results with actual construction costs.

Departures from the LCCT's design defaults include a smaller drainage-area to surface-area ratio and less filter media. The actual designs also called for more pea gravel (15 cm) than the tool uses by default (10 cm) and the calculated cell for gravel depth had to be decreased from .275 m to .15 m.

Table 6: site and design inputs into the tool for County Court Boulevard in Brampton

Site and Design Information

USER INPUTS			
Drainage area (DA)		3094	m^2
Native soil infiltration rate		15	mm/hr
Design type [1]		No Infiltration	Unitless
Drainage period		24	hours
BR surface area length to width ratio		52	Unitless
Project land value classification		None	Unitless
DESIGN DEFAULTS	defaults	***(values in col G can be changed)***	
Maximum drainage area to surface area ratio	20	6.7	Unitless
Water Quality Volume Requirement	45	45	m^3/ha
Filter Media Depth	0.75	0.5	m
Ponding depth	0.2	0.3	m
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Mulch depth	0.075	0.075	m
DESIGN CALCULATIONS			
Pea gravel depth		0.15	m
Filter media depth		0.50	m
Gravel storage layer depth		0.15	m
Total depth [2]		0.88	m
Underdrain diameter		0.15	m
Surface area (SA)		461.8	m^2
Length		155.0	m
Width		3.0	m
Maximum duration of ponding		50.0	hours
Water storage volume [3]		161.6	m^3
Maximum rainfall captured		52.2	mm

Tool results were 29% higher than construction costs, and 17% higher with the 10% overhead removed. Because the cost given above is just for construction, the latter comparison is more accurate test of the tool.

Table 7: tool results for County Court Boulevard compared with construction costs

Construction Cost (2019, Canadian dollars)	**LCCT result**	**LCCT result (without 10% overhead)**
$130,365	$168,081	$152,801
Per cent difference from construction cost	29%	17%

5.0 CVC PARKING LOT

A portion of CVC's permeable paver parking lot in Mississauga, Ontario was constructed in 2012, at a cost of $270,614 (adjusted for inflation to 2019 dollars). Table 10 shows the site and design inputs into the tool, and Table 11 the comparison with acutal construction costs.

For this design, the bedding depth was 25 millimetres rather than the 50 millimetres given as default by the tool, the base depth was increased to 200 mm from 100 mm, and the sub-base depth was 250 millimetres as opposed to the tool's default 200 millimetres. Finally, the sub-base in this project was recycled concrete, which CVC received for free. Accordingly, the cost for 50 mm clear stone that the tool uses to cost out the sub-base materials was removed from the sub-total.

Table 8: site and design inputs into the tool for CVC's parking lot

Site and Design Information

USER INPUTS			
Drainage area		2327	m^2
Impermeable portion of area draining to pavers		0	m^2
Native soil infiltration rate		15	mm/hr
Design type [1]:		Partial Infiltration	Unitless
Drainage period		48	hours
Total length of permeable area		60	m
DESIGN DEFAULTS	**defaults**	**(values in col G can be chang**	
Time to fill stone bed	2	2	hr
Bedding depth (2-5 mm dia clear stone)	50	25	mm
Base depth (20 mm dia clear stone)	100	200	mm
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Height of pavers	80	80	mm
Underdrain Diameter	150	150	mm
Minimum sub-base depth (50 mm dia clear stone)	200	250	mm
Rainfall depth: Pearson 2 yr event	56	56	mm
TOOL RESULTS			
Permeable pavement area within drainage area		2327	m^2
Ratio of contributing to permeable area		0.00	Unitless
Total width		38.8	m
Underdrain diameter		150	mm
Sub-base depth (50 mm dia clear stone)		250	mm
Total depth		0.555	m
Max reservoir depth		720	mm
Water storage volume		448	m^3

As seen in Table 9, tool results were 22% over construction costs with the 10% overhead, and 11% over construction costs without the overhead. Since contingency or construction management were not included in the construction cost, the latter is the more accurate test of the tool.

Table 9: tool results compared with construction costs

Construction Cost (2019, Canadian dollars)	LCCT result	LCCT result (without 10% overhead)
$270,614	$330,257	$300,234
Per cent difference from construction cost	22%	11%

6.0 FOREST GLEN DRIVE

Built in 2016, this Lake Simcoe Region Conservation Authority (LSRCA) project comprised two roadside linear partial bioretention units along Forest Glen Road in Newmarket, which cost $404,681 (adjusted for inflation to 2019 dollars) to construct. Table 8 shows the site and design inputs into the tool, and Table 9 compares the tool results with construction costs.

Departures from the design deafuals for this project desing included a .1 m ponding depth (tool default: .2 m), and the filter media depth was lowered from the default .75 m to .6 m. For the calculated cells, the design did not include pea gravel, and the gravel storage layer had to be increased to .8 m.

Table 10: site and design inputs into the tool for Forest Glen Drive

Site and Design Information

USER INPUTS			
Drainage area (DA)		11600	m^2
Native soil infiltration rate		15	mm/hr
Design type [1]		Partial Infiltration	Unitless
Drainage period		24	hours
BR surface area length to width ratio		86.4	Unitless
Project land value classification		None	Unitless
DESIGN DEFAULTS	defaults	***(values in col G can be changed)***	
Maximum drainage area to surface area ratio	20	21.5	Unitless
Water Quality Volume Requirement	45	45	m^3/ha
Filter Media Depth	0.75	0.6	m
Ponding depth	0.2	0.1	m
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Mulch depth	0.075	0.075	m
DESIGN CALCULATIONS			
Pea gravel depth		0.00	m
Filter media depth		0.60	m
Gravel storage layer depth		0.8	m
Total depth [2]		1.48	m
Underdrain diameter		0.30	m
Surface area (SA)		539.5	m^2
Length		215.9	m
Width		2.5	m
Maximum duration of ponding		16.7	hours
Water storage volume [3]		318.3	m^3
Maximum rainfall captured		27.4	mm

Note that for this project, project costs included a $30,000 continency, so the LCCT result which includes the 10% overhead is the more accurate comparison. The initial tool results were about half the actual construction costs.

Table 11: tool results compared with construction costs

Construction Cost (2019, Canadian dollars)	LCCT result	LCCT result (without 10% overhead)
$404,681	$202,269	$183,881
Per cent difference from construction cost	-50%	-54%

Why does the tool undershoot for this project by so much? Well, designs for this project included several features which for which the tool does not provide costs:

- Armourstone blocks
- Clay seals

- Driveway removals and reconstructions
- Iron filings for biomedia enhancement
- Triton system and installation

Because of these significant departures from the model designs used by the tool, we did not consider removing these costs to be “cheating”. (Alternatively, we could have just added the costs to the tool). Doing so gives a pre-contingency cost of $198,927. Halving the contingency, adding HST and adjusting for inflation produced a total adjusted project cost of $253,719. Table 10 shows the tools results against this recalculation of the construction costs. Because the costs for his construction project did include contingency, the LCCT result with the 10% overhead is the more accurate test.

Table 12: tool results compared with adjusted construction costs

Construction Cost (2019 dollars)	**LCCT result**	**LCCT result (without 10% overhead)**
$253,719	$214,348	$195,228
Per cent difference from construction cost	-16%	-23%

7.0 TRCA PARKING LOT – INFILTRATION TRENCH

Constructed in 2012, an in infiltration trench at TRCA’s Kortright centre cost $18,990 to build (adjusted for inflation to 2019 dollars). Table 13 shows the inputs into the tool, and Table 14 gives the tool’s results compared with construction costs.

Table 13: inputs into the tool for the Kortright centre infiltration trench

Site and Design Information

USER INPUTS			
Roof drainage area			m2
Road drainage area		265	m2
Drainage period		24	hours
Inlet locations (manholes)		1	Unitless
Infiltration rate of the subgrade		15	mm/hr
Rainfall capture target		11.5	mm
Project land value classification		None	Unitless
DESIGN DEFAULTS	**defaults**	**(values in col G can be chang**	
Safety factor	2.5	2.5	Unitless
Void ratio	40	40	%
Width of trench	2	1.50	m
Maximum acceptable drainage area ratio	20	20.0	x:1
TOOL RESULTS			
Total drainage area (DA)		265	m2
Drainage type		Road Only	Unitless
Depth of trench 1		0.14	m
Length of trench		23.7	m
Surface area of trench		35	m2
Drainage ratio		7.47	x:1
Rainfall captured		11.5	mm
Total drainage area to surface area ratio (DA:SA)2		7.5	x:1, unitless
Water storage volume		3.0	m3

The tool automatically assumes that road runoff requires treatment with a hydrodynamic separator. However, this facility did not include an OGS, so this cost was removed. Because the construction cost cited here does include a 10% contingency, the result with the 10% overhead contingency is with contingency is the more accurate test.

Construction Cost (2019, Canadian dollars)	LCCT result	LCCT result (without 10% overhead)
$18,990	$17,074	$15,521
Per cent difference from construction cost	-10%	-18%

8.0 CONCLUSION

For construction costs the tool is reasonably accurate (±14%), with the outliers being 18% under (Kenollie Public School) and 17% over (County Court). The results are well within ±30% goal set for the tool.