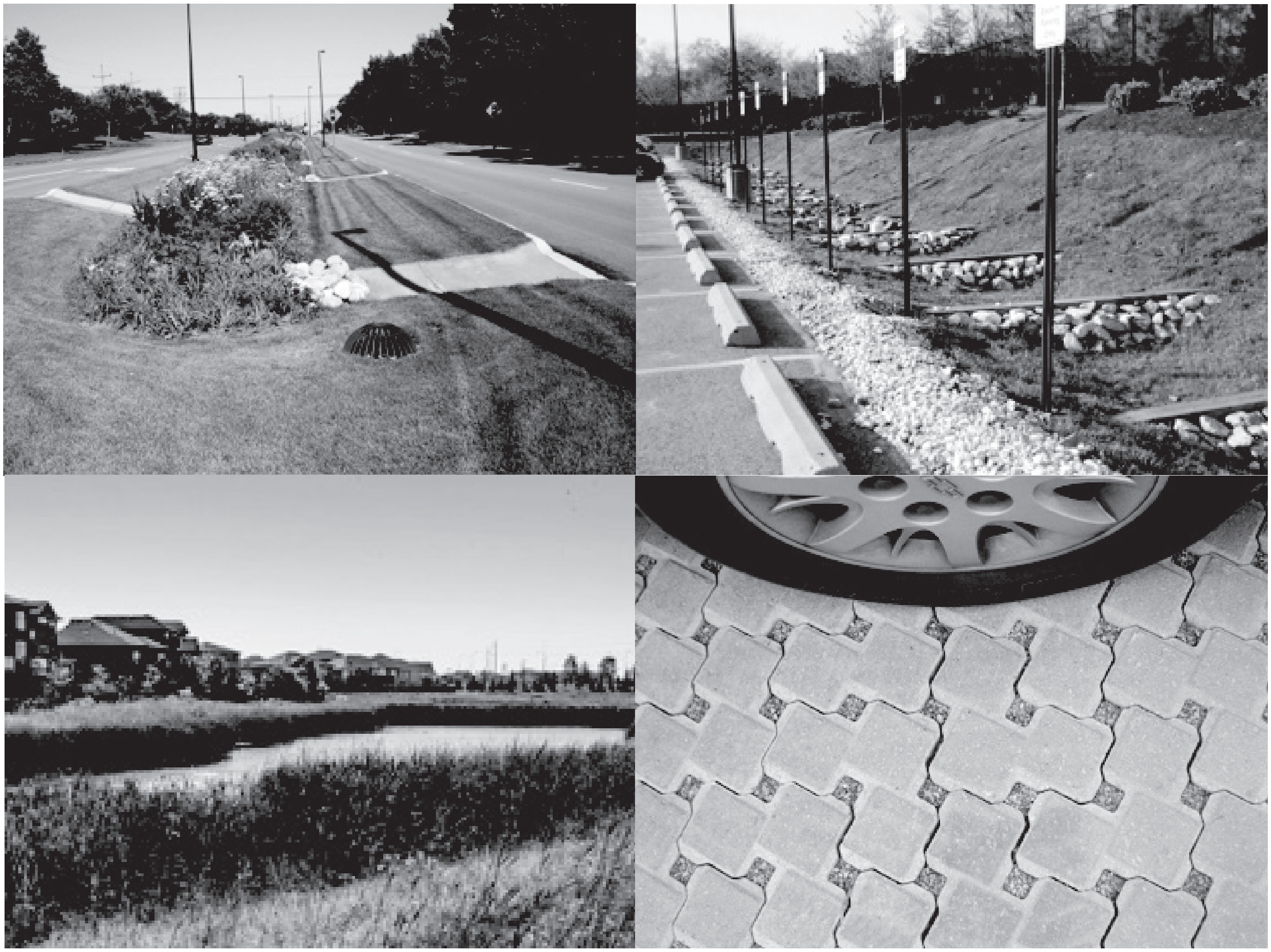

Life Cycle Cost Analysis Of Natural On-site Stormwater Management Methods

CANADIAN NURSERY
LANDSCAPE ASSOCIATION

Executive Summary

Increased development is creating greater impervious areas in the built environment, causing stormwater runoff volumes to rise and add to the workload of municipal waste water treatment plants. Treating, pumping and distributing water uses a large amount of energy, resulting in greenhouse gas emissions and increased carbon footprints. The landscape horticulture industry is in a unique position to provide alternative solutions to traditional stormwater management techniques by reducing the runoff at the source and therefore reducing the environmental impacts of stormwater treatment.

This paper applies the Life Cycle Cost Analysis (LCCA) method to five scenarios to determine their economic performance compared to traditional strategies. In almost every case these sustainable, low impact designs were cost effective over the life of the project compared to traditional "pave and convey-away" methods while also providing additional environmental and social benefits. Average annual maintenance costs were consistently lower than the traditional techniques, which often required significant material removal as part of their rehabilitation unlike the more durable natural designs.

It is clear that on-site stormwater management methods are viable strategies that add to the sustainability of our built environment. The planning and expertise from a variety of professions working together are essential to achieve success with these stormwater management methods - each site has its own characteristics that can be developed into cost effective and sustainable landscape solutions.

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Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is a method used to assess the total cost of ownership for a project, or elements of a project. LCCA takes all the economic impacts of design alternatives into consideration and creates an apples-to-apples comparison of the choices[1]. LCCA is most effective when used early in the design phase of a project, as it enables decision-makers to select products/solutions that are based on the long-term economic analysis of each, and not simply the first cost. By comparing product LCCA results, trade-off can be made between high initial cost items and long-term operating costs/savings.

LCCA has gained popularity in recent years as an economic management tool. The LCCA method provides a standardized assessment approach that helps remove divisional conflicts within organizations, by accounting for all associated costs and benefits. The result is a robust economic comparison of product alternatives over time, and an improved understanding of how periodic costs impact the total cost of ownership. It should be noted that LCCA is flexible by design and allows for the incorporation of any unique periodic, or reoccurring costs that might be incurred over the economic evaluation period.

This is especially relevant to stormwater infrastructure due to the ongoing maintenance and repair costs required to maintain the structures over long lifetimes.

Typical costs that should be consideration in any LCCA include the following:

Initial Costs – Initial costs include the purchase, acquisition, design, and installation of equipment and/or products.

Energy Costs – For products, or project components, that consume energy, fuel rates and equipment efficiencies should be considered for each alternative.

Operation, Maintenance, and Repair Costs – All costs associated with the upkeep and maintenance of a product or system should be incorporated.

Replacement Costs – For products with a life span that is shorter than the LCCA baseline evaluation period replacement costs must be included.

Residual Values – Like replacement costs, any associated resale or salvage value for products with remaining life expectancy should be estimated. A common method for estimating the residual value of an item is as follows:

$$\text{Residual Value} = \text{Initial Cost} \times \left(\frac{\text{Remaining Life}}{\text{Expected Life}}\right)$$

Disposal Costs – Depending on the nature of the product there can be significant variations in the disposal cost, which should be considered for each alternative.

Financial Variables – Project-related interest expenses, such as a company's internal discount rate,regional energy escalation rates, and inflation rates should be included as they all affect the time-value of money.

[1] Stanford University Land and Buildings, (2005). Guidelines for Life Cycle Cost Analysis.

Calculating Life Cycle Cost

Calculating the life cycle cost of multiyear investments requires the collection of all initial and ongoing costs over a predetermined life of a project. As each alternative will have some variation in the anticipated life expectancy and maintenance requirements, LCCA uses a fixed life cycle for all alternatives and compares the total cost of ownership using net present values for each. Since the value of money declines over time all future costs must be brought back to current dollars to account for the time value of money, which accounts for inflation, energy price escalation and the opportunity cost of the investment. This is important in the LCCA for stormwater management methods, as all conventional and natural infrastructure requires ongoing maintenance and periodic repair costs.

The Life Cycle Cost (LCC) is calculated as the sum of all initial costs, plus the sum of all future costs, and the sum of any end of life disposal or salvage costs. All costs that occur outside of year one must be converted into equivalent present values before being summed. These future costs include items such as ongoing maintenance, periodic replacement costs, stormwater charges, and energy.

Life Cycle Cost Equation

Sum of Initial Costs + Sum of Future Costs

+/- Sum of Disposal/Salvage Costs

Calculation Variables

For this analysis, several of the calculation variables had to be fixed upfront to ensure that the results were consistent across the alternatives being considered. The following points list describes the key financial and design variables used in this LCCA.

Inflation Rate – A default inflation rate was chosen for all the following analysis; the selected rate used for the LCCA calculations was 2%, a conservative long-term value.

Internal Discount Rate – The discount rate is used to discount an estimated future value to a present value figure. If a $1.00 investment is made with 5% annual interest, the investment will be worth $1.05 in one year; conversely, we can see that $1.05 in one year is worth $1.00 at present, so the future value must be discounted. Typically, an organization will use a discount rate equal to their cost of capital, that is the rate of return their money could earn from a similar-risk investment. Civil infrastructure projects typically use a discount rate of 3-5%[2,3], so the default discount rate was conservatively set at 5% for all calculations.

Average Stormwater Cost – As landscaped surfaces have a reduced runoff rate in comparison to paved, or impervious surfaces, an average stormwater charge was developed to represent the typically avoided cost of paying the regional utility to treat stormwater runoff from the site. The average annual stormwater cost for a 2,000-square meter surface was determined to be $1,238.76.

Average Energy for Stormwater Treatment – To determine GHG reductions two average energy consumption factors had to be determined. For the supply of treated water to the site a value of 0.58 kWh/m3, and for stormwater treatment a value of 0.10 kWh/m3 was calculated.

Average GHG Emission Factors for Electricity – In order to convert the avoided energy from the supply of treated water and/or the treatment of stormwater an average emission factor of 160 gCO2 per kWh was used[4].

National Unit Costs for Alternatives – Since the basis of LCCA is to accurately determine the total cost of ownership for each alternative, a set of national average install costs for various componentswas required. Using a variety of tools such as the RSMeans costing database installation and maintenance estimates were created for each scenario being assessed.

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2 https://www.codot.gov/programs/research/pdfs/2006/discountrate.pdf

3 http://www.wisconcrete.org/wp-content/uploads/2016/02/5b-Wathne-LCCA-Fundamentals.pdf

4 Canadian Electricity Sector 2015 National Average CO2 Emissions Factor from the 2015 National Inventory Report

Calculation Example

A simplified example of a life cycle costing analysis has been created to help clarify the calculation procedure. The LCC example will show which of the two options is the better financial choice for the organization to undertake. In this case, Option A costs $50,000 and has ongoing maintenance that increases each year while Option B has a starting cost of $45,000 and the annual maintenance cost is $4,000. A simple cash flow analysis shows both options would cost the same at $65,000:

	Option A	Option B
Year 0	$ 50,000	$ 45,000
Year 1	$ 1,000	$ 4,000
Year 2	$ 2,000	$ 4,000
Year 3	$ 3,000	$ 4,000
Year 4	$ 4,000	$ 4,000
Year 5	$ 5,000	$ 4,000
Total	$ 65,000	$ 65,000

This is incorrect, as neither the inflation or time value of money was considered. Inflation will cause the cost of the same maintenance activity to increase over time, and we then must discount that future value to a present dollar value to make an equal comparison. With an inflation rate of 2% and discount rate of 5%, the cashflow becomes:

	Option A	Option B
Year 0	$ 50,000	$ 45,000
Year 1	$ 971.43	$ 3,885.71
Year 2	$ 1,887.35	$ 3,7774.69
Year 3	$ 2,750.13	$ 3,666.85
Year 4	$ 3,562.08	$ 3,562.08
Year 5	$ 4,325.38	$ 3,460.30
Total	$ 63,496.37	$63,349.64

After accounting for inflation and the time value of money, Option B results in a lower life cycle cost by $146.73 and is therefore the better economical choice. The process is the same for real-world projects only they often contain many more variables – the base case asphalt parking lot included 28 variables in determining the initial cost and the routine maintenance consisted of five activities, not all of them occurring annually.

Bioretention

Bioretention cells are vegetated filter beds which capture the surface runoff from surrounding hardscape, removing runoff contaminants and total stormwater runoff volume. The substrate in a bioretention cell may be a mix of sand, sandy loam topsoil and composted biological material to provide a well draining soil. Underdrains may be required depending on the infiltration rate of existing soils. The vegetation is typically densely planted deep-rooting drought tolerant plants which can thrive on the runoff water. Runoff will pass through a prefilter to separate out large solids that would reduce the filtering capacity of the bioretention cell. As these systems are designed to handle small runoff events, an overflow drain or alternative conveyance should be provided to handle large stormwater volumes.

The model used for the LCCA was a 2,000m² asphalt drainage area feeding a 133m² full infiltration bioretention cell which included mulch and bioretention filter soil layers, but did not require the gravel underdrain found in designs for sites with poor or no natural drainage. Maintenance activities included capital and labour costs associated with the initial care and ongoing maintenance of the bioretention cell, as well as restoration after 25 years. Activities included watering, weeding and pruning, restoring mulch depth and planting density, prefilter sediment removal and debris/clog removal.

The results of the Bioretention LCCA indicate an initial cost of \$69.65/m² for the full infiltration design, with 25-year and 50-year net present values of \$108.93/m² and 128.86/m² respectively. The initial cost was higher than the standard catchbasin system by \$2.65/m², however the net present value at year 25 was \$2.71/m² less than the base case due to stormwater reductions and lower maintenance costs. It is important to note that the underdrain components needed in a partial infiltration system increase both the initial and maintenance costs; this results in approximately \$9/m² increased cost over the baseline that continues through the project life due to equal maintenance costs.

Greenhouse gas reductions were realized by reducing the volume of stormwater conveyed and processed by the waste water treatment facility. The full infiltration bioretention cell saved 625.6kg of CO2e at 25 years and 1,251.2kg at 50 years by reducing runoff 85% compared to traditional methods while the partial infiltration design would reduce runoff by 45%, thus saving 331kg of CO2e at 25 years and 662kg at 50 years.

Enhanced Grass Swale

Enhanced grass swales (EGS) are an improvement on typical ditches and channels, adding features that reduce total runoff volume while filtering out suspended sediments. The enhanced features typically include a trapezoidal cross section, regularly spaced check dams and vegetation along the bottom of the channel. These features are designed to control the runoff flow rate, allow water to infiltrate into the ground and provide sediment and contaminant filtration. The check dams create small pools of water, increasing retention time for more effective runoff treatment compared to typical gutter and catchbasin systems, which only remove oil and grit. Similar to bioretention cells, gravel prefilters placed on the swale banks prevent large particles and debris from entering the swale and allow for easy removal.

The EGS model used for the LCCA was a 2,000m^2 drainage area feeding a 3.25m by 61.5m EGS, with check concrete curb check dams along the swale length and a catchbasin to capture excess runoff.

Maintenance activities included initial watering and vegetation maintenance, annual inspections and debris/sediment removal. The primary maintenance required in an established EGS is sediment removal every two years; consequently, this simple system should not require restoration work during its lifetime.

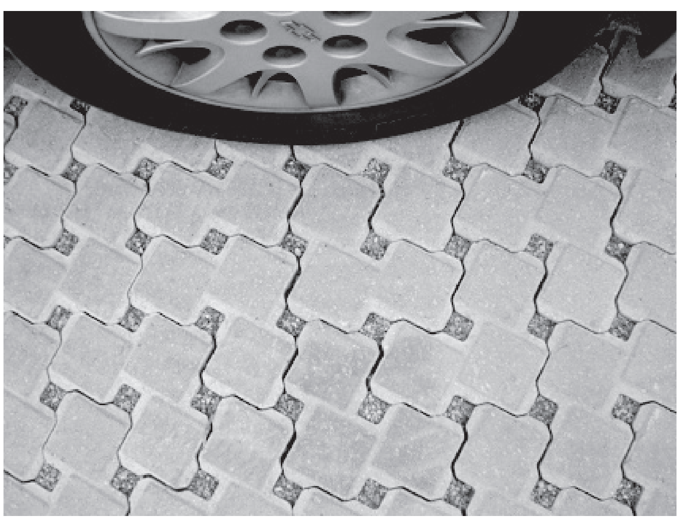
The results of the enhanced grass swale LCCA indicate an initial cost of \$61.12/m^2, approximately 9% less than the traditional conveyance system. The annualized maintenance costs were slightly cheaper for the EGS as well, improving the savings over time – 25-year and 50-year net present values of \$102.98/m^2 and 1125.80/m^2 respectively. The initial costs savings of \$5.88/m^2 grew to \$8.66/m^2 at year 25 and \$11.37/m^2 at the 50-year mark. Like the bioretention case, the majority of the annualized maintenance cost comes from the asphalt portion of the model; the annualized costs from the EGS itself are \$447 and \$312 at the 25-year and 50-year lifetimes respectively.

Enhanced grass swales achieve a stormwater volume reduction of 20% compared to traditional design. The EGS saved 147kg of CO2e at 25 years and 294kg at 50 years by the 20% runoff reduction. Although increasing the runoff reduction percentage would result in larger GHG savings, the EGS is still a conveyance structure by design and is meant to move the water. The EGS can be used in combination with other partial or non-infiltration low impact design structures, conveying the water from these structures to further reduce total runoff volume and offering total project cost savings.

5 http://clean.ns.ca/wp-content/uploads/2013/05/Native-Plant-SolutionsPPTX-SWIMS-Conference-Halifax-June-20131.pdf

Permeable Interlocking Concrete Pavers

Traditional concrete and asphalt pavement places a continuous impervious layer on top of existing land, accumulating all rainfall as runoff which all needs to be conveyed to the local stormwater system. Permeable Interlocking Concrete Pavers (PICP) are an alternative solution that allow stormwater to filter through gaps in the pavers to a gravel bed below, removing the need for conveyance. Like bioretention cells, the underlying native soil will determine if an underdrain system is required or if full infiltration is possible. Low traffic roads, parking lots and driveways are all excellent candidates for PICP, with the pavers able to treat runoff from impervious areas of equal area.



The same 2,000m² drainage area was used in the PICP analysis, with half the area composed of traditional asphalt draining to the PICP half.

Maintenance is limited to removal of small sediments that collect in the permeable voids, replacing damaged pavers, repainting any traffic markings and cleanout of the underdrain if present. The expected lifetime of a PICP solution is 30 years compared to the 25-year lifetime of traditional asphalt paving, so the residual value of the PICP was calculated and included in the NPV.

The PCIP analysis indicated an initial cost of \$83.28/m² averaged over the full 2,000m² drainage area, assuming the impervious asphalt area was also new construction and part of the project costs. The higher capital cost for the PCIP system is balanced by reduced ongoing maintenance costs and a longer product lifetime before rehabilitation is required. The PICP system had a net present value of \$101.46/m² at year 25 and \$125.84/m² at the 50-year mark; more than \$10/m2 less than the base case at both evaluation points thanks to the residual value of the more durable product.

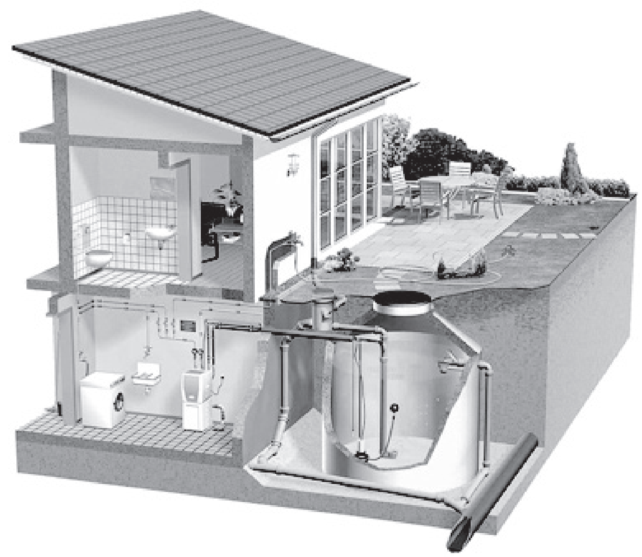
The PCIP system reduces runoff by approximately 45% compared to the full asphalt design. The total GHG saved was 331kg of CO2e at 25 years and 662kg at 50 years with the partial infiltration PCIP system. Similar to bioretention cells, the amount of runoff reduction can be much higher for this system depending on the design and soil infiltration rates and consequently the GHG reductions would increase.

Rainwater Harvesting

Rainwater harvesting makes use of hardscape like roofs and parking lots to divert the runoff to a storage tank for reuse within a building. The captured rainwater is fit for non-potable uses like flushing toilets, watering plants and washing clothes and cars. Different pretreatment strategies are selected based on the rainwater capture source to filter out debris before storage in a cistern, either buried or above ground.

The rainwater harvesting system analyzed was a 1,000m^2 roof collection system which passed through a filter tank and was stored in a concrete tank below grade. Once constructed, the only routine maintenance required is an annual inspection and filter cleaning, with the holding tank cleaned every decade. The water pump and attached pressure tank that distribute the rainwater would also be replaced after 10 years.

The rainwater harvesting system is unique in that it entails investing capital in a site-level capture and storage system while the alternative is simply paying a monthly water bill to use the existing infrastructure. The LCCA determined the rainwater harvesting system had initial costs at \$47.30/m^2, while the base case of purchasing municipal water had no upfront costs. The annualized costs associated with the rainwater harvesting are \$555 at a 25-year project life and \$466 at a 50-year life; in the case of using municipal services there is a charge for purchasing the water consumed and a separate cost for the water treatment, with annualized values of \$1995.07 at 25 years and \$2,159.49 at 50 years. The large difference in ongoing costs results in the rainwater harvesting system becoming the more attractive option in the long term, with 50-year net present values of \$70.58/m^2 for rainwater harvesting versus 96.10/m^2 for the municipally serviced scenario.



Rainwater harvesting systems create greenhouse gas savings by collecting greywater on-site via gravity instead of relying on the municipal system, which must filter and pump water from a much farther source. The energy consumed by the municipal pumping and distribution system requires approximately six times the energy per cubic meter compared to just treating the wastewater as was done in the previous scenarios. As a result, the total GHG savings for rainwater harvesting are 4,268.8kg of CO2e at 25 years and 8,537.6kg at 50 years.

Naturalized Stormwater Pond

Stormwater ponds are designed to receive the stormwater surge from upstream hardscape and control the discharge. Conventional stormwater ponds have little to no vegetation underwater and are surrounded by standard grass, which creates an unbalanced ecosystem. The lack of submerged plants allows for uncontrolled algae growth in the pond and large geese populations can develop as the grass offers no camouflage for predators. Routine maintenance costs on standard stormwater ponds are high, with regular grass mowing and control/removal of unwanted aquatic weeds. Naturalized stormwater ponds include natural plantings both on the banks and below the surface of the pond, creating a fully balanced ecosystem where weeds cannot compete while also providing superior water treatment.

A case study of a 16,900m² stormwater pond was used to evaluate the benefits of naturalizing stormwater ponds[5] . Naturalized stormwater ponds consist of a variety of pants ranging from fully underwater plants to natural grasses with wetland plants in between. Initial maintenance consists of weeding and waterfowl deterrence until the vegetation is established, at which point the remaining maintenance is clearing the inlet and outlet pipes and prescribed burning of the surrounding prairie grasses to maintain a healthy ecosystem.

The analysis of traditional versus naturalized stormwater retention ponds favour the naturalized option from the very start – both initial and ongoing costs are lower for the naturalized option. The initial costs of the traditional retention pond were $37.50/m² versus $32.76/m² for a naturalized pond, net present value at year 25 was $55.15/m² for traditional versus $35.91/m² for naturalized and at year 50 the net present values are $63.73/m² and $37.43/m² respectively. The large savings for the naturalized system arise from having a balanced ecosystem which requires little maintenance, whereas the traditional design is constantly combatting nature by weeding and herbicide use, both costly measures. This is reflected in the present value maintenance costs of $17.65/m² at 25 years and $26.23/m² at 50 years for the traditional retention pond, while the respective values for the naturalized retention pond are $3.15/m² at 25 years and $4.67/m² at 50 years.

Stormwater retention ponds are designed to absorb the surge of incoming stormwater during large precipitation events and allow suspended sediments and nutrients to settle in the pond before mechanical treatment. The naturalized retention pond doesn't reduce the overall volume of water sent to the wastewater treatment facility, thus GHG savings have not been calculated for this scenario.
The additional plantings in the naturalized retention pond would improve the quality of water sent to the treatment facility, however any savings arising from this have not been accounted for in the analysis.

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[5] http://clean.ns.ca/wp-content/uploads/2013/05/Native-Plant-SolutionsPPTX-SWIMS-Conference-Halifax-June-20131.pdf

Typical Construction Details

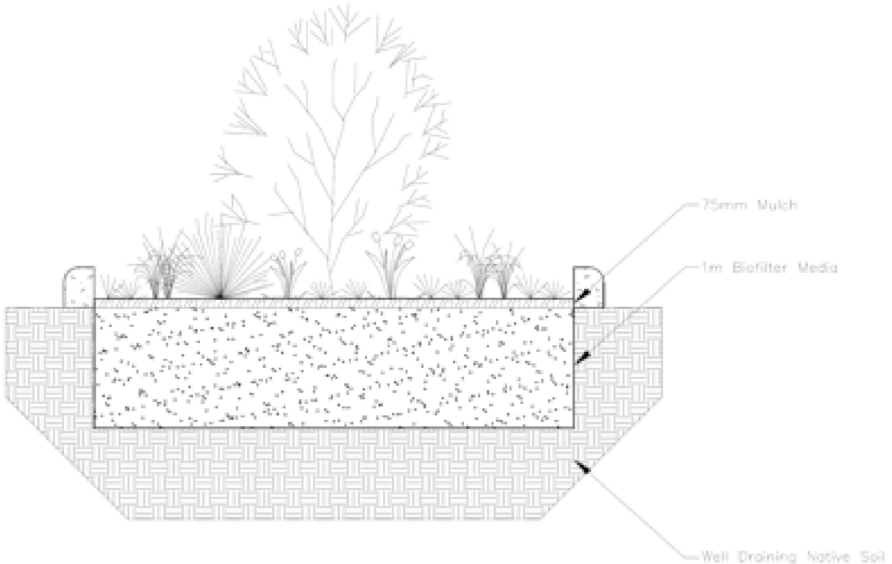


Figure 1.
Full Infiltration Bioretention

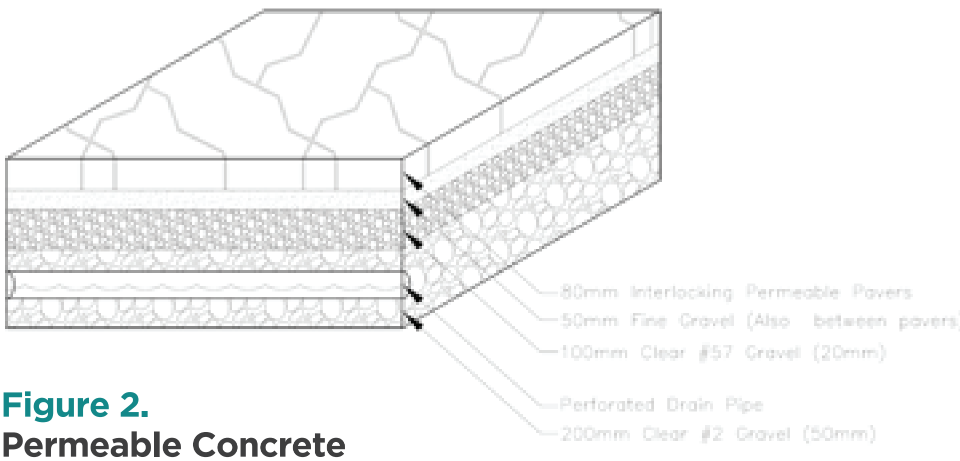


Figure 2.
Permeable Concrete Interlocking Pavers

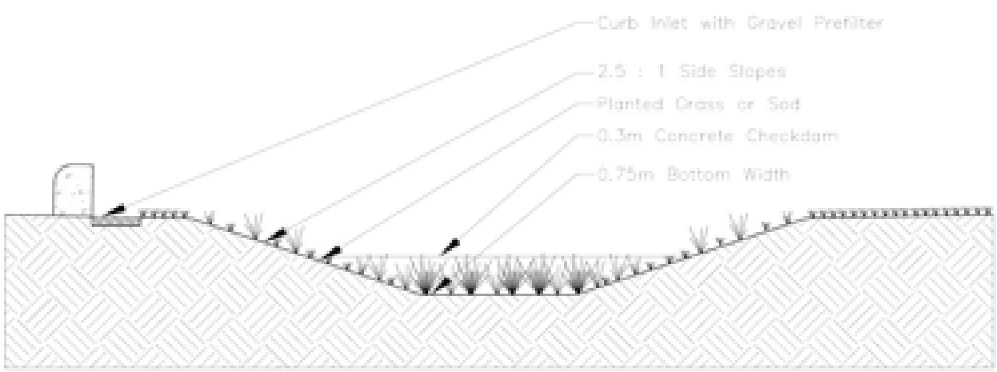


Figure 3.
Enhanced Grass Swale

Typical Construction Details

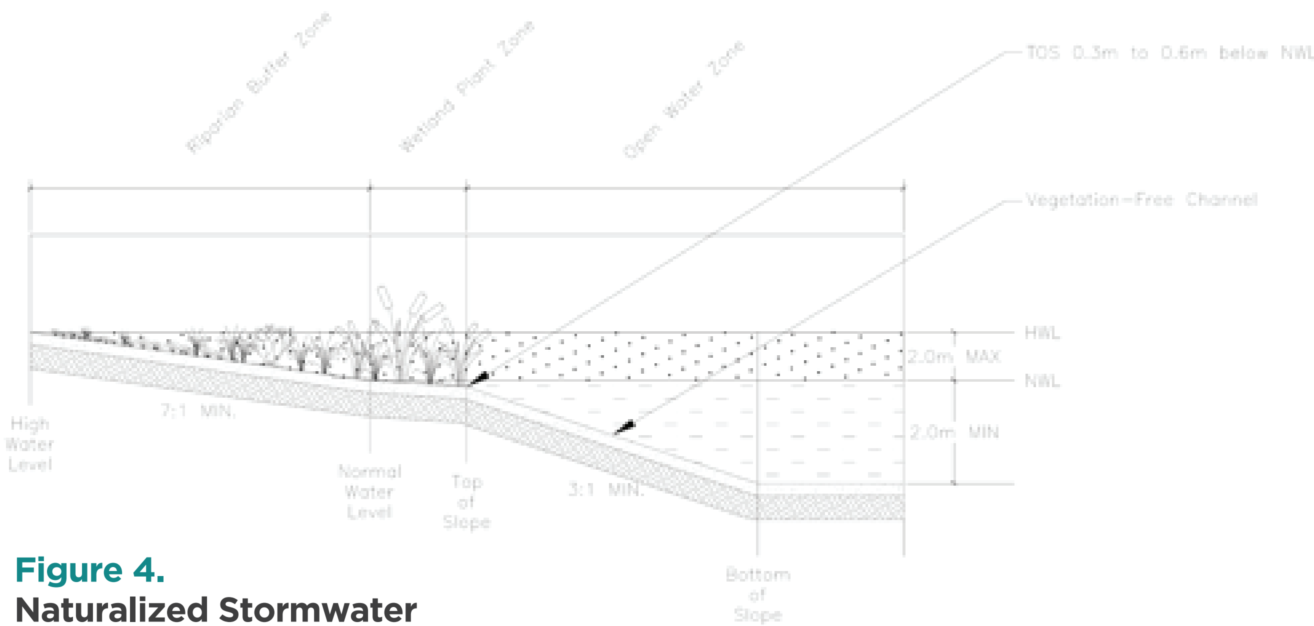


Figure 4.
Naturalized Stormwater Retention Pond

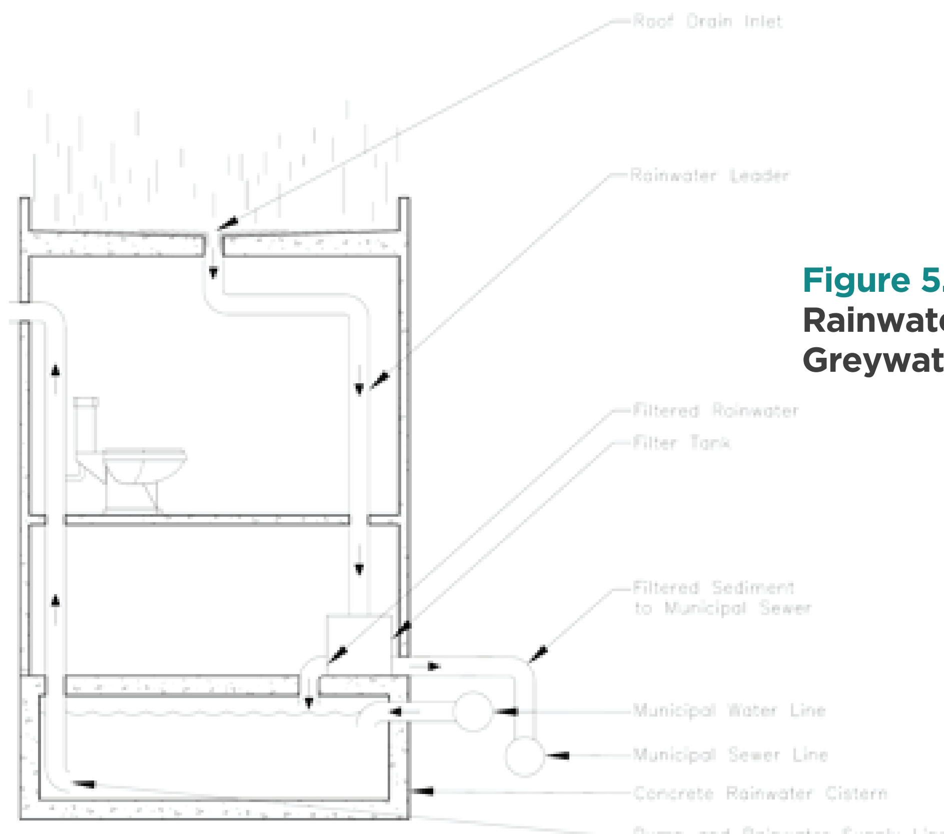


Figure 5.
Rainwater Harvesting Greywater Sysytem

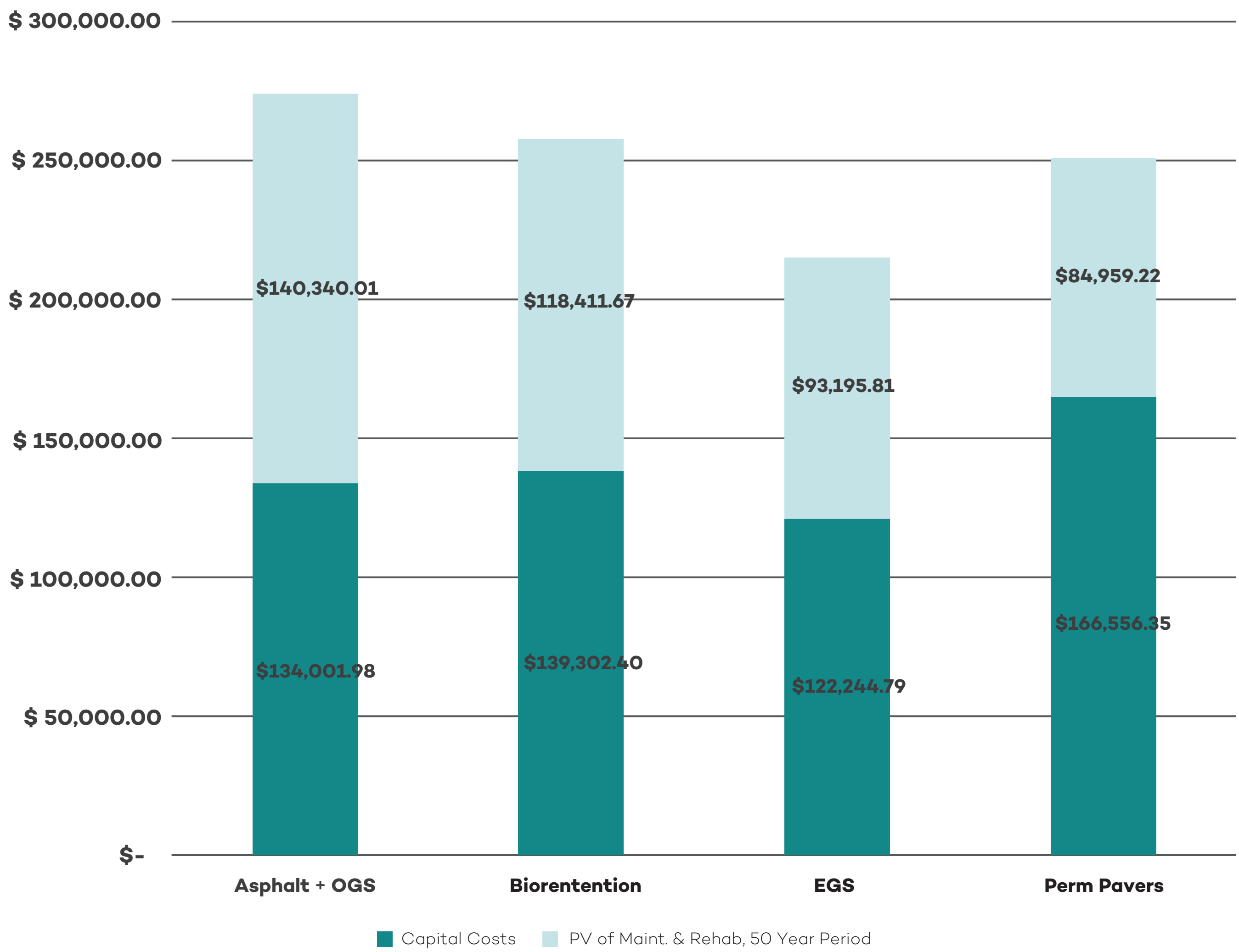
Table 2
LCCA Results

	Asphalt & OGS	Bioretention	Enhanced Grass Swale	Permeable Pavers	Conventional Stormwater Pond	Naturalized Stormwater Pond	No Rainwater Harvesting	Rainwater Harvesting
Initial Cost, $/m²	$ 67.00	$ 69.65	$ 61.12	$ 83.28	$ 37.50	$ 32.76	$ 0	$ 47.30
Runoff Reduction	0%	85%	20%	45%	–	–	0%	100%
Annualized Maintenance Cost, 25 years	$ 2,521	$ 2,984	$ 2,508	$ 1,371	$ 11,932	$ 2,128	$ 1,707[a]	$ 555
Annualized Stormwater Cost, 25 years	$ 1,050	$ 158	$ 840	$ 578	–	–	$ 525	$ 0
Net Present Value at 25 years, $/m²	$ 111.64	$ 108.93	$ 102.98	$ 101.46	$ 55.15	$ 35.91	$ 55.81	$ 61.19
Kg CO2e Saved at 25 years	0kg	626kg	147kg	331kg	–	–	0kg	2,540kg
Annualized Maintenance Cost, 50 years	$ 1,903	$ 2,232	$ 1,864	$ 1,699	$ 8,865	$ 1,579	$ 1,470[a]	$ 466
Annualized Stormwater Cost, 40 years	$ 904	$ 136	$ 723	$ 497	–	–	$ 452	$ 0
Net Present Value at 50 years, $/m²	$ 137.17	$ 128.86	$ 125.80	$ 125.84	$ 63.73	$ 37.43	$ 96.10	$ 70.58
Kg CO2e Saved at 50 years	0kg	1,251kg	294kg	662kg	–	–	0kg	5,081kg

[a]Sum of purchased water costs only, no maintenace factor included.

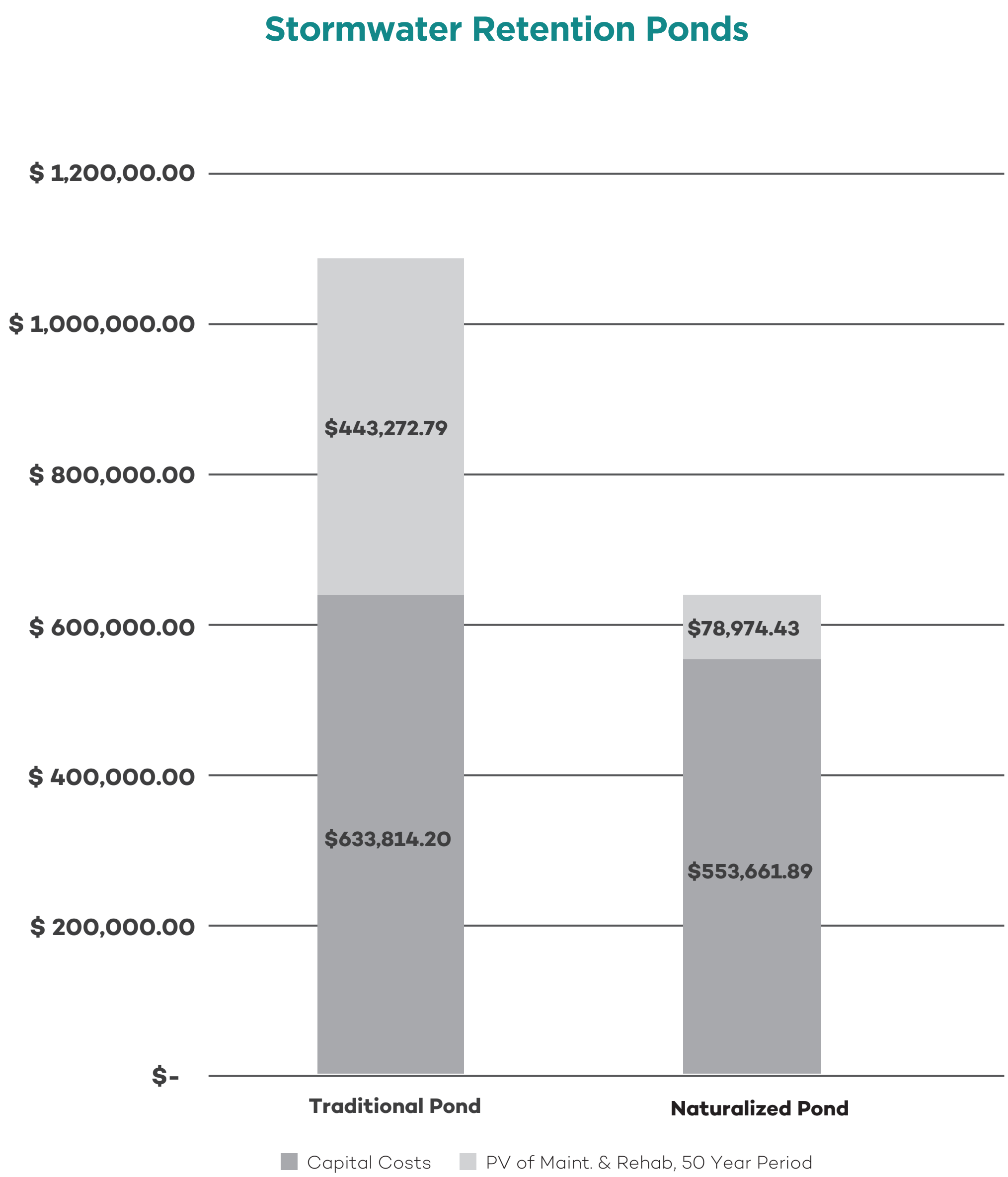
Present Value of All Costs at 50 Years

Figure 6.
Net Present Value of All Costs at 50 Years – Asphalt Alternatives



Present Value of All Costs at 50 Years

Figure 7.
Net Present Value of All Costs at 50 Years



Present Value of All Costs at 50 Years

Figure 8.
Net Present Value of All Costs at 50 Years Rainwater Harvesting

kg CO2e Saved Over 50 Years
Stormwater Reductions

Figure 9.
kg CO2e Saved Over 50 Years from via Stormwater Reductions