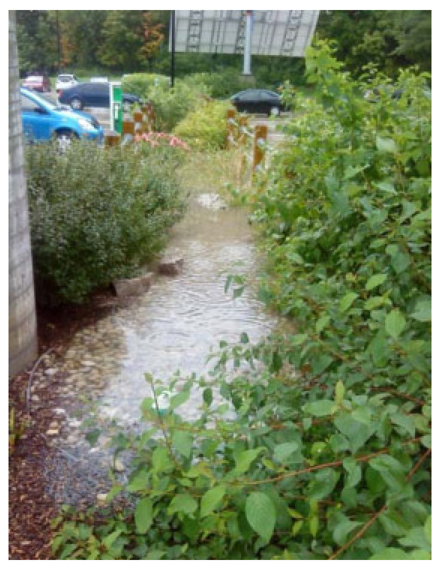
Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices



Prepared by: Toronto and Region Conservation
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Final Report 2013

ASSESSMENT OF LIFE CYCLE COSTS FOR LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT PRACTICES

Final Report

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NOTICE

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities for implementing technologies;
- develop supporting tools, guidelines and policies; and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical products or devices; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

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EXECUTIVE SUMMARY

This project evaluates the capital and life cycle costs of Low Impact Development (LID) practices over a 50 year time horizon based on a detailed assessment of local input costs, maintenance requirements, rehabilitation costs and design scenarios relevant to Canadian climates. The LID practices evaluated include bioretention cells, permeable pavement, infiltration trenches and chambers, enhanced swales, rainwater harvesting and green roofs. Dry swales and perforated pipe systems were considered to be similar to bioretention and infiltration trenches, respectively, and therefore were not evaluated as separate practices. The savings from LID approaches associated with improved aesthetics, air quality, community livability and other public benefits were not assessed, as these savings are best evaluated in relation to specific case study examples.

A robust and replicable methodology was used to compile capital and life cycle costs for the LID practices evaluated in this project. Model designs were developed for up to 3 typical variations of each LID practice assuming a 2000 m^2 paved and/or roof drainage area. An RSMeans database, widely used for construction and maintenance cost estimation, was used as the basis for most of the costing. Where RSMeans cost data were not available, costs were derived from other sources (e.g. supplier quotes, experienced construction managers). Maintenance and rehabilitation schedules for each practice were assessed based on local guidance manuals and literature sources.

Model LID practice design costs evaluated in this study indicated that bioretention, infiltration chambers, infiltration trenches and enhanced swales are some of the least expensive practices to implement when only the practice cost itself is considered. The practice of rainwater harvesting provides additional savings by reducing the cost of potable water supplies. Permeable pavements are comparably more expensive than most other practices, but in many instances these costs would be offset to some extent by a reduction in the need to pave the drainage area, since the pavements serve both as a parking surface and stormwater treatment practice. The practice also does not require as much land as some other practices, making it particularly well suited to retrofit contexts. Green roofs are the most expensive practice as they are installed in less accessible locations and need to be carefully engineered to protect the integrity of the building envelope. This practice is often selected because of its aesthetic, biodiversity and energy saving benefits, as well as its overall contribution to green building rating schemes, the value of which were not considered in the cost assessment provided in this study.

An analysis of different treatment scenarios for an asphalt parking lot revealed that LID practices had comparable life cycle costs to conventional treatment using an oil grit separator (OGS). Incorporating the stormwater treatment benefits of the practices into the analysis showed that LID practice life cycle costs were between 35 and 77% less than conventional OGS treatment.

A spreadsheet decision support tool based on the cost calculations gathered during this study was developed to assist industry professionals calculate the initial capital and life cycle costs of site specific LID practice designs. The tool provides users with a more comprehensive understanding of all relevant costs, facilitates cost comparisons, and allows users to optimize proposed designs based on both performance and cost. The tool is available free of charge on the Toronto and Region Conservation's Sustainable Technologies Evaluation Program website.

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1.0 INTRODUCTION

1.1 Background

Over the past several years, the practice of stormwater management in Ontario has shifted from an approach focused narrowly on centralized water quality treatment and peak flow control towards a broader, more decentralized approach oriented towards maintaining or re-establishing the pre-development hydrologic regime. This new approach utilizes a series of decentralized micro controls at or near the source of drainage networks to supplement conventional detention facilities. Alterations to the pre-development urban water cycle are minimized through site planning techniques and measures aimed at infiltrating, filtering, evaporating and detaining runoff, as well as preventing pollution. In Ontario and some parts of the United States, this approach is commonly referred to as Low Impact Development (LID), and includes measures such as green roofs, permeable pavement, bioretention, infiltration trenches, swales and alternative site design strategies.

Within the Greater Toronto Area, the results of several years of watershed monitoring and modeling, published in documents such as the Toronto and Region Conservation's (TRCA) Watershed Plans for the Rouge (2007), Humber (2008) and Don (2009) Rivers have concluded that this shift towards Low Impact Development is essential to protect watershed health and improve the resilience of watercourses to the hydrologic impacts associated with climate change. In July 2010 TRCA and Credit Valley Conservation (CVC) released the *Low Impact Development Stormwater Management Planning and Design Guide* (hereafter referred to as *LID Guide*) to assist local developers, consultants, municipalities and landowners to better understand, plan and implement LID stormwater management practices. The *LID Guide* provides a wealth of information on the planning, selection, and design of LID, and helps to streamline the design and review process to encourage widespread adoption of these technologies. Uncertainties remain, however, about the capital and long terms costs associated with these technologies relative to conventional end-of-pipe approaches.

While there are software tools and literature that provide detailed cost data for LID practices, particularly with respect to the capital costs of materials and labour, many of these resources (e.g. WERF, 2009; Olson et al, 2010) are based on markets in the U.S. or other countries, and are therefore not directly applicable to local conditions. These resources also often use designs that are either no longer considered best practice, or are not in accordance with cold climate design adaptations commonly used in Ontario. Life cycle costs provided in this report are directly applicable to Ontario because they are derived, to the extent possible, from local sources and based on design specifications provided in the *LID Guide,* which incorporates design modifications and maintenance considerations relevant to local geologic and climatic conditions.

In addition to research on the capital and long term operation and maintenance costs of LID, there are also several studies that attempt to quantify the value of LID based on the full range of costs and benefits to the individual site owner, the community and broader public. One such study, conducted by the USEPA in 2007 reported lower total costs for 11 of 12 green infrastructure projects relative to conventional grey infrastructure. Savings were often realized due to reduced costs for site grading and preparation, stormwater drainage infrastructure, curbs and gutters, site paving and downstream stormwater treatment. Other studies have attempted to monetize the broader public benefits of the practices (e.g. Odefey et al, 2012; Buckley et al, 2012a, 2012b; Marbek, 2010). These include avoided costs associated with reduced runoff and water quality (e.g. reduced frequency of combined sewer overflows, lower stream erosion rates) as well as benefits related to energy, air quality, climate change, urban heat island, habitat improvements and aesthetics. These studies have shown that LID approaches can lead to significant long term fiscal savings for local governments.

1.2 Project Objectives

The purpose of this project is to evaluate the capital and life cycle costs of LID practices over a 50 year time horizon based on a detailed assessment of local input costs, maintenance requirements and specific design scenarios presented in the *LID Guide*. The following practices are evaluated:

- Bioretention cells
- Permeable Interlocking Concrete Pavement
- Infiltration trenches
- Infiltration chambers
- Enhanced swales
- Rainwater harvesting, and
- Green roofs

Dry swales and perforated pipe systems were considered to be similar to bioretention and infiltration trenches, respectively, and therefore were not costed out as separate practices. The savings from LID approaches associated with improved aesthetics, air quality, community livability and other public benefits were not assessed, as these are best evaluated in relation to specific case study examples.

A spreadsheet decision support tool based on the cost calculations gathered during this study was developed to assist industry professionals calculate the initial capital and life cycle costs of site specific LID practice designs. The tool provides users with a more comprehensive understanding of all relevant costs, facilitates cost comparisons, and allows users to optimize proposed designs based on both performance and cost. The tool is available free of charge on the Toronto and Region Conservation's Sustainable Technologies Evaluation Program website.

2.0 LIFE CYCLE COSTING METHODOLOGY

2.1 Costing Methodology

The following steps were followed to develop detailed costs of all the LID measures.

2.1.1 Preparation of Model Designs

Model designs were developed for up to 3 typical variations of each LID practice assuming a 2000 m^2 paved and/or roof drainage area. The conceptual designs were developed for costing purposes based on design guidelines provided in the *LID Guide* (TRCA and CVC, 2010). This information was supplemented with other guidelines, literature references and professional advice when additional information was needed. Several conceptual designs were based on existing applications of the practices within the GTA.

The process and steps involved in construction of the practices were obtained from the *LID guide*, a review of regulatory requirements, and other references as needed. This step in the costing process describes the construction sequence, construction methods, and details of additional tasks required prior to undertaking construction (*e.g.* soil testing).

2.1.2 Construction Costing

All material, delivery, labour, equipment (rental, operating, operator), hauling and disposal costs were included in the cost spreadsheet. The RSMeans database (Toronto, 2010) was used as the basis for most of the costing. This standard database used widely for construction cost estimation provides detailed unit material (including delivery), labour and equipment costs. The costs in RSMeans marked "O&P" were used, which are the installing contractor's price including their overhead and profit. It was assumed there would be no general contractor for the construction project.[1] Standard Union labour costs were used, which are about 18%[2] higher than Open Shop labour costs. Note that the RSMeans costs do not include sales tax.

Where data were not available in RSMeans, costs were solicited from other sources (*e.g.* suppliers, experienced construction managers). These costs were often Open Shop labour rates and did not include sales tax. For rainwater harvesting, costs were obtained from an existing tool developed in 2010 through a partnership between University of Guelph, TRCA and Connect the Drops (STEP, 2011). The costs in the tool were also based on RSMeans 2010, and were cross

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[1] If a general contractor were used, there would be an average 10% markup as well as general contractor main office overhead & profit (RSMeans)

[2] Standard union costs are 16% more than open shop costs for a light truck driver, and 19% more for a light equipment operator as well as for a common building labourer (RSMeans, 2010 US average). Therefore on average 18% higher.

checked and supplemented as needed to ensure consistency with the methodology used in this study.

In compiling the cost data it was assumed that the practice was being constructed as part of a larger new development, and therefore mobilization/demobilization costs were not included unless a particular piece of equipment (*e.g.* crane for green roof) would not normally have been present on the site. Also, it was assumed that excavated soil could be dumped elsewhere on site.

Costs that would have been incurred whether or not the LID was being constructed were normally not included (*e.g.,* for rainwater harvesting, the pipes collecting runoff from the roof were not included because they would be required regardless). One exception is for green roofs, where the cost of the roof with and without the roof membrane was assessed.

For all LIDs, the following overhead costs were assumed:

- Construction management (4.5%),
- Design (2.5%), small tools (0.5%),
- Clean up (0.3%).

These are at the low end of the cost range suggested by RSMeans. Also, no contingency costs were included.

In rare instances, suitable costing data could not be found, in which case costs were estimated based on other data or costs from similar equipment or task. All assumptions and sources of data were documented.

2.1.3 Establishing Maintenance and Rehabilitation Requirements and Costs

Maintenance tasks and frequencies were determined based on the *LID guide* and other references where necessary. Assessment of the life span of the practices was based on literature where available, but in cases where there was conflicting information, a judgment was made based on a 'weight of evidence' approach. Assumptions on practice life spans are provided in each case to provide readers with a basis for interpretation of results.

The costs of maintenance and rehabilitation were determined using the same approach as for the construction costing. One difference, however, was that (de)mobilization of equipment was included as equipment would not already be on site. Design costs were not included in the rehabilitation or replacement costs as it was assumed that the original LID practice design would be used to inform this work.

2.1.4 Life Cycle Cost Calculation

Once all capital, maintenance and rehabilitation costs were determined, the lifecycle cost for each model design was calculated based on an evaluation period of 50 years, which is typical of the time span over which infrastructure decisions are made. The approach used was similar to that in the *Best Management Practice and Low Impact Development Whole Life Cost Models* developed by the Water Environment Research Foundation (2009). WERF's analysis includes any rehabilitation required within the 50 year period. At the end of 50 years, the LID is considered to have no salvage value, and no extra value is attributed to the additional lifespan expected for the LID beyond the 50 year mark.

The present value of the cost of each LID model design was calculated as follows:

PV = design and construction cost + PV of maintenance + PV of rehabilitation

The following present value formula was used to obtain the present value of the future cost:

$$PV = FC/(1 + r)^n$$

where,

PV = present value in $

FC = future cost in $

r = discount rate

n = year of future cost

Discount rates of 0, 3, and 5% were considered. Inflation was assumed to be 0%.

In addition to the 50-year analysis, a 25-year analysis was conducted. This was done to eliminate the impact on cost of any major rehabilitation that occurs in later years. Note that for the 50-year analysis, major maintenance activities that would normally be done at the 50 year mark were not included as the LID was assumed to retire after 50 years. For the 25-year analysis, however, these major maintenance activities were included at year 25 as it was expected that the LID would continue to be used.

In addition to the Net Present Values, the *annual average maintenance cost* and the *rehabilitation cost* were determined. The *annual average maintenance cost* does not include rehabilitation and as such represents an average of regular maintenance activities over the 50 year time period. The *rehabilitation cost* includes not only the cost of the actual rehabilitation but also of the consequent changes in maintenance activities. Thus the cost of the actual rehabilitation (not including maintenance activities) were added and maintenance tasks were removed[3], added[4] or

[3] When a rehab occurs, some maintenance activities are no longer needed in that year (e.g., no need to repair small leak in green roof membrane).

[4] When a rehab occurs, some additional maintenance activities are required (e.g. watering green roof).

shifted[5] in time as a result of the rehabilitation. The total cost of maintenance plus rehabilitation over 50 years was then summed. The difference between this sum and the total maintenance cost over 50 years in the scenario where no rehabilitation was required was calculated. This difference was the *rehabilitation cost*.

2.1.5 Comparison to Literature

A literature review was conducted for each LID to compare the construction and maintenance costs established in this study to other sources. The literature review was not meant to be comprehensive, as there are limited cost data available on LID practices, and those that are available are not necessarily applicable to local conditions. Thus the literature reviews consisted of comparisons to only a few references. Since different studies included different design assumptions, not all of which were clearly described, a straightforward comparison to our results was difficult to achieve.

5 When a rehab occurs, some maintenance activities may be shifted to later years (e.g. do not have to repair small leak in green roof membrane for next 10 years).

3.0 CAPITAL AND LIFE CYCLE COSTS

3.1 Bioretention

Bioretention uses the natural properties of soils, plants and associated microbial activity to infiltrate water and remove pollutants from stormwater runoff. It can be designed in various ways but the most common form consists of a shallow, excavated depression with layers of stone, prepared soil mix, mulch and specially selected native vegetation that is tolerant to road salt and periodic inundation. They remove pollutants from runoff through filtration by soil media and uptake by plant roots, and reduce runoff volume through evapotranspiration. The practice provides aesthetic benefits and can easily be modified to fit a wide variety of space and drainage contexts, making it one of the more common LID practices for reducing runoff volumes and achieving groundwater recharge targets on development sites.

Bioretention can be designed with full, partial or no infiltration depending on the underlying soil permeability and objectives of the project. Partial infiltration systems with underdrains are recommended where the underlying native soil has a permeability of less than 15 mm/h. In areas with contaminated native soils, or high groundwater tables, the practice may be designed with no infiltration, in which case it would contribute to lower runoff volumes entirely through temporary storage and evapotranspiration.

3.1.1 Model Scenarios and Designs

<u>Full infiltration</u>

Bioretention areas designed for full infiltration do not have underdrains, and are installed where the native soils are relatively permeable (>15 mm/h). In the simple design used for costing (see Figure 3.1), runoff from a 2000 m^2 parking lot drains into a 130 m^2 system through curb inlets spaced 6 m apart with splash pads to dissipate the energy of the flowing water. The drainage area is roughly 15 times greater than the footprint of the facility, which is the maximum allowed in the *LID Guide*. Pre-treatment is provided through the splash pads and 75 mm mulch layer, which captures fine sediment and debris, and helps maintain the integrity of the filter media by preventing fines from migrating into the filter media. An overflow is provided to convey runoff from storms large enough to fill the system, which in this case would be equivalent to a 37 mm rain event. Two monitoring wells were added to facilitate inspection and eventual maintenance of the system.

<u>Partial infiltration</u>

The partial infiltration system shown in Figure 3.2 is similar to the full infiltration system, but includes a raised underdrain and granular storage reservoir, which increases the depth of the system from 1.28 in the full infiltration example, to just over 2 m. The depth of granular material below the underdrain was sized to store and infiltrate runoff from a 25 mm event over the drainage area, not including moisture retention in the overlying soils. The additional granular material, underdrain and clean out pipes all add to the cost of this scenario relative to full infiltration.

No infiltration

The no infiltration design is the least common, and is implemented only where there are constraints to infiltration. The granular reservoir in the no infiltration model design is 40 cm shallower than the partial infiltration model design, and it includes an impermeable liner (Figure 3.3). It functions largely as a filtration system for water quality improvement, with some reduction of runoff through evapotranspiration by plants.

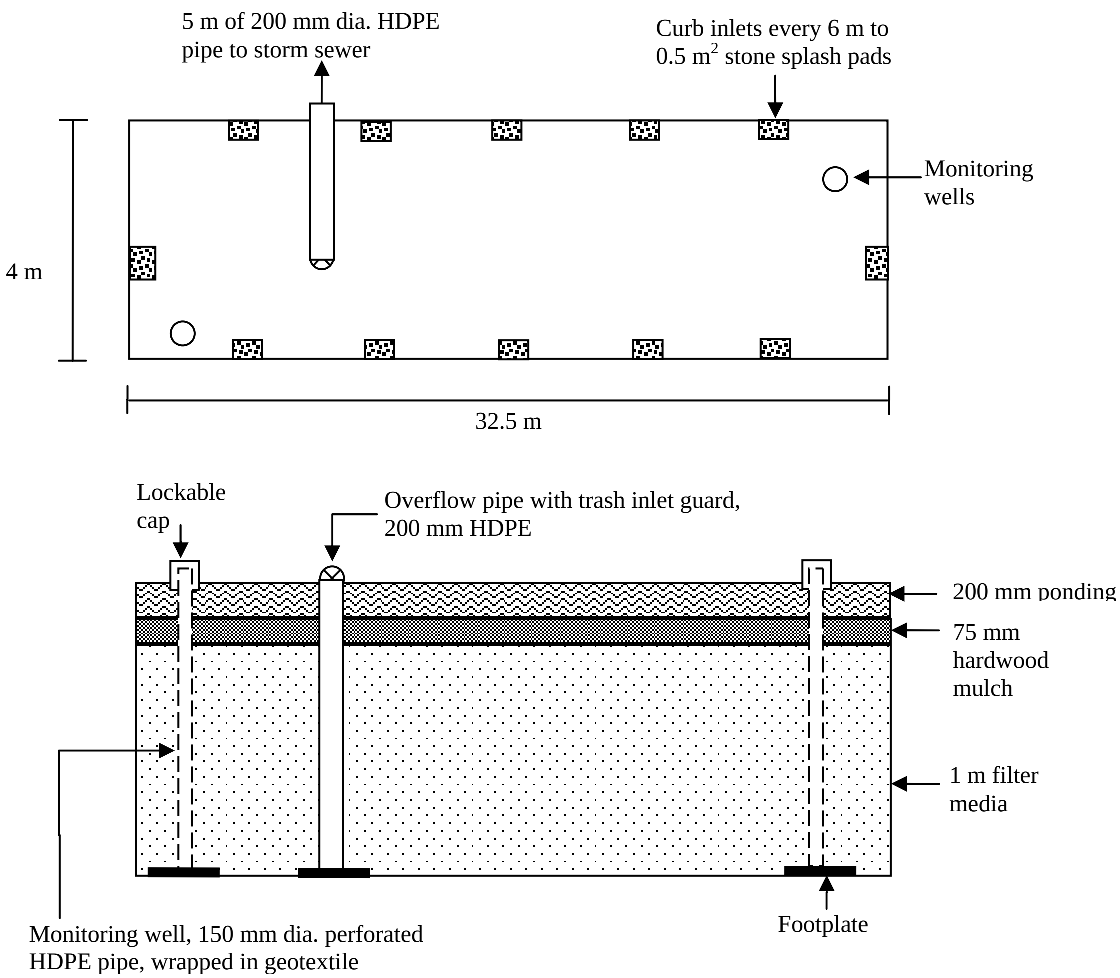

Figure 3.1: Bioretention full infiltration design. Plan view (top) and cross section (bottom)

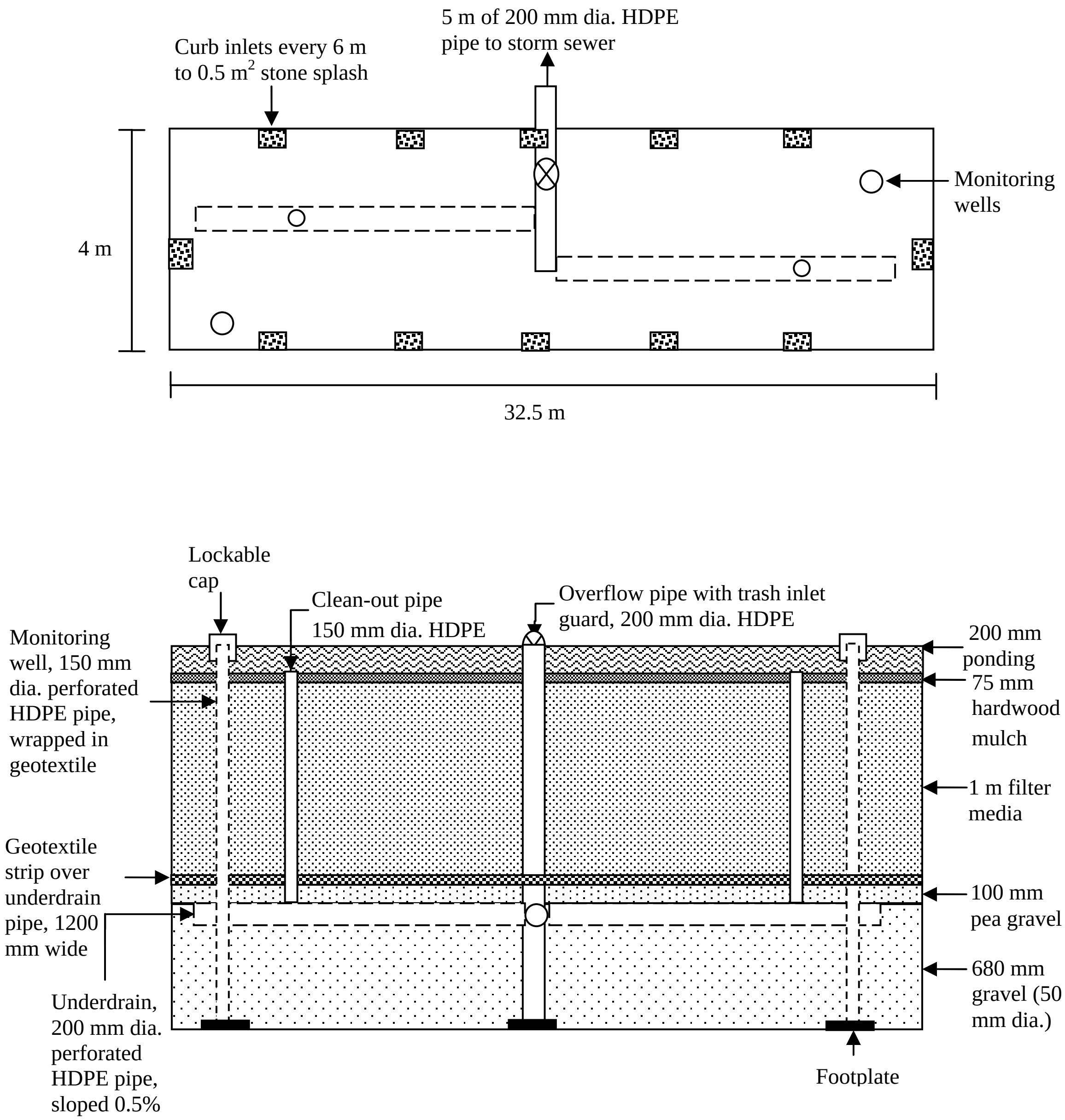

Figure 3.2: Bioretention partial infiltration design. Plan view (top); cross section (bottom)

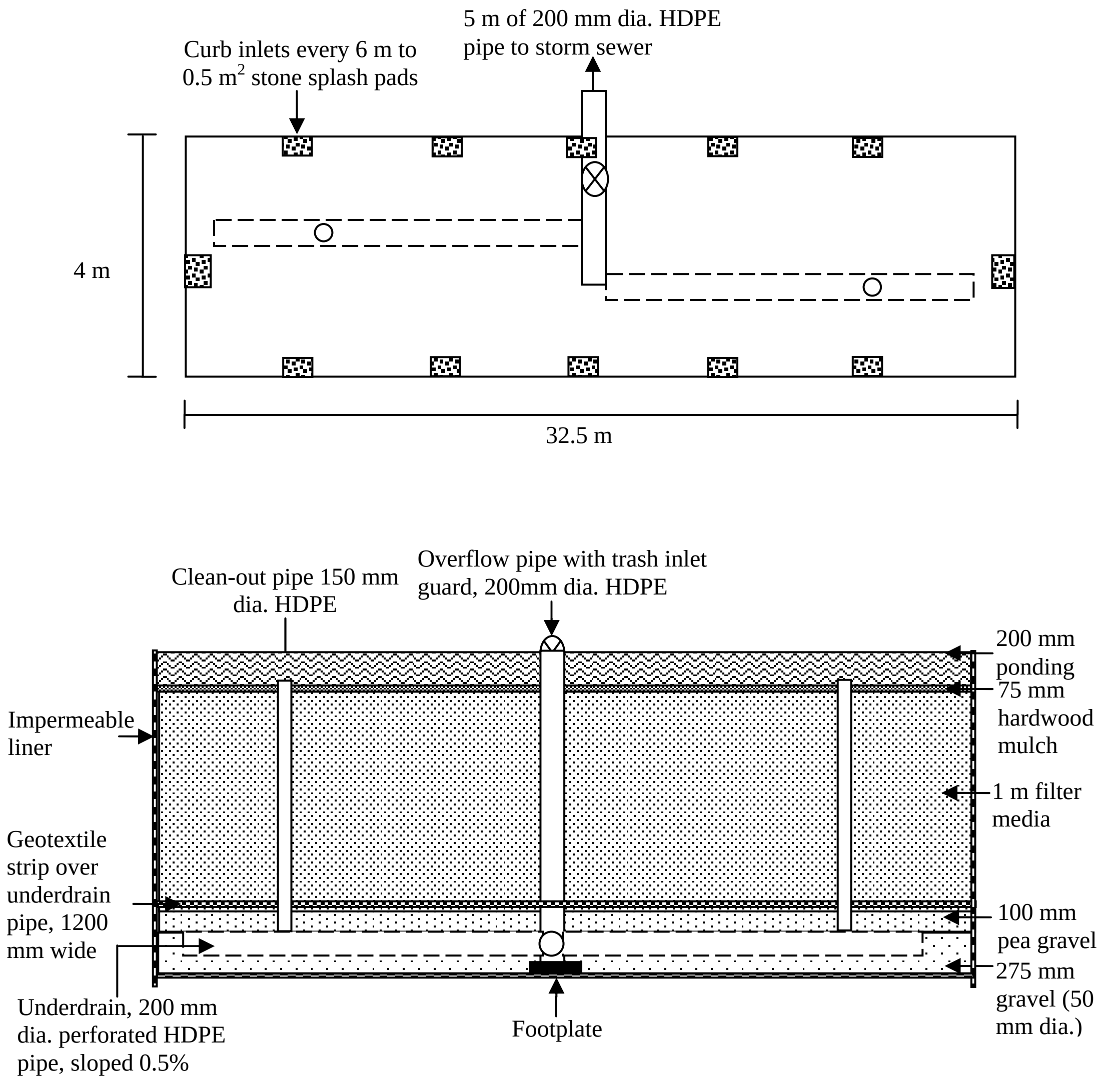

Figure 3.3: Bioretention no infiltration design. Plan view (top); cross section (bottom)

3.1.2 Capital Costs

The major capital cost categories for bioretention are shown in Table 3.1. A detailed breakdown of costs is provided in Appendix A. Full infiltration bioretention systems are considerably cheaper than partial or no infiltration designs because they do not require underdrains or granular storage reservoirs, and are shallower and therefore cheaper to excavate and construct. The no infiltration system has the highest material and installation costs because of the impermeable liner, but planning and site preparation is less expensive because there is no requirement for digging soil pits and infiltration testing which, when conducted according to specifications in the *LID Guide*, can account for over 8% of total costs in the other scenarios. In practice, soil infiltration capacity is often estimated more cheaply using soil texture and/or a more limited number of infiltration tests.

Table 3.1: Bioretention capital costs (130 m^2)

Input Parameters	Full Infiltration	Partial Infiltration	No Infiltration
Planning & Site Preparation	$6,652	$7,955	$4,048
Excavation	$2,087	$3,160	$2,551
Materials & Installation	$23,234	$30,361	$32,429
Total	$31,973	$41,476	$39,028

3.1.3 Life Cycle Costs

As mentioned in the previous chapter, life cycle costs were calculated based on three different discount rates. Net present values based on a discount rate of 5% are shown in Table 3.2. There are few data on the operation and maintenance of bioretention areas because only recently have they started to become more widely implemented. However, it was assumed that if the bioretention area was routinely maintained, it would need major rehabilitation only once in 25 years, at a cost of roughly $6345. This rehabilitation cost includes replacement of the filter media, re-mulching and replanting. Average costs of regular maintenance and landscaping are similar over the entire 50 year time period ($945 to $952). The exceptions are higher costs for watering and inspection in the early phases of plant establishment initially and after rehabilitation, and cleaning of underdrain pipes once every 10 years. Variation in present values is largely explained by differences in capital costs, as the maintenance and rehabilitation of the different scenarios was similar.

Table 3.2: Bioretention life cycle costs (130 m^2)

	Full Infiltration	Partial Infiltration	No Infiltration
Input Parameters			
Life span	25 years	25 years	25 years
Capital cost	$31,973	$41,476	$39,028
Rehabilitation cost at 25 years	$7,504	$7,504	$7,504
Annual maintenance	$945	$952	$952
Present Value including capital, maintenance and rehabilitation costs			
NPV at 50 years			
if i = 0 %	$86,716	$96,604	$94,156
if i = 3 %	$60,471	$70,146	$67,698
if i = 5 %	$52,183	$61,798	$59,350
NPV at 25 years			
if i = 0 %	$56,266	$65,923	$63,475
if i = 3 %	$49,228	$58,831	$56,383
if i = 5 %	$46,129	$55,709	$53,261

Note: i = discount rate

3.2 Permeable Pavement

Permeable pavements allow water to permeate through the surface or paver joints into a granular reservoir where water either infiltrates into the native soil and/or is released to a surface water body through a perforated underdrain. Various types of permeable pavements are available, including porous asphalt, pervious concrete, plastic grid pavers, and interlocking concrete permeable pavements (PICP). The PICP product was selected for costing in this project because it is currently the most common type used in Ontario, and the maintenance costs are well understood. As with bioretention, these pavements can be designed for full, partial or no infiltration and have been used to treat stormwater draining from an impervious pavement. In the scenarios described below, it is assumed that a 60 m x 16.7 m impermeable asphalt drains onto an equal sized area of permeable pavers. A concrete curb extending to the native soil separates the two types of pavements.

3.2.1 Model Scenarios and Designs

<u>Full infiltration</u>

The pavement can be designed for full infiltration if the underlying subsoil has a permeability of 15 mm/h or greater (after compaction). The base granular reservoir without underdrains is 350 mm deep, and is capable of storing runoff from a 61 mm rain event over the catchment area (Figure 3.4). Plastic edge restraints are used to prevent slumping of pavers along the edges and a monitoring well is included for inspection purposes.

<u>Partial infiltration</u>

A partial infiltration system is used where the post compaction permeability of the native subsoil is less than 15 mm/h. The system has the same depth as the full infiltration system, but an underdrain is included to ensure full drainage between rain events (Figure 3.5). The perforated pipe in this case is raised roughly 50 mm above the native subsoil to allow for some infiltration. Since the depth below the underdrain is only capable of storing runoff from a 9 mm event, a flow restrictor is sometimes included to retain water in the base above the perforated underdrain, and thereby promote greater infiltration. Since these restrictors are optional and relatively inexpensive, the cost of this feature has not been included.

<u>No infiltration</u>

No infiltration systems are applied when infiltration is not desirable. In this case, the pavement structure would help to filter contaminants but runoff would not be reduced. The primary additional feature is the impermeable liner that surrounds the pavement base and sides (Figure 3.6)

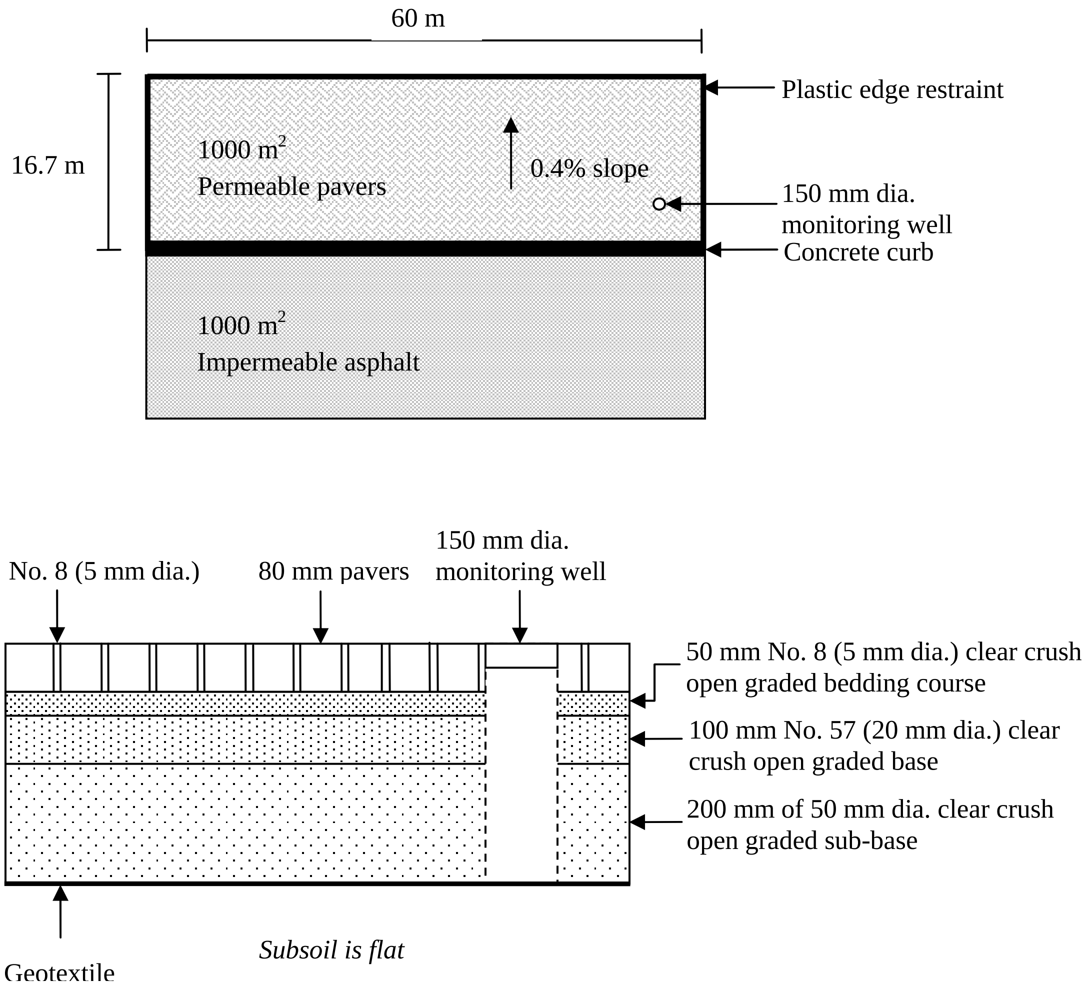

Figure 3.4: Permeable pavement full infiltration design. Plan view (top); cross section (bottom)

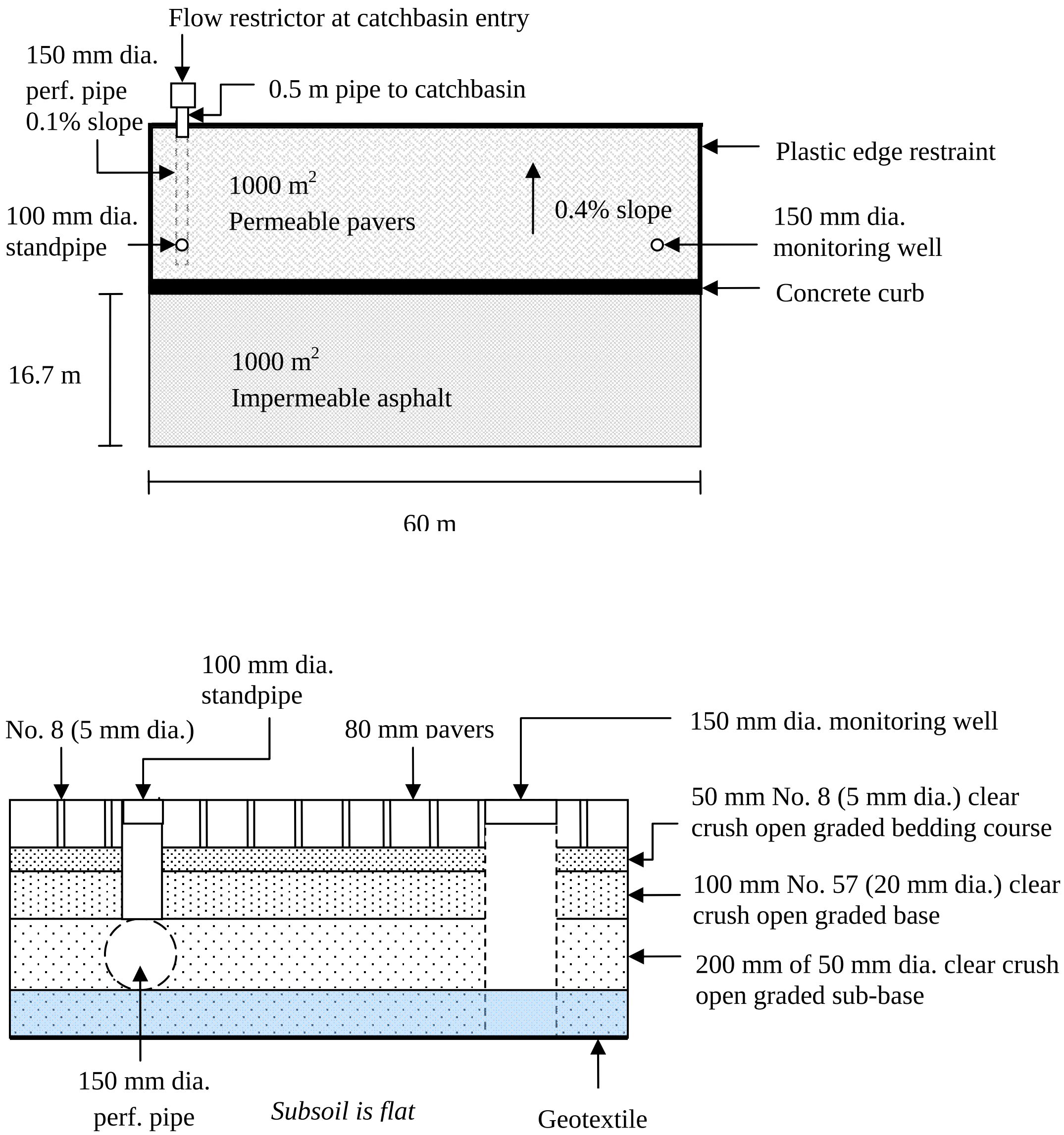

Figure 3.5: Permeable pavement partial infiltration design. Plan view (top); cross section (bottom)

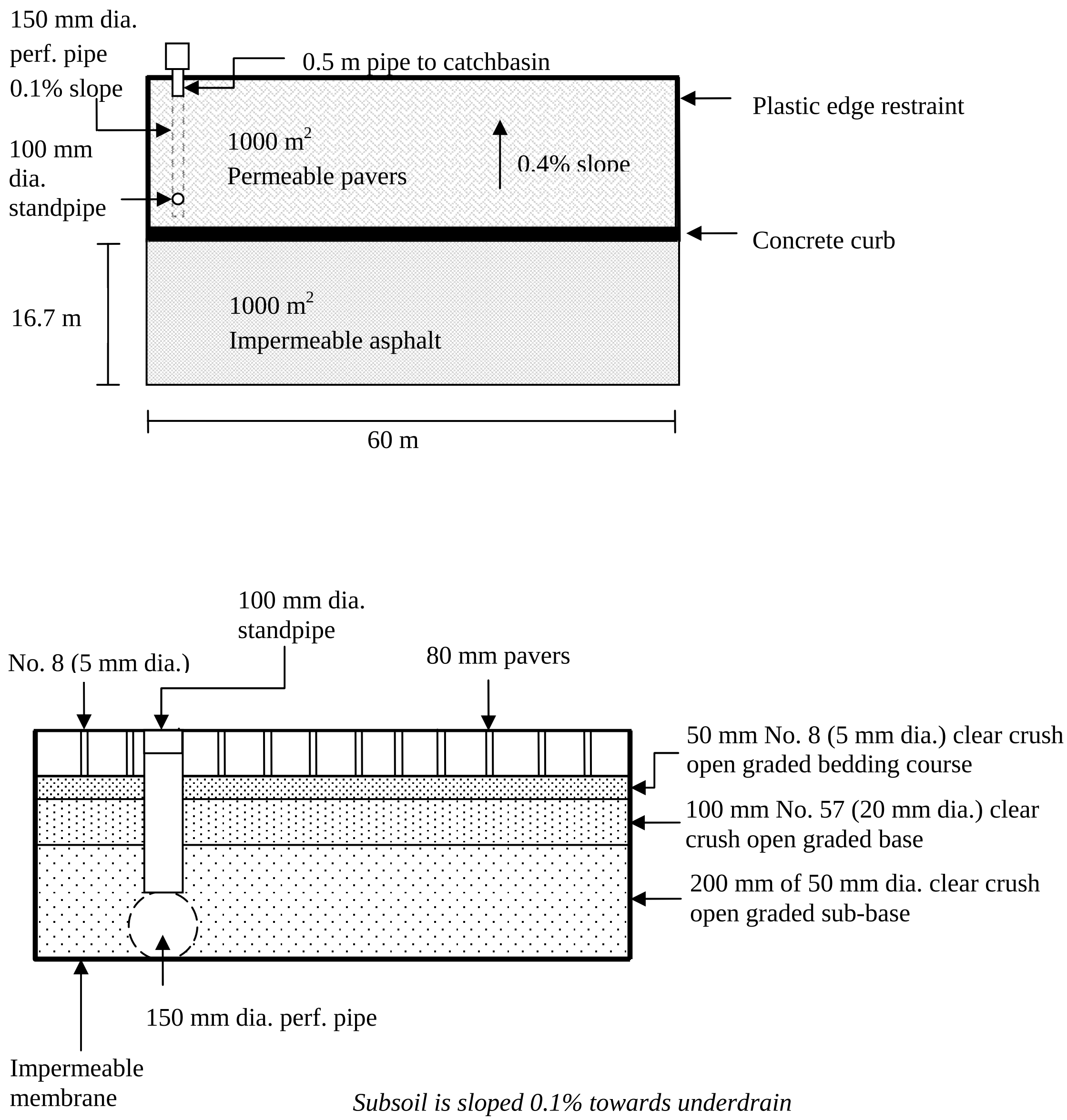

Figure 3.6: Permeable pavement no infiltration design. Plan view (top); cross section (bottom)

3.2.2 Capital Costs

General cost categories and totals for the three permeable pavement designs and a conventional asphalt (for comparison) are presented in Table 3.3. Detailed costs are provided in Appendix A. The presence of an underdrain made little difference in the overall cost. However, the addition of the impermeable liner in the 'no infiltration' scenario increased the cost considerably, even though test pits and infiltration measurements were not required (Table 3.3).

Table 3.3: Permeable pavement and conventional asphalt capital costs (1000 m^2)

Input Parameters	Permeable Interlocking Concrete Pavements			Asphalt
	Full Infiltration	Partial Infiltration	No Infiltration	
Planning & Site Preparation	$12,537	$12,659	$10,514	$4,714
Excavation	$5,584	$5,584	$5,584	$4,870
Materials & Installation	$80,192	$81,409	$94,055	$36,769
Total	$98,313	$99,652	$110,153	$46,353

The asphalt was assumed to be 50 mm thick and constructed over a 300 mm crusher run granular base. The total cost of asphalt was just less than half the price of permeable pavement for an equivalent area.

At this cost, the entire parking lot with 1000 m^2 of asphalt draining onto 1000 m^2 of a partial infiltration permeable pavement would be roughly $146,000. By comparison, the cost of a parking lot with a partial infiltration bioretention system and an asphalt drainage area would be $134,182 (2000 m^2 of asphalt + 130 m^2 bioretention). Although the capital cost of the bioretention stormwater control system is lower, the system requires 130 m^2 of additional space.

3.2.3 Life Cycle Costs

The life cycle costs for permeable pavements and asphalt are presented in Table 3.4. The paver costs are based on the assumption that the pavers would need to be replaced in 30 years, and that annual inspections, replacement of selected pavers, and periodic cleaning would cost on average $433 to $436. The cost of replacement is less than the initial installation cost because the base granular materials can be largely re-used, and there are no excavation costs. The asphalt costs assume a 25 year life cycle assuming it is well maintained, with annual patching and crack sealing costs of $1000 and seal coating every three years at a cost of $3580. Asphalt pavements that are not maintained in this fashion would have a shorter life.

At the 25 year period of evaluation, neither the permeable pavement nor asphalt would have been replaced. Higher permeable pavement present value costs over this time period largely reflect the higher initial capital costs. The present value cost differences narrow considerably over the 50 year evaluation period as the higher asphalt maintenance costs accumulate, particularly at low discount rates.

Table 3.4: Permeable pavement and conventional asphalt life cycle costs (1000 m^2)

Input Parameters	Permeable Interlocking Concrete Pavements			Asphalt
	Full Infiltration	Partial Infiltration	No Infiltration	
Life span	30 years	30 years	30 years	25 years
Capital cost	$98,313	$99,652	$110,153	$46,353
Replacement cost at 30 years (25 years for asphalt)	$72,990	$7,990	$72,990	$26,951
Annual maintenance	$433	$436	$436	$2,146
Present Value including capital, maintenance and rehabilitation costs				
NPV at 50 years				
if i = 0 %	$192,970	$194,462	$204,963	$180,584
if i = 3 %	$139,552	$140,968	$151,469	$113,887
if i = 5 %	$123,081	$124,472	$134,973	$92,812
NPV at 25 years				
if i = 0 %	$109,146	$110,562	$121,063	$99,993
if i = 3 %	$105,796	$107,185	$117,686	$83,382
if i = 5 %	$104,325	$105,703	$116,204	$76,117

Note: i = discount rate

3.3 Infiltration Trenches

Infiltration trenches consist of rectangular excavations filled with clean stone granular material. Runoff from the road or roof enters the system through a perforated pipe that conveys water to the trench where it can infiltrate into the subsoil. Pretreatment is required for road runoff. Unlike permeable pavement and bioretention, infiltration trenches and chambers are typically located under paved or landscaped areas. These practices are often used in tight spaces where surface areas are either not available or are designated for other uses.

3.3.1 Model Scenarios and Designs

Infiltration trenches are often designed similarly on low and high permeability soils because runoff is controlled at the entry point to the system, typically via a weir in a manhole or concrete chamber, allowing water to bypass the system when the trench or chamber system is full. Thus, the scenarios in this case do not include partial, full and no infiltration, but are instead divided according to the type of runoff received. Relatively clean runoff from roofs require considerably less pretreatment than runoff from roads. The addition of pre-treatment devices for road drainage can add considerably to the cost of the system.

<u>Roof Runoff</u>

In this scenario, runoff drains into a 2 x 51 m trench via a control manhole from a 2000 m^2 industrial or commercial roof (Figure 3.7). The footprint of the facility is approximately 1/20th the size of the roof. The system is 1.62 m deep (Figure 3.8) with the capacity to store runoff from a 29 mm rain event. Additional storage is available in the contributing storm sewer pipes. The invert of the overflow is located at 1.2 m below the surface to protect against frost. Other than a sump in the manhole, which allows for some settling of larger solids, there is no pre-treatment. Monitoring wells are provided to facilitate inspections.

Road and Roof Runoff

This scenario is identical to the previous one, but the drainage area consists of roof (500 m^2) and road runoff (1500 m^2), with pretreatment via a hydrodynamic separator for the road runoff portion (Figure 3.9 and 3.10). The roof runoff portion flows directly to the control manhole without pre-treatment. If the road and roof runoff were combined in the same sewer, the hydrodynamic separator would need to be larger.

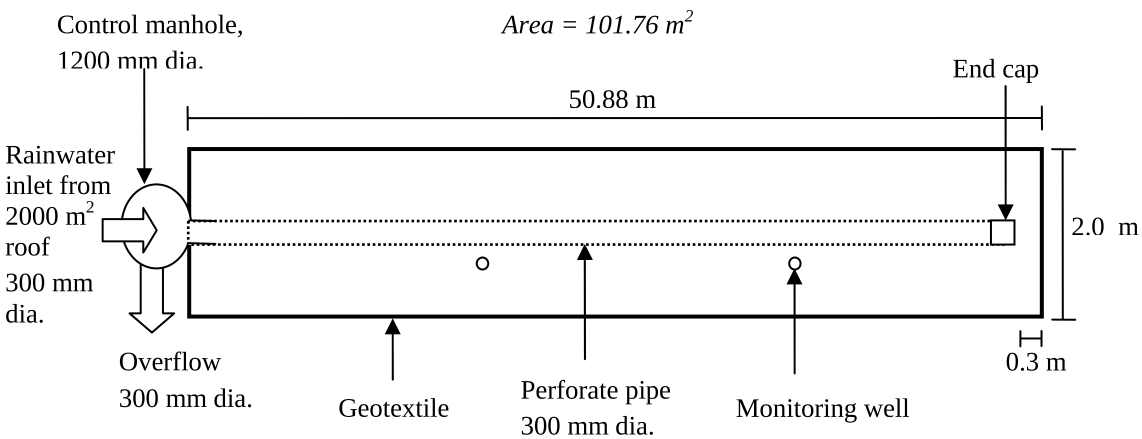

Figure 3.7: Plan view of the infiltration trench receiving roof runoff only

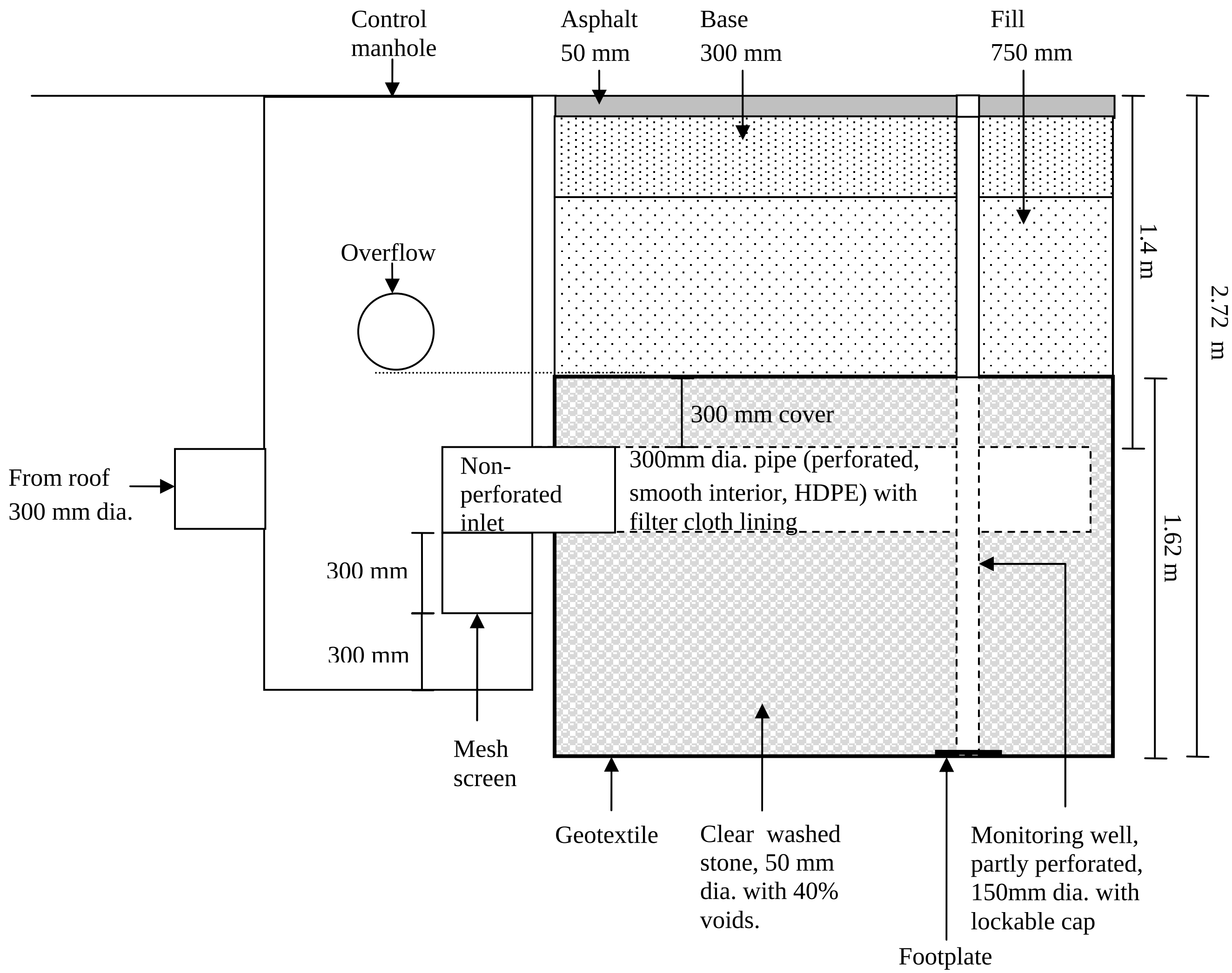

Figure 3.8: Cross section of infiltration trench receiving roof runoff only.

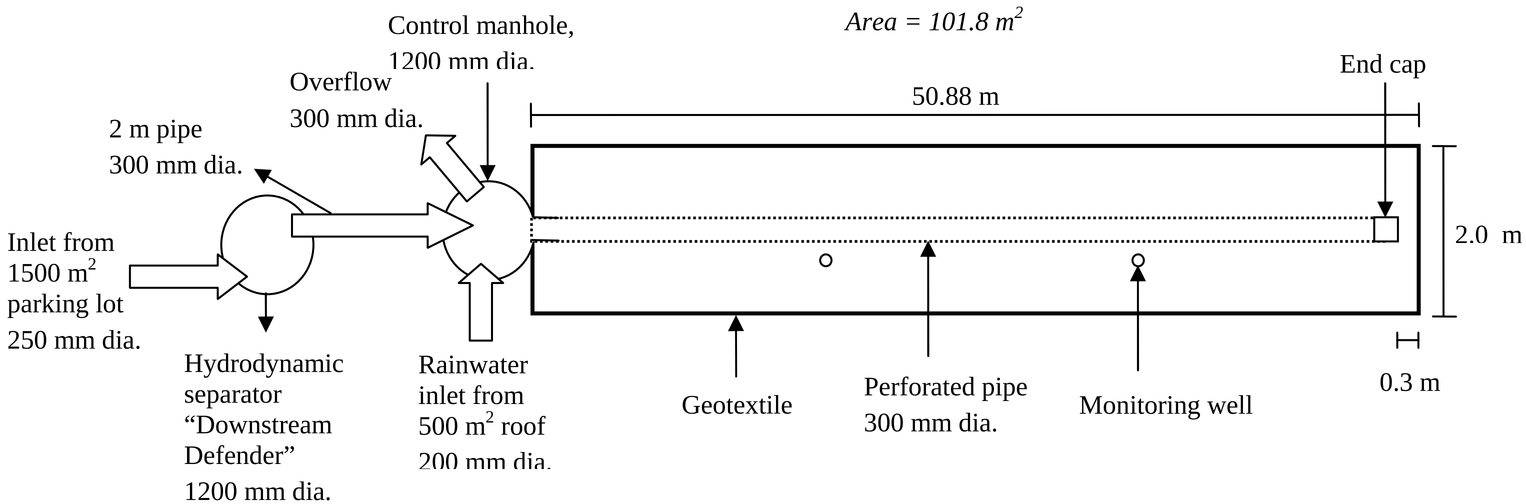

Figure 3.9: Plan view of the infiltration trench receiving road (1500 m^2) and roof runoff (500 m^2)

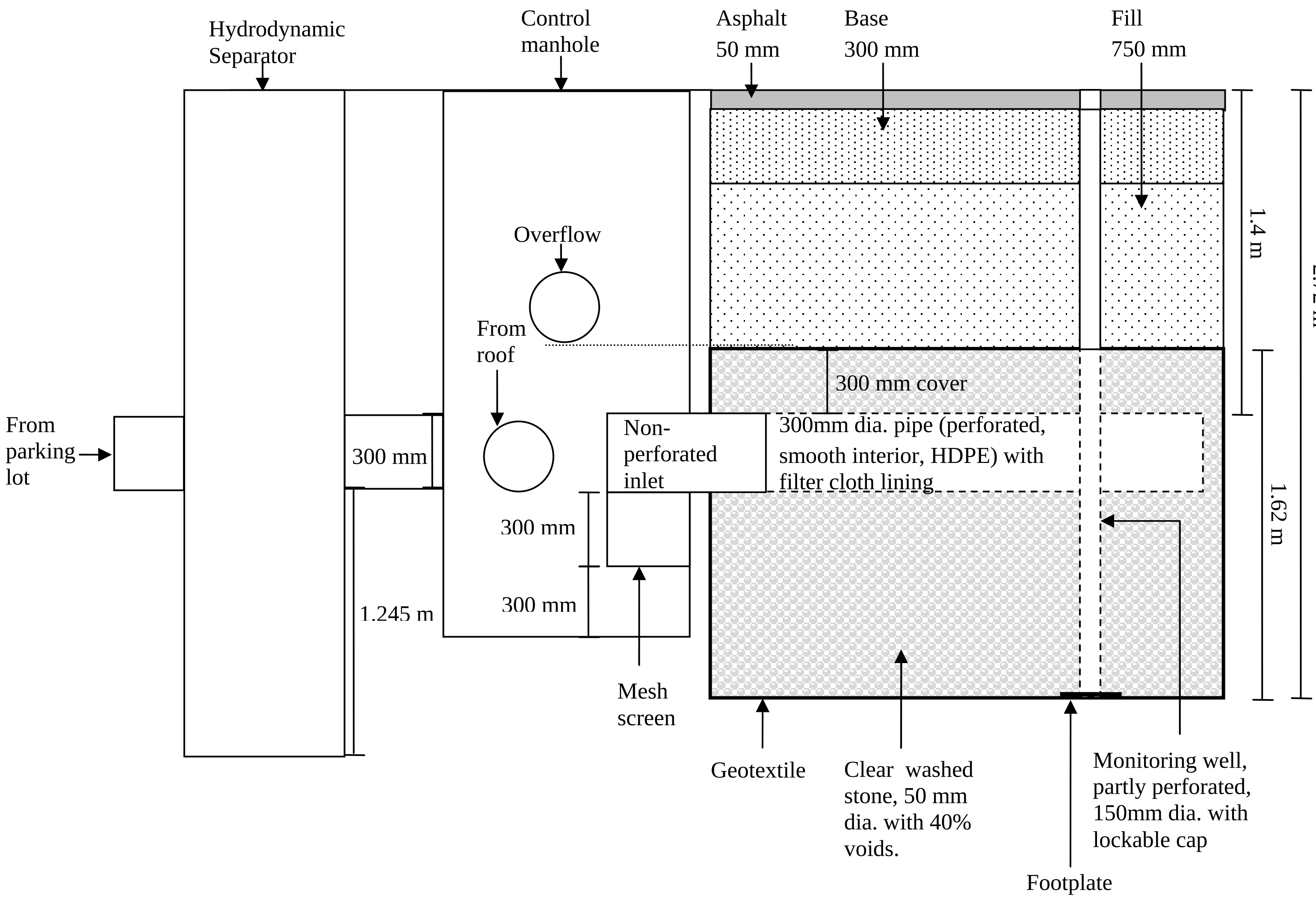

Figure 3.10: Cross section of the infiltration trench receiving road (1500 m^2) and roof runoff (500 m^2)

3.3.2 Capital Costs

The capital costs presented in Table 3.5 and Appendix A shows the road runoff scenario with pretreatment to be 63% more expensive than the roof runoff scenario due to the requirement for expensive pre-treatment via an Oil Grit Separator in the road runoff scenario. These results indicate that if only a portion of the runoff from a site is infiltrated, it is clearly cheaper to prioritize roof runoff for this purpose.

Table 3.5: Infiltration trench capital costs

Input Parameters	Roof Only	Road & Roof
Planning & Site Preparation	$7,436	$9,068
Excavation	$2,642	$2,642
Materials & Installation	$17,498	$33,824
Total	$27,575	$45,534

3.3.3 Life Cycle Costs

Studies have shown that infiltration trenches can continue to function well over long time periods (*e.g.* JF Sabourin and Associates, 2008). Hence it was assumed that, with adequate maintenance, replacement or major rehabilitation would not be required over the 50 year evaluation period. The road runoff scenario was considerably more expensive to maintain than the roof runoff scenario because the hydrodynamic separator requires regular inspections and vacuum removal of sediments. Also, the inner filter cloth held in place by expandable rings would need to be pulled out and changed every 8 years. Incorporating these higher maintenance costs increased the long term cost of the road runoff scenario to a 50 year present value equal to more than double that of the roof runoff scenario.

Table 3.6: Infiltration trench life cycle costs

	Roof Only	Road & Roof
Input Parameters		
Life span	50+ years	50+ years
Capital cost	$27,575	$45,534
Replacement cost	n/a	n/a
Annual maintenance	$74	$1,277
Present Value including capital, maintenance and rehabilitation costs		
NPV at 50 years		
if i = 0 %	$31,250	$109,384
if i = 3 %	$29,432	$77,810
if i = 5 %	$28,873	$68,090
NPV at 25 years		
if i = 0 %	$29,375	$77,134
if i = 3 %	$28,808	$67,127
if i = 5 %	$28,561	$62,760

Note: i = discount rate

3.4 Infiltration Chambers

A number of proprietary manufactured modular chambers are available as an alternative to infiltration trenches. These large open perforated structures create temporary storage of stormwater for infiltration (Figure 3.11). The chamber sections can be installed individually or in series in large trench formations. Since the chambers are empty, they are able to store more water than a stone filled trench over the same area.

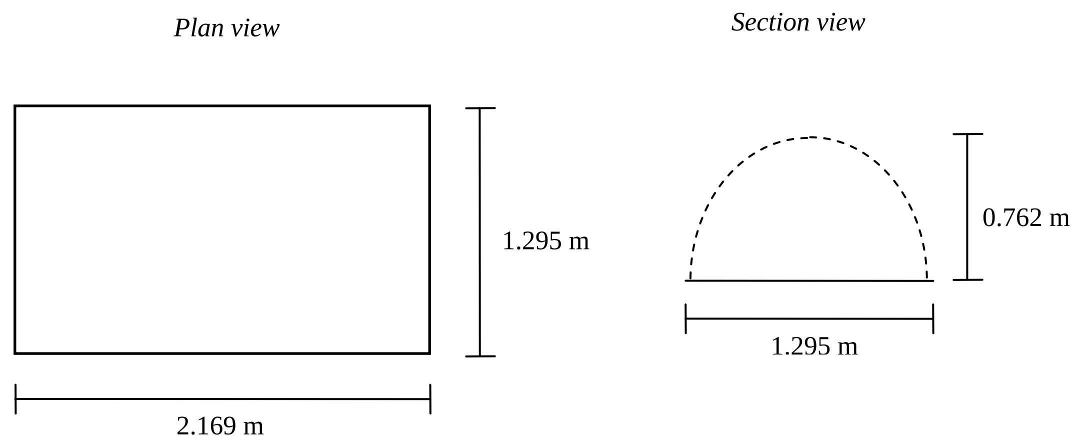

Figure 3.11: Sections of corrugated wall chambers

3.4.1 Model Scenarios and Designs

The two model scenarios are similar to those described earlier for infiltration trenches. The first scenario is for roof runoff, the second for a combination of roof and road runoff. As with trenches, the primary difference between the scenarios is the need for pretreatment in the road runoff scenario, which is accomplished by using an appropriately sized hydrodynamic separator.

<u>Roof runoff</u>

The footprint of the chamber is similar to the trench discussed in the previous section (1/20th of the drainage area), but the depth is 0.55 m shallower (Figure 3.12) because the empty chambers have the capacity to store a larger volume of water. Even with the shallower depth, however, the chambers have the capacity to store roughly one third more stormwater than the trench. The control manhole with weir is designed the same way as the trench to permit direct comparisons between the two practices.

<u>Road and roof runoff</u>

As with trenches, the drainage area is comprised of 25% roof and 75% road. A hydrodynamic separator is included to provide pre-treatment for the road runoff portion. Roof runoff is directed to the control manhole in the same manner as the previous scenario, since the cleaner roof water requires less pre-treatment.

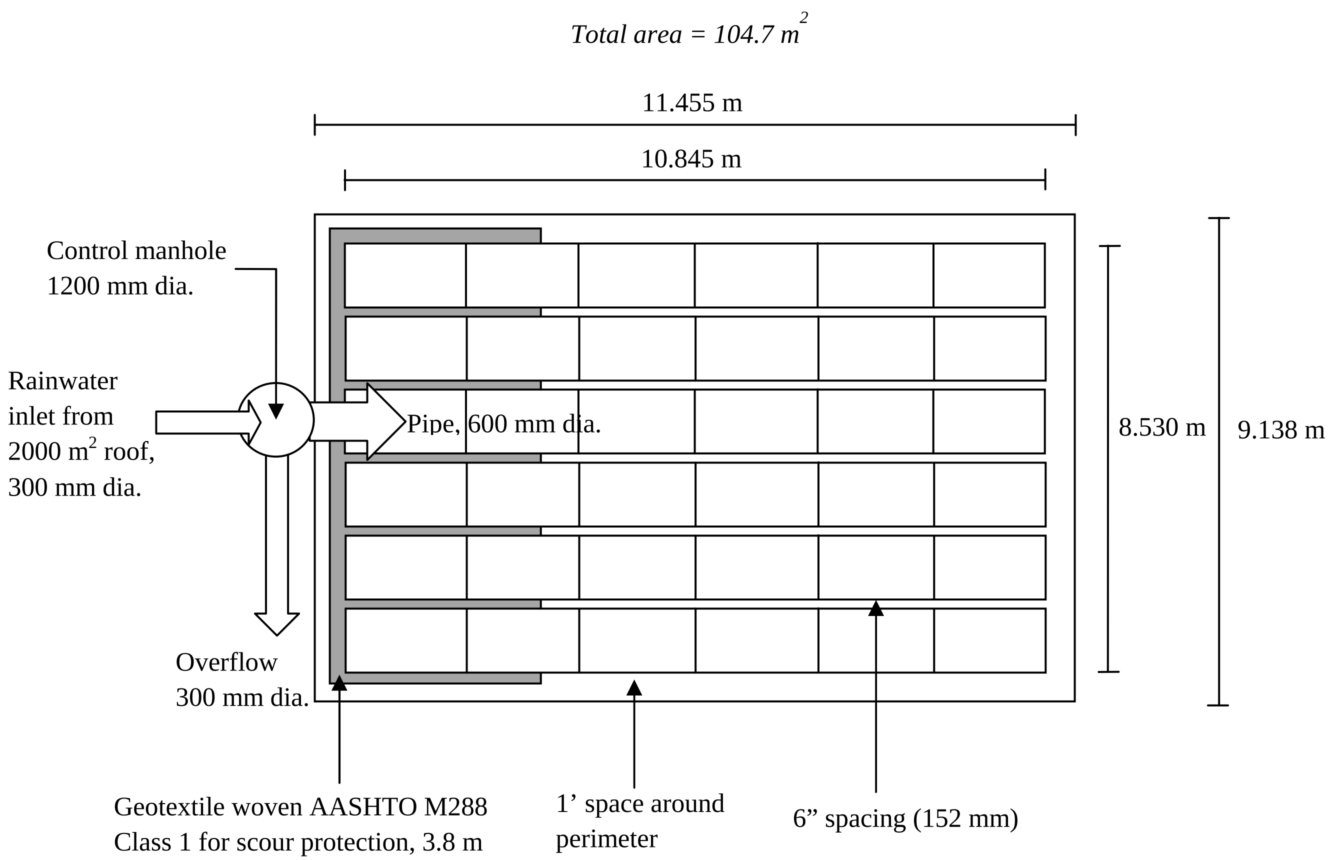

Figure 3.12: Plan view of infiltration chambers receiving roof runoff only

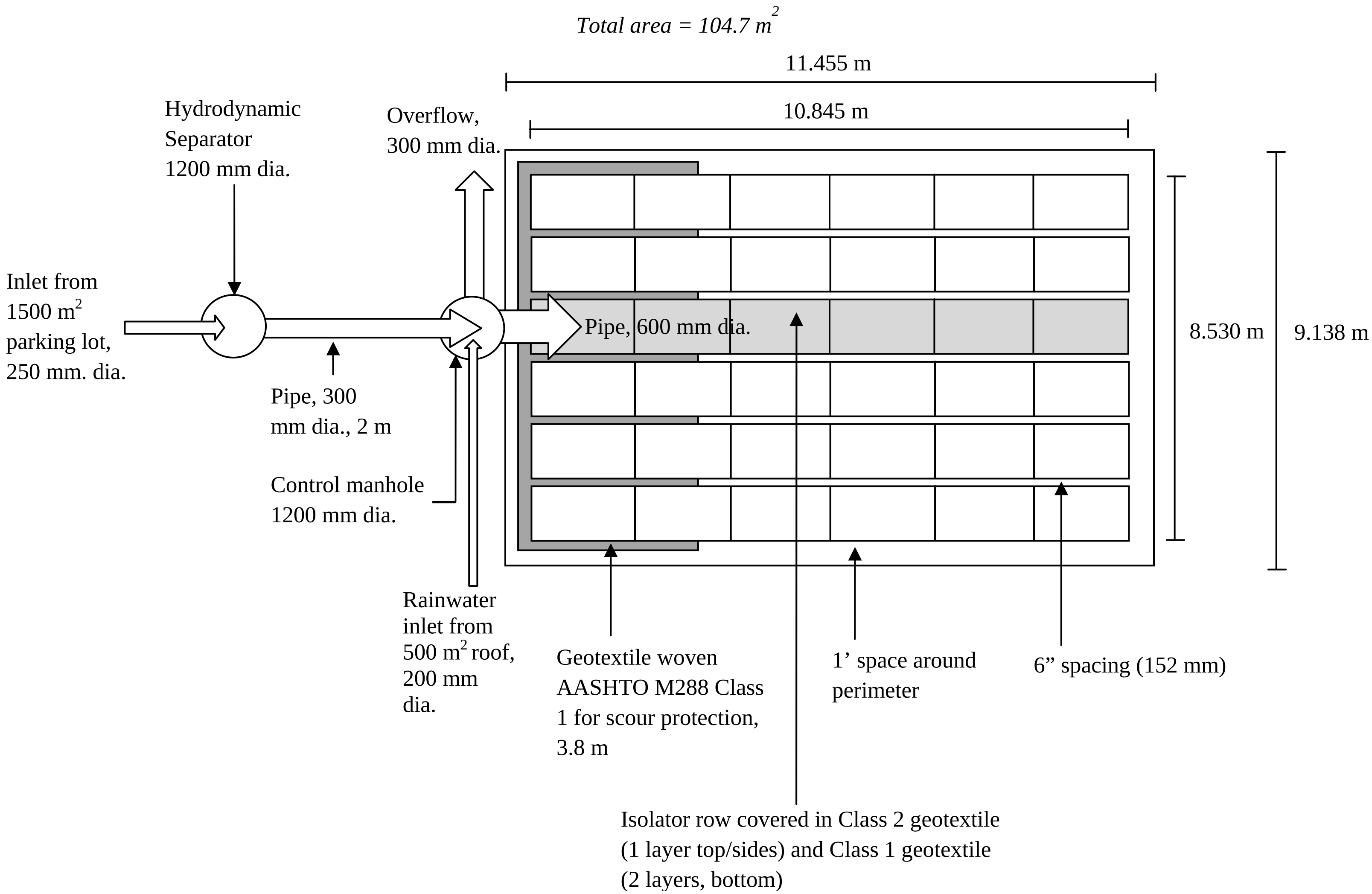

Figure 3.13: Plan view for infiltration chambers receiving road (1500 m^2) and roof runoff (500 m^2)

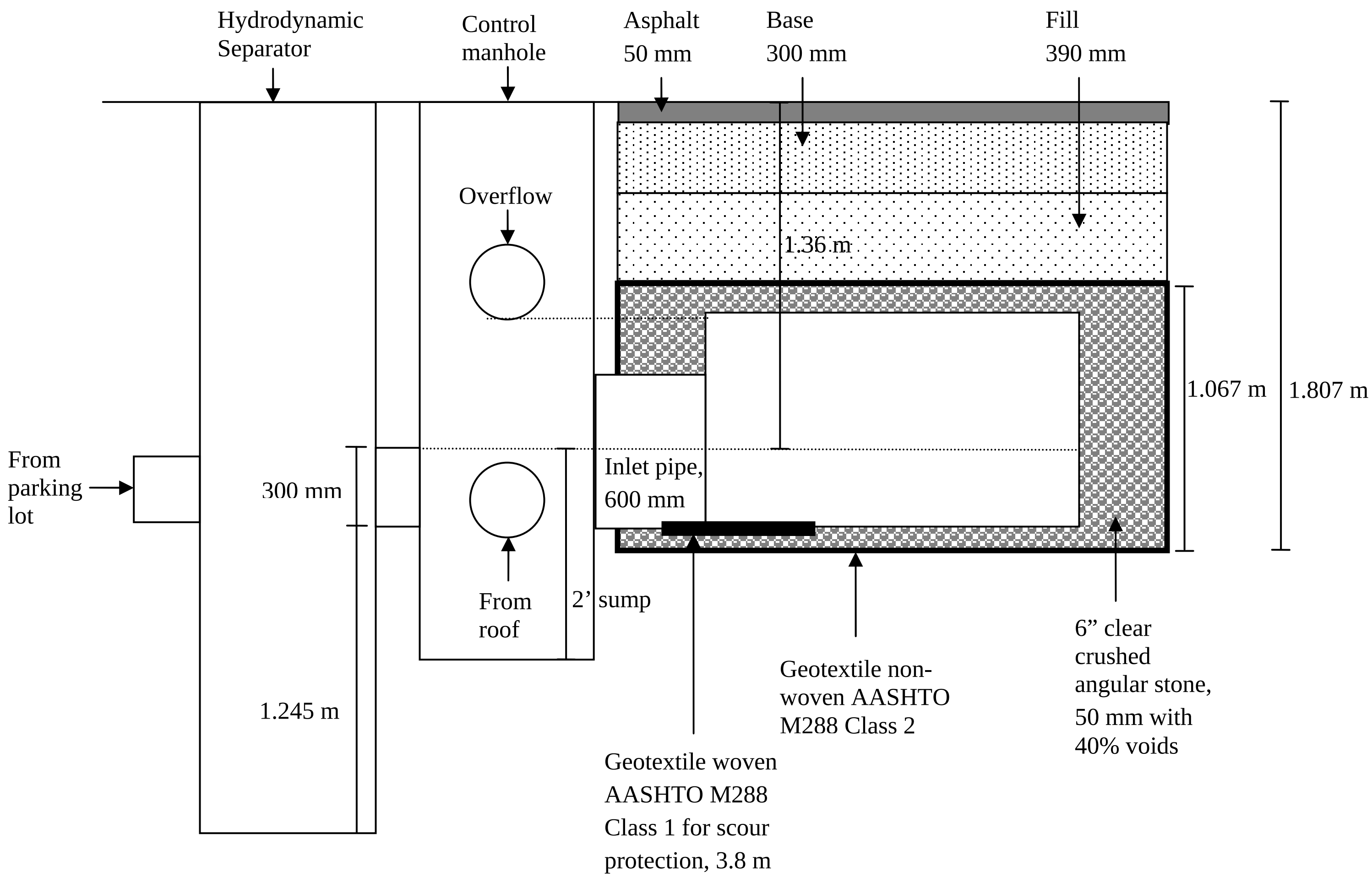

Figure 3.14: Cross section of infiltration chambers receiving road (1500 m^2) and roof runoff (500 m^2)

3.4.2 Capital Costs

The capital cost of the road/roof runoff scenario was 70% more than that of the roof runoff scenario because the former required expensive pre-treatment via a hydrodynamic separator (Figure 3.13). Chamber materials are more expensive than clear stone, but savings on perforated pipes and other installation expenses resulted in the two practices having very similar material and installation costs. Overall, the infiltration chamber costs were only slightly higher than the infiltration trench costs discussed in the previous section. The benefit of chambers, however, is that these provide considerably more storage per unit area than a simple gravel filled trench.

Table 3.7: Infiltration chambers capital costs

Input Parameters	Roof Only	Road & Roof
Planning & Site Preparation	$5,723	$7,373
Excavation	$2,141	$2,141
Materials and Installation	$17,683	$34,192
Total	$25,547	$43,706

3.4.3 Life Cycle Costs

The underground chambers were expected to last at least 50 years if they were adequately maintained, and therefore replacement costs were not applied. Costs of maintenance were very low for the roof runoff scenario because maintenance activities were limited to cleaning out the control manhole once per year. The hydrodynamic separators in the road/roof runoff scenario required inspection, cleanout and sediment disposal, which resulted in an average annual maintenance cost of $1,212. Overall net present value costs for the road/roof runoff scenario were well over double that of the roof runoff scenario. Maintenance costs for the trenches and chamber system were expected to be the same, hence NPV differences between the two practices were a result of differences in the initial capital cost alone.

Table 3.8: Infiltration chambers life cycle costs

	Roof Runoff	Road and Roof Runoff
Input Parameters		
Life span	50+ years	50+ years
Capital cost	$25,547	$43,706
Replacement cost	na	na
Annual maintenance	$74	$1,212
Present Value including capital, maintenance and rehabilitation costs		
NPV at 50 years		
if i = 0 %	$29,222	$104,306
if i = 3 %	$27,404	$74,269
if i = 5 %	$26,845	$65,038
NPV at 25 years		
if i = 0 %	$27,347	$73,406
if i = 3 %	$26,780	$64,008
if i = 5 %	$26,533	$59,909

Note: i = discount rate

3.5 Enhanced Grass Swales

Enhanced swales are designed to detain, infiltrate and convey flows to the storm sewer system or directly to the receiving water. Check dams help slow and filter water to enhance sedimentation, soil infiltration and evapotranspiration by plants and/or grasses. Unlike dry swales, they do not incorporate an engineered soil media mix and optional underdrain. Therefore, this practice does not usually provide the same runoff reduction and water quality benefits as a dry swale or bioretention system.

Swales and open channels are often used adjacent to roadways. They can also be used along the perimeter of parking lots and other impervious drainage areas. Swales can be planted with grass or other herbaceous plants, with rainwater entering either through curb cuts or as sheet flows.

3.5.1 Model Design and Scenarios

In the model scenario, runoff enters the swale as sheetflow through curb cut inlets. The swale is planted with grass and check dams are provided at 30 m intervals. Check dams can be made of different materials. The cost of three options were evaluated – concrete curbs, compost filter socks, and rocks. The swale footprint is one tenth the size of the drainage area. Culverts are used to convey water below driveways or sidewalks, and a culvert at the downstream end of the swale conveys water to the conventional sewer system.

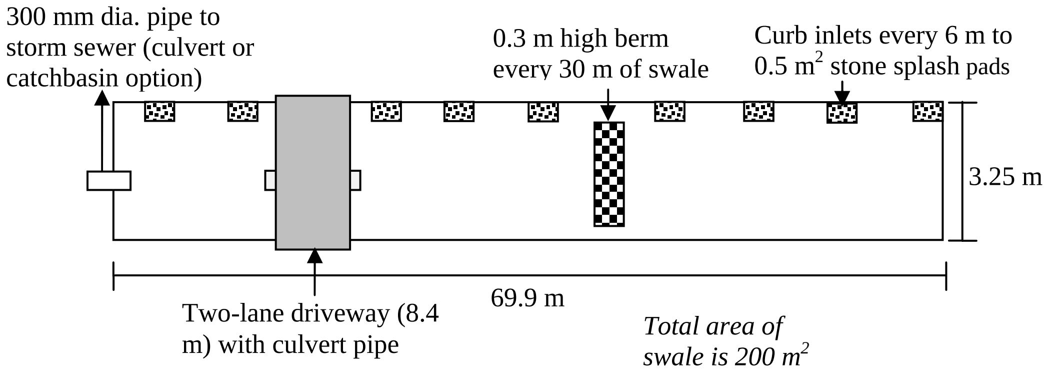

Figure 3.15: Plan view of enhanced grass swale. Drainage area is 2000 m^2

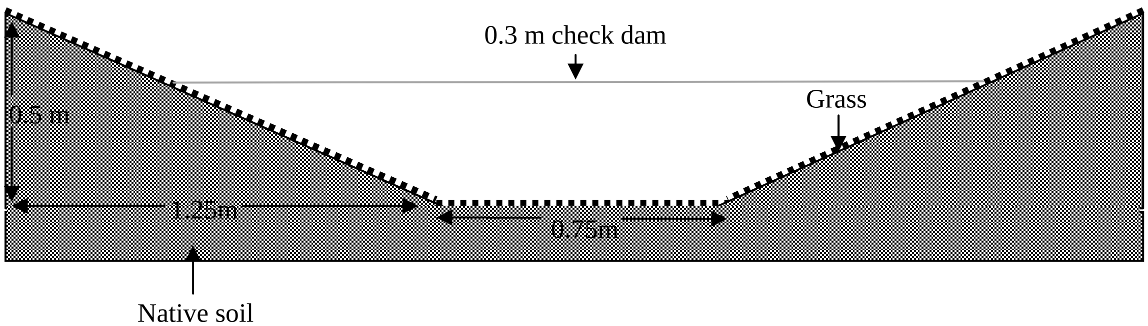

Figure 3.16: Cross section of enhanced grass swale

3.5.2 Capital Costs

Enhanced swales are one of the least expensive stormwater practices because they do not require significant excavation, and include pipes only at driveway or road crossings, and at the downstream connection to the storm sewer system. The curbs and curb cuts added significantly to the overall cost (see Appendix A). These are not necessary in swale designs where runoff enters the swale as sheet flow across its full length. Parking wheel stops or bollards can be used to prevent vehicle damage to the swale. Removal of the curbs and gutters from the model design would save approximately $5500. There was only a minor difference in cost between the different check dam options.

Table 3.9: Enhanced grass swale capital costs

Input Parameters	Curb check dam	Filter sock check dam	Rock check dam
Planning & Site Preparation	$5,726	$5,694	$5,705
Excavation	$1,455	$1,455	$1,455
Materials and Installation	$11,401	$11,084	$11,187
Total	$18,582	$18,233	$18,347

3.5.3 Life Cycle Costs

Maintenance of enhanced swales consists of regular inspections, watering, litter and sediment removal, and mowing. Grass may also need to be restored periodically. These routine costs add significantly to the overall long term costs, but the practice remains one of the least expensive LID practices evaluated in this study.

Table 3.10: Enhanced grass swale life cycle costs

	Curb check dam	Filter sock check dam	Rock check dam
Input Parameters			
Life span	50+ years	50+ years	50+ year
Capital cost	$18,582	$18,233	$18,347
Replacement cost	n/a	n/a	n/a
Annual maintenance	$500	$500	$500
Present Value including capital, maintenance and rehabilitation costs			
NPV at 50 years			
if i = 0 %	$43,567	$43,218	$43,333
if i = 3 %	$32,351	$32,003	$32,117
if i = 5 %	$28,874	$28,525	$28,639
NPV at 25 years			
if i = 0 %	$32,011	$31,662	$31,777
if i = 3 %	$28,505	$28,156	$28,270
if i = 5 %	$26,947	$26,598	$26,712

Note: i = discount rate

3.6 Rainwater Harvesting

The term *Rainwater Harvesting* (RWH) refers to the ancient practice of collecting rainwater from roofs or other impermeable surfaces for future use in satisfying daily water needs. A RWH system typically consists of three basic elements: the collection system (such as a roof), the conveyance system (infrastructure that transports the water), and the storage system (above or below ground cistern); however in larger systems or ones designed to produce potable water, a pressurized or non-pressurized water discharge system and pre/post treatment unit is usually included. In most cases, a cistern overflow draining to an infiltration basin or municipal sewer system is necessary in order to prevent system backups.

3.6.1 Model Scenarios and Designs

The RWH scenarios selected for detailed costing are applicable to large commercial, industrial or institutional contexts, which are currently the most common type of system installed within the Greater Toronto Area. Both scenarios were developed using a RWH sizing and costing tool developed in 2009 by the University of Guelph, Connect the Drops and TRCA to facilitate wider adoption of RWH systems in Ontario (STEP, 2011). The tool uses RS Means databases for costing and optimal cistern sizing based on local rainfall data for the GTA and recommendations provided in recent guidelines on RWH in Ontario.

Concrete cistern outside

The first scenario consists of a 23,000 L concrete cistern buried adjacent to the building with dual plumbing distribution, an 81.2 LPM submersible pump, and a 439 L expansion tank. The system also includes a float switch to prevent the pump from dry running, a top-up float switch and associated wiring, a solenoid valve, air gap to prevent backflow, as well as backflow preventer at the premise boundary, a water meter and water hammer arrestor. In the portion of the building using the rainwater cistern for toilet flushing there were 260 occupants and two hose bibs were used on average 14 minutes per day from April to September.

Plastic tank inside

The plastic tank is also 23,000 L, but is stored inside the building. It was costed out volumetrically and therefore could consist of one large unit or several smaller units, depending on space constraints. Many of the same features in the concrete cistern case would apply here as well, but since the cistern is inside, there would be no need for excavation.

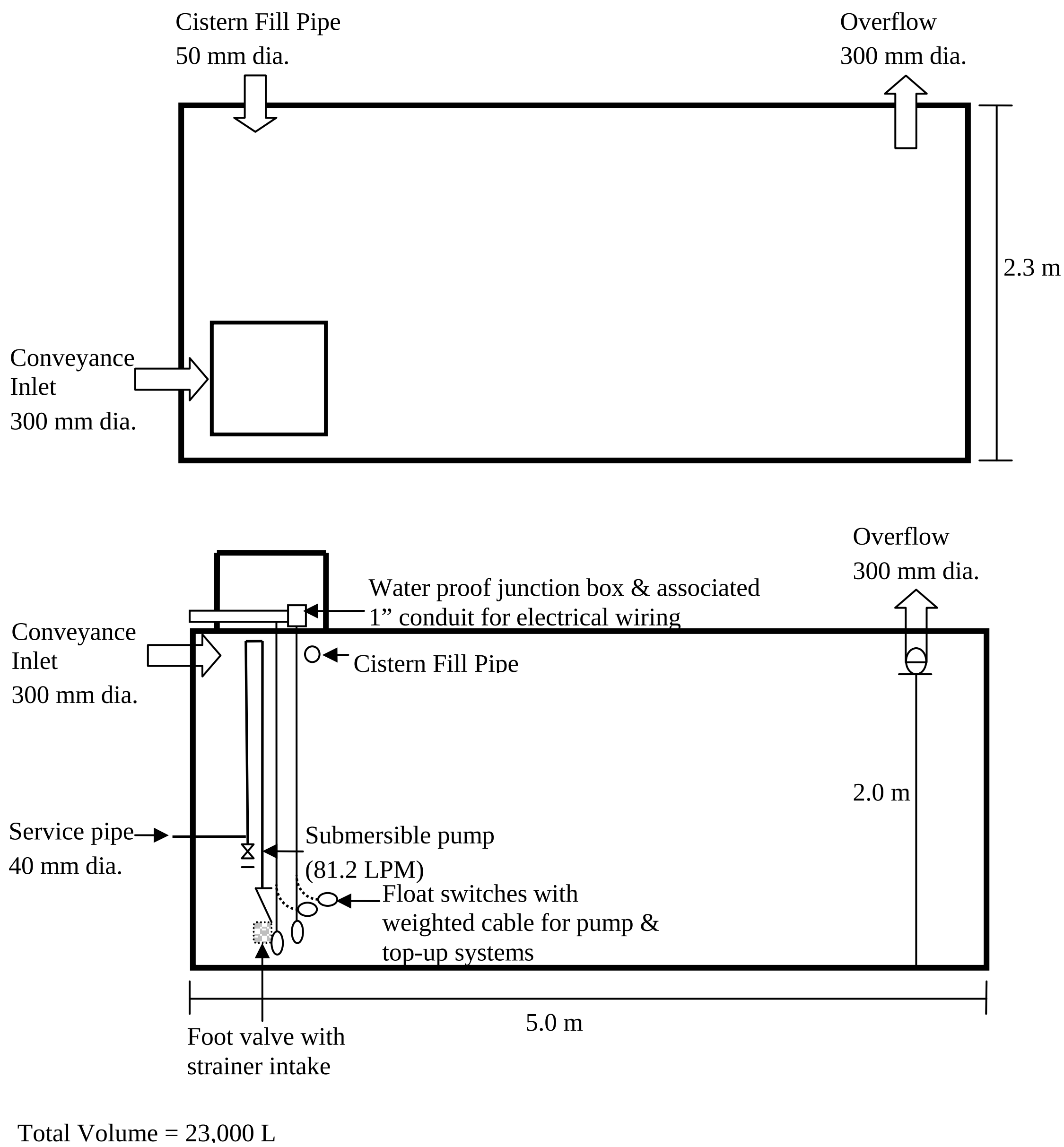

Figure 3.17: Pre-cast concrete tank design

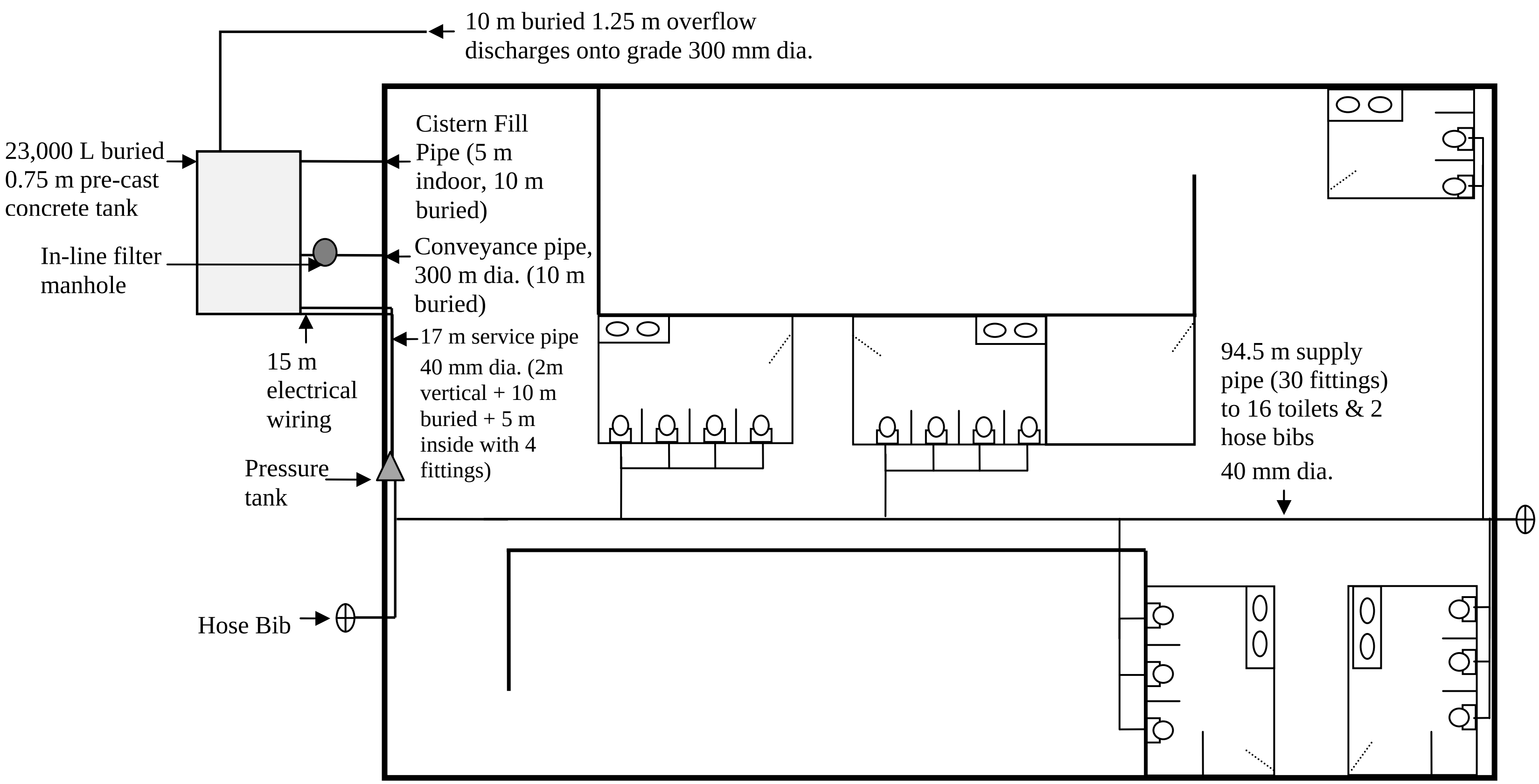

Figure 3.18: Site design for buried pre-cast concrete tank

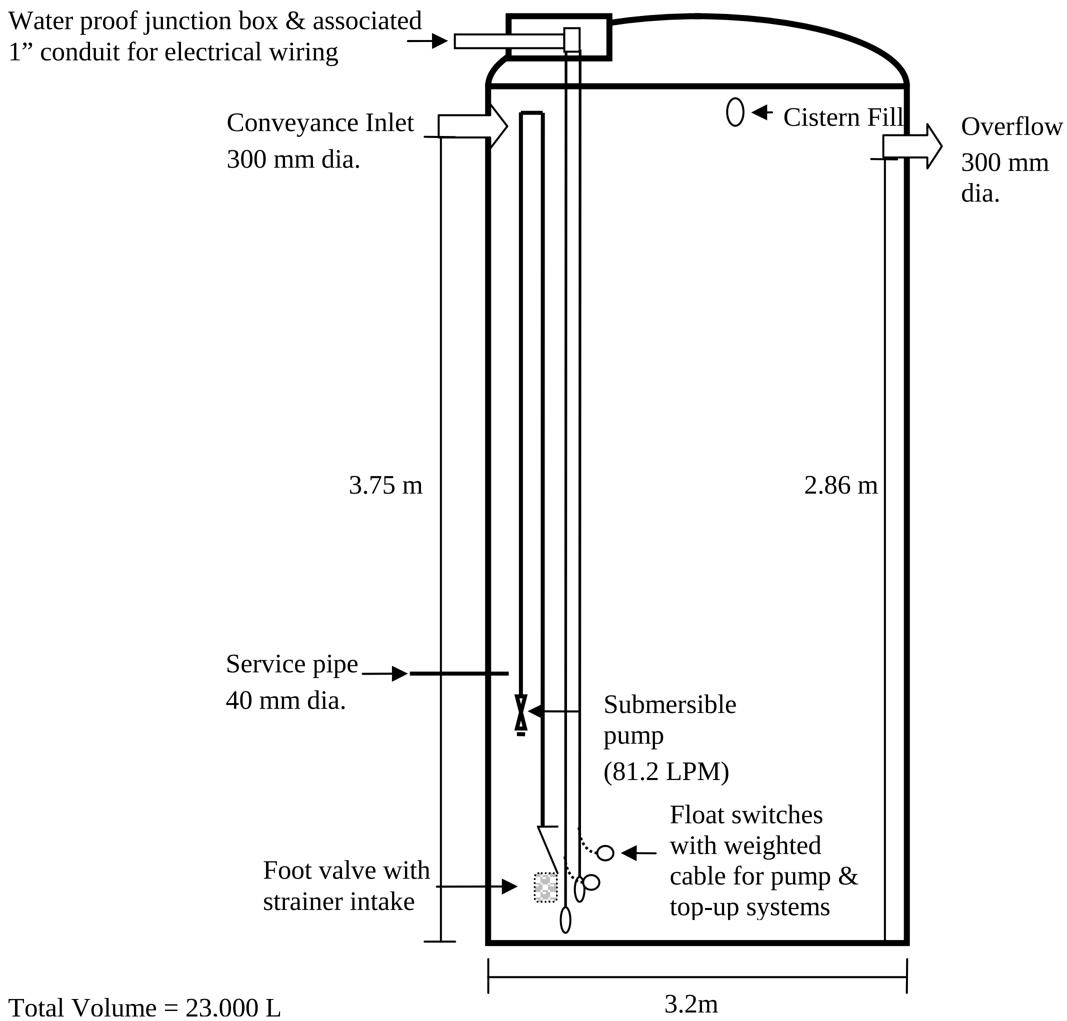

Figure 3.19: Plastic tank design

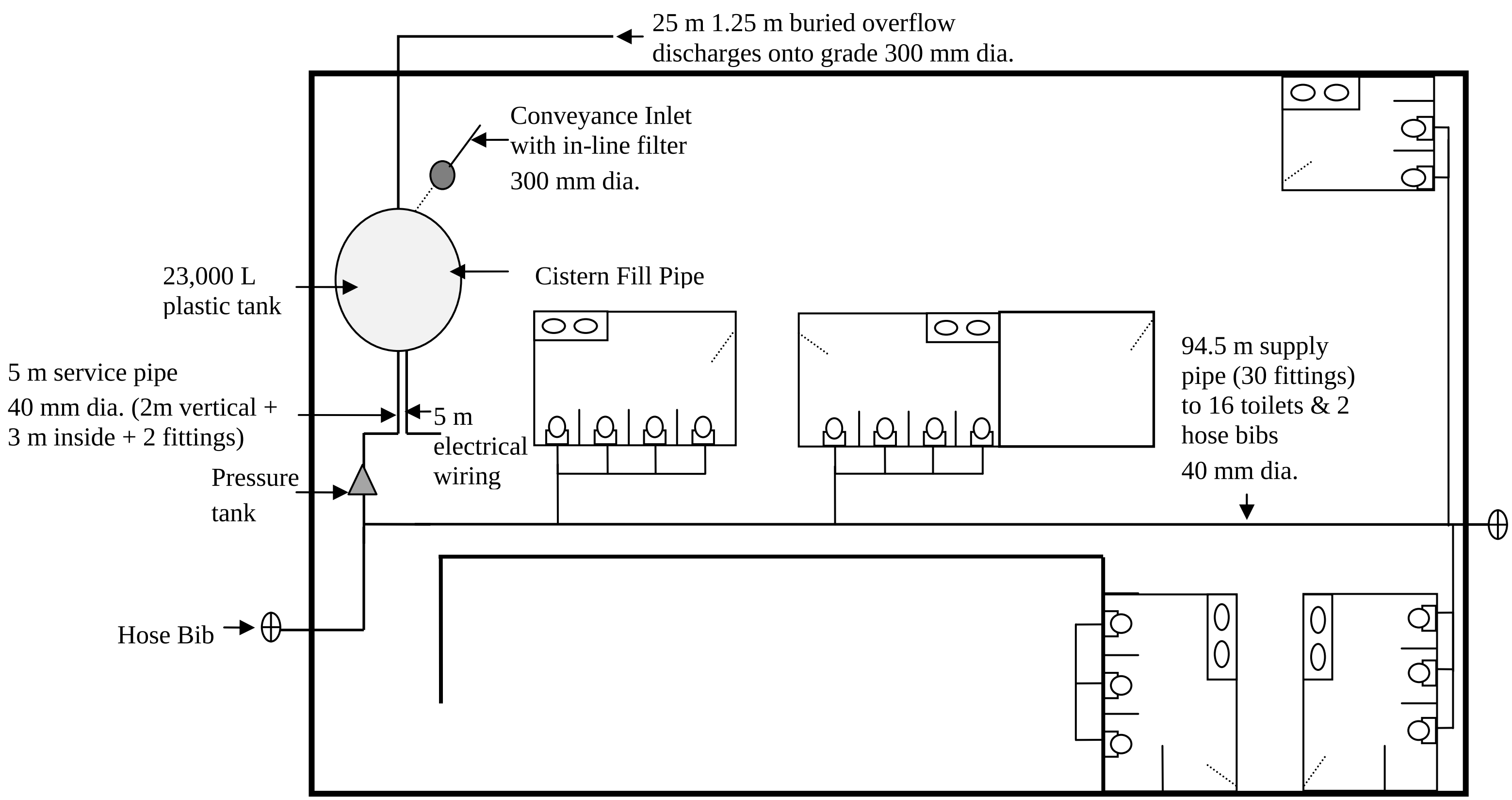

Figure 3.20: Site design for indoor plastic tank

3.6.2 Capital Costs

The concrete tank cost more than the plastic tank, primarily due to the added costs for excavation (Table 3.11). The trench and piping for the overflow cost more for the plastic tank because it was assumed that it would be further from the discharge point and therefore needed to be double the length. Most of the major costs for the tank, pump and piping were similar.

Table 3.11: Rainwater harvesting capital costs

Input Parameters	Concrete Tank Outdoor	Plastic Tank Indoor
Planning & Site Preparation	$4,794	$3,694
Excavation	$1,244	$0
Materials & Installation	$41,199	$36,943
Total	$47,237	$40,637

3.6.3 Life Cycle Costs

In the life cycle cost estimates shown in Table 3.12 the plastic tank is replaced in year 40, at a cost of $7,170, whereas the concrete cistern is assumed to last longer. Average annual maintenance costs are the same in the two scenarios at roughly $744. The requirement for replacing the plastic tank brings the net present values of the two scenarios closer together, with the plastic tank being only slightly less expensive at a 0% discount rate over the 50 year evaluation period.

Table 3.12: Rainwater harvesting life cycle costs

	Concrete Tank Outdoor	Plastic Tank Indoor
Input Parameters		
Life span	50+ years	40 years
Capital cost	$47,237	$40,637
Replacement cost at 40 years	na	$5,970
Annual maintenance	$744	$744
Present Value including capital, maintenance and rehabilitation costs		
NPV at 50 years		
if i = 0 %	$84,451	$83,821
if i = 3 %	$66,088	$61,318
if i = 5 %	$60,140	$54,388
NPV at 25 years		
if i = 0 %	$65,844	$59,244
if i = 3 %	$59,519	$52,919
if i = 5 %	$56,754	$50,154

Note: i = discount rate

3.7 Extensive Greenroof

Greenroofs are typically classified as either extensive or intensive. Extensive greenroofs support low growing plants and have substrate depths ranging from 5 to 15 cm. A greenroof with a substrate deeper than 15 cm is normally defined as intensive. Extensive roofs are much more common and were therefore selected as the basis for detailed costing in this project.

A green roof assembly usually consists of the following components above the roofing membrane: a root-resistant layer to minimize root damage to the membrane; a drainage layer to remove excess water from the drainage medium; a filter fabric to prevent fine particles in the growing medium from clogging the drainage layer; a growing medium to support healthy plant growth, and plants selected for their adaptability to local climate conditions. An irrigation system may also be needed depending on the type of plants selected.

3.7.1 Model Scenarios and Designs

The scenarios selected for model costing include inexpensive and more expensive variations of an extensive green roof. Since green roofs are usually installed on gently sloping roofs, both scenarios assume a roof slope of 2%. As with other practices, it is assumed that the green roof is installed as part of the original new building design (i.e. not a retrofit).

<u>‘Cheap’ system</u>

The inexpensive system involves installing a sedum cutting system with a 10 cm growing medium on a building less than 5 stories high, which makes it easier to get the plants and green roof materials onto the roof. This scenario does not include pathways, fencing or other features that help improve accessibility. The water leakage test is a simpler, less expensive test than the more sophisticated methods. A TPO waterproof membrane is used.

<u>Expensive system</u>

In this scenario, the building is over 5 stories tall, the waterproof membrane is more expensive and a sophisticated water leakage test is performed. It also includes a root barrier, an irrigation system, more expensive edging and a 15 cm growing medium. Plants are in the form of sedum mats, which are much more expensive than sedum plugs or cuttings. A more expensive EPDM waterproof membrane was used in this scenario.

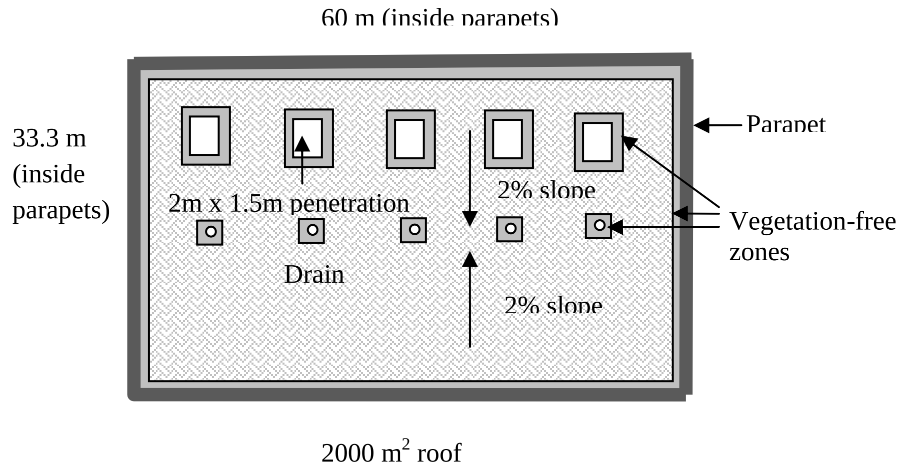

Figure 3.21: Plan view of greenroof design

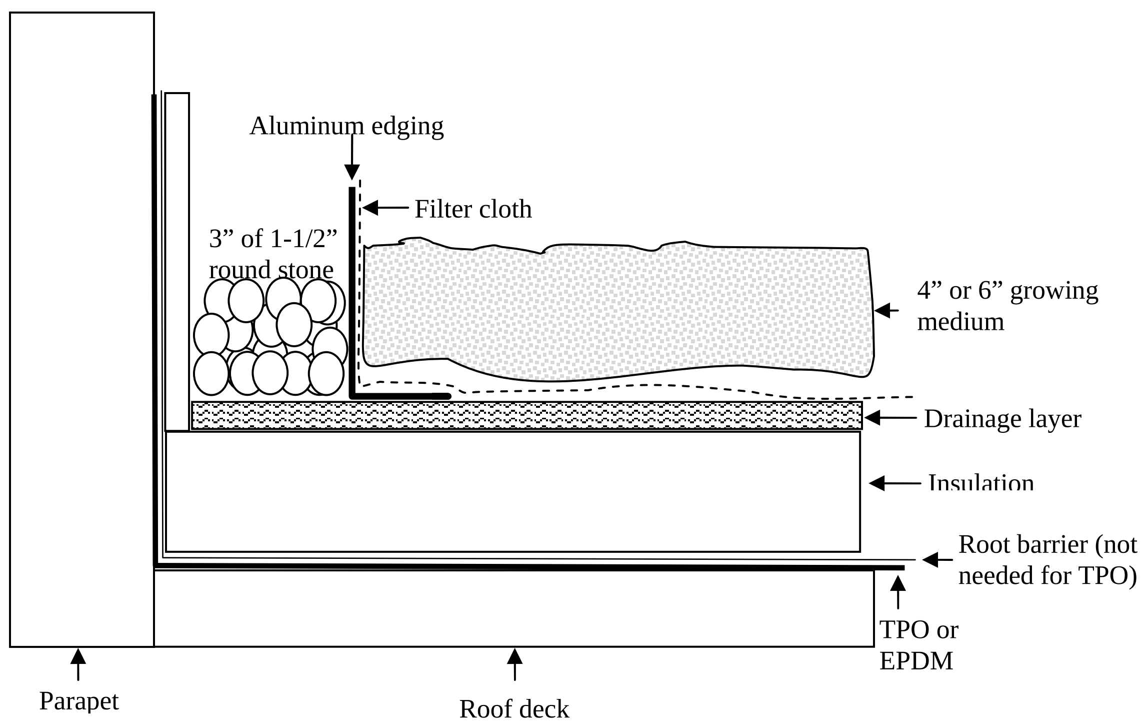

Figure 3.22: Cross section of greenroof design

3.7.2 Capital Costs

The capital cost breakdown shown in Table 3.13 and Appendix A shows how the differences between the two scenarios affect the overall price of the systems. The expensive system is more than twice the cost of the cheap system, mostly due to differences in the cost of materials. The membrane represents a significant component of the cost, but since all roofs require membranes, it should not be regarded as a cost that is unique to green roofs. Only the 'expensive' green roof has a specialized membrane that would be more costly than a conventional roof.

Table 3.13: Extensive greenroof capital costs

Input Parameters	Cheap		Expensive	
	With Membrane	Without Membrane	With Membrane	Without Membrane
Planning & Site Preparation	$21,341	$10,163	$44,804	$31,693
Craning	$13,897	$9,265	$56,676	$51,524
Materials & Installation	$196,040	$90,631	$371,430	$255,441
Total	$231,278	$110,060	$472,909	$338,658

Detailed costs for conventional roofs were not calculated in this project. However, these were estimated in an earlier study (STEP, 2007) that compared the life cycle cost of green roofs to conventional roofs under various scenarios. In that study, the initial capital cost of a new conventional roof of an equivalent area (2000 m^2) was estimated to be a minimum of $172,000, not including the roof deck. Accordingly, a green roof would add at least $59,278 to the initial capital cost of the roof. These extra initial costs would be recouped to some extent by the green roof's much longer life and other energy, stormwater and biodiversity benefits.

3.7.3 Life Cycle Costs

The life span of the green roofs was estimated to be 40 years regardless of the scenario. The less expensive scenario had much lower replacement costs, but the $308 higher annual maintenance costs resulted in a similar net present value for overall maintenance and rehabilitation (assuming a 5% discount rate). The discount rate is a particularly important factor in these scenarios because the high replacement costs play a significant role in the overall Net Present Value calculations.

Table 3.14: Extensive greenroof life cycle costs

Input Parameters	Cheap		Expensive	
	With Membrane	**Without Membrane**	**With Membrane**	**Without Membrane**
Life span	40 years	40 years	40 years	40 years
Capital cost	$231,278	$110,060	$472,909	$338,658
Replacement cost at 40 years	$373,628	$209,187	$613,542	$436,068
Annual maintenance	$2,022	$1854	$1,714	$1546
Present Value including capital, maintenance and rehabilitation costs				
NPV at 50 years				
if i = 0 %	$706,022	$411,947	$1,172,167	$852,026
if i = 3 %	$413,506	$237,683	$705,990	$513,139
if i = 5 %	$341,174	$193,720	$592,200	$429,862
NPV at 25 years				
if i = 0 %	$301,346	$175,920	$519,577	$381,118
if i = 3 %	$288,698	$164,706	$504,838	$367,814
if i = 5 %	$282,999	$159,617	$498,524	$362,109

Note: i = discount rate

In the earlier STEP study (2007) that compared the cost of conventional roofs to green roofs, various cost and roof longevity scenarios were also evaluated. The scenario that assumed a discount rate of 3.5% and green roof longevity of 45 years showed that even moderately priced green roofs, with initial capital costs similar to this study, can cost less than conventional roofs (which were assumed to last 15 years) while providing other stormwater, biodiversity, energy and heat island mitigation benefits.

4.0 COMPARISON OF LID PRACTICE COSTS

Selecting the preferred combination of stormwater practices for a development site requires knowledge of environmental conditions, space constraints, the anticipated water balance and water quality impacts, as well as the type of practices that would help mitigate these impacts. Since different practices can achieve similar benefits, cost becomes an important criterion for selecting among available stormwater treatment options.

4.1 Capital Costs

The initial capital costs associated with planning, design and construction of the different practice scenarios and practice types are compared in Figure 4.1. The comparison shows that bioretention, rainwater harvesting and the road runoff variations of infiltration chambers and trenches fall within a similar range of costs. Permeable pavements are more expensive, mostly due to the higher cost of materials and installation. Enhanced swales are the least expensive in part because they are designed primarily for conveyance, rather than water balance control. Infiltration trenches and chambers that receive only roof runoff are also relatively cost effective because of the lower costs for pre-treatment. Green roofs are the most expensive but offer a range of benefits that are unique to this practice. They also displace the need to install a conventional roof, which none of the other practices do.

In interpreting these results, it is important to recognize that only the practice itself is assigned a cost. The savings that may be gained from implementing one practice over another are not captured. Thus, for instance, if the project involves building a new parking lot, there would be costs associated with paving the parking lot with asphalt and installing a practice that helps mitigate the water quantity and quality impacts of the runoff generated. Selecting permeable pavement would mean that only a portion of the parking lot would require paving (assuming some asphalt drains onto the pavement), resulting in cost savings over a practice such as bioretention, which cannot be used as a parking surface, and would therefore require more asphalt paving. In the case of bioretention, there may also be a cost associated with the larger area required to accommodate the practice, given that each practice has the same roof and/or paved drainage area. If instead, an underground chamber were used, the cost of asphalt above the chamber would be extra, but there would be no impact on buildable area. The specific context of the project, therefore, will play a critical role in the overall cost of the project

The cost data can also be viewed through the lens of the benefits the different practices provide with regards to stormwater treatment. Focusing specifically on volume reduction is perhaps the simplest means of accomplishing this task because reducing runoff volumes addresses multiple issues, including water quality, stream erosion, thermal impacts and groundwater recharge. The costs could then be expressed per unit volume of runoff reduced through infiltration and/or evapotranspiration. This approach works less well for building integrated practices such as green roofs and rainwater harvesting because the unique practice values associated with, for example,

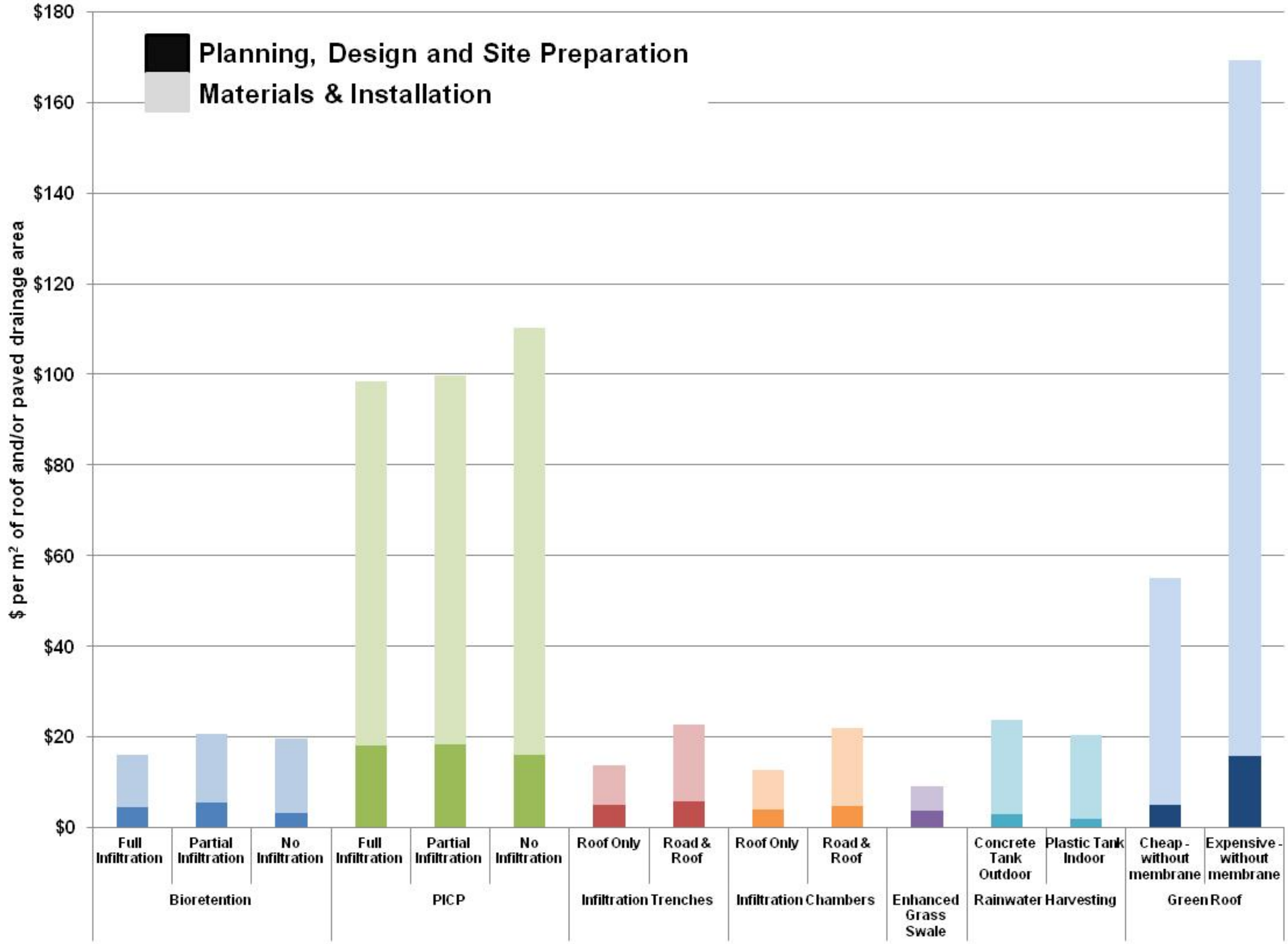

Figure 4.1: Capital costs for all practices per m^2 of roof and/or paved drainage area

energy reduction or potable water savings, are not accounted for in the overall cost/benefit. An example of costs expressed in relation to the load of suspended solids reduced for different treatment options is provided in section 4.3.

4.2 Life Cycle Costs

Table 4.1 compares LID practice costs for annual maintenance, rehabilitation and overall net present values at discount rates ranging from 0 to 5%. Figure 4.2 shows net present values for the 25 and 50 year time periods. Annual maintenance costs averaged over 50 years ranged from $74 for infiltration chambers and trenches treating roof runoff to $2,022 for green roofs. In general, maintenance costs were higher for practices requiring plant maintenance, such as bioretention and green roofs, or extensive pre-treatment, such as infiltration chambers and trenches treating road runoff. Rainwater harvesting systems require relatively little maintenance but pumps and pressure tanks need to be replaced at 10 year intervals.

All practices except rainwater harvesting (concrete cistern), underground chambers or trenches and enhanced grass swales required major rehabilitation at some point in the 50 year time period. These expensive rehabilitation costs weigh heavily in the net present value calculations, particularly at low discount rates, making the practices not requiring rehabilitation comparably less expensive over the long term.

Table 4.1: Life cycle costs for all practices

	Bioretention			Permeable Pavement			Infiltration Trenches		Infiltration Chambers		Enhanced Grass Swales	Rainwater Harvesting		Green Roofs			
														Cheap		Expensive	
	Full Infiltration	Partial Infiltration	No Infiltration	Full Infiltration	Partial Infiltration	No Infiltration	Roof Only	Road & Roof	Roof Only	Road & Roof	Rock Check Dam	Concrete Tank Outdoor	Plastic Tank Indoor	With membrane	Without membrane	With membrane	Without membrane
Construction	$31,973	$41,476	$39,028	$98,313	$99,652	$110,153	$27,575	$45,534	$25,547	$43,706	$18,347	$47,237	$40,637	$231,278	$110,060	$472,909	$338,658
50 year evaluation period																	
Ave. annual maintenance	$945	$952	$952	$433	$436	$436	$74	$1,277	$74	$1,212	$500	$744	$744	$2,022	$1,854	$1,714	$1,546
Rehabilitation	$7,504	$7,504	$7,504	$72,990	$72,990	$72,990	na	na	na	na	na	na	$5,970	$373,628	$209,187	$613,542	$436,068
Year rehabilitation required	25	25	25	30	30	30	na	na	na	na	na	na	40	40	40	40	40
Present Value of maintenance & rehabilitation only																	
if i=0%	$54,743	$55,128	$55,128	$94,657	$94,810	$94,810	$3,675	$63,850	$3,675	$60,600	$24,985	$37,214	$43,184	$474,744	$301,887	$699,258	$513,368
if i=3%	$28,498	$28,670	$28,670	$41,239	$41,316	$41,316	$1,857	$32,276	$1,857	$30,563	$13,769	$18,851	$20,681	$182,228	$127,623	$233,081	$174,481
if i=5%	$20,210	$20,322	$20,322	$24,768	$24,820	$24,820	$1,298	$22,556	$1,298	$21,332	$10,292	$12,903	$13,751	$109,896	$83,660	$119,291	$91,204
Present value of all (capital cost, maintenance & rehabilitation)																	
if i=0%	$86,716	$96,604	$94,156	$192,970	$194,462	$204,963	$31,250	$109,384	$29,222	$104,306	$43,333	$84,451	$83,821	$706,022	$411,947	$1,172,167	$852,026
if i=3%	$60,471	$70,146	$67,698	$139,552	$140,968	$151,469	$29,432	$77,810	$27,404	$74,269	$32,117	$66,088	$61,318	$413,506	$237,683	$705,990	$513,139
if i=5%	$52,183	$61,798	$59,350	$123,081	$124,472	$134,973	$28,873	$68,090	$26,845	$65,038	$28,639	$60,140	$54,388	$341,174	$193,720	$592,200	$429,862
25 year evaluation period																	
Ave. annual maintenance	$972	$978	$978	$433	$436	$436	$72	$1,264	$72	$1,188	$537	$744	$744	$2,802	$2,634	$1,867	$1,698
Rehabilitation	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Year rehabilitation required	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Present Value of maintenance & rehabilitation only																	
if i=0%	$24,293	$24,447	$24,447	$10,833	$10,910	$10,910	$1,800	$31,600	$1,800	$29,700	$13,429	$18,607	$18,607	$70,068	$65,860	$46,668	$42,460
if i=3%	$17,255	$17,355	$17,355	$7,483	$7,533	$7,533	$1,233	$21,593	$1,233	$20,302	$9,922	$12,282	$12,282	$57,420	$54,646	$31,929	$29,156
if i=5%	$14,156	$14,233	$14,233	$6,012	$6,051	$6,051	$986	$17,226	$986	$16,203	$8,365	$9,517	$9,517	$51,721	$49,557	$25,615	$23,451
Present value of all (capital cost, maintenance & rehabilitation)																	
if i=0%	$56,266	$65,923	$63,475	$109,146	$110,562	$121,063	$29,375	$77,134	$27,347	$73,406	$31,777	$65,844	$59,244	$301,346	$175,920	$519,577	$381,118
if i=3%	$49,228	$58,831	$56,383	$105,796	$107,185	$117,686	$28,808	$67,127	$26,780	$64,008	$28,270	$59,519	$52,919	$288,698	$164,706	$504,838	$367,814
if i=5%	$46,129	$55,709	$53,261	$104,325	$105,703	$116,204	$28,561	$62,760	$26,533	$59,909	$26,712	$56,754	$50,154	$282,999	$159,617	$498,524	$362,109

Note: i = discount rate

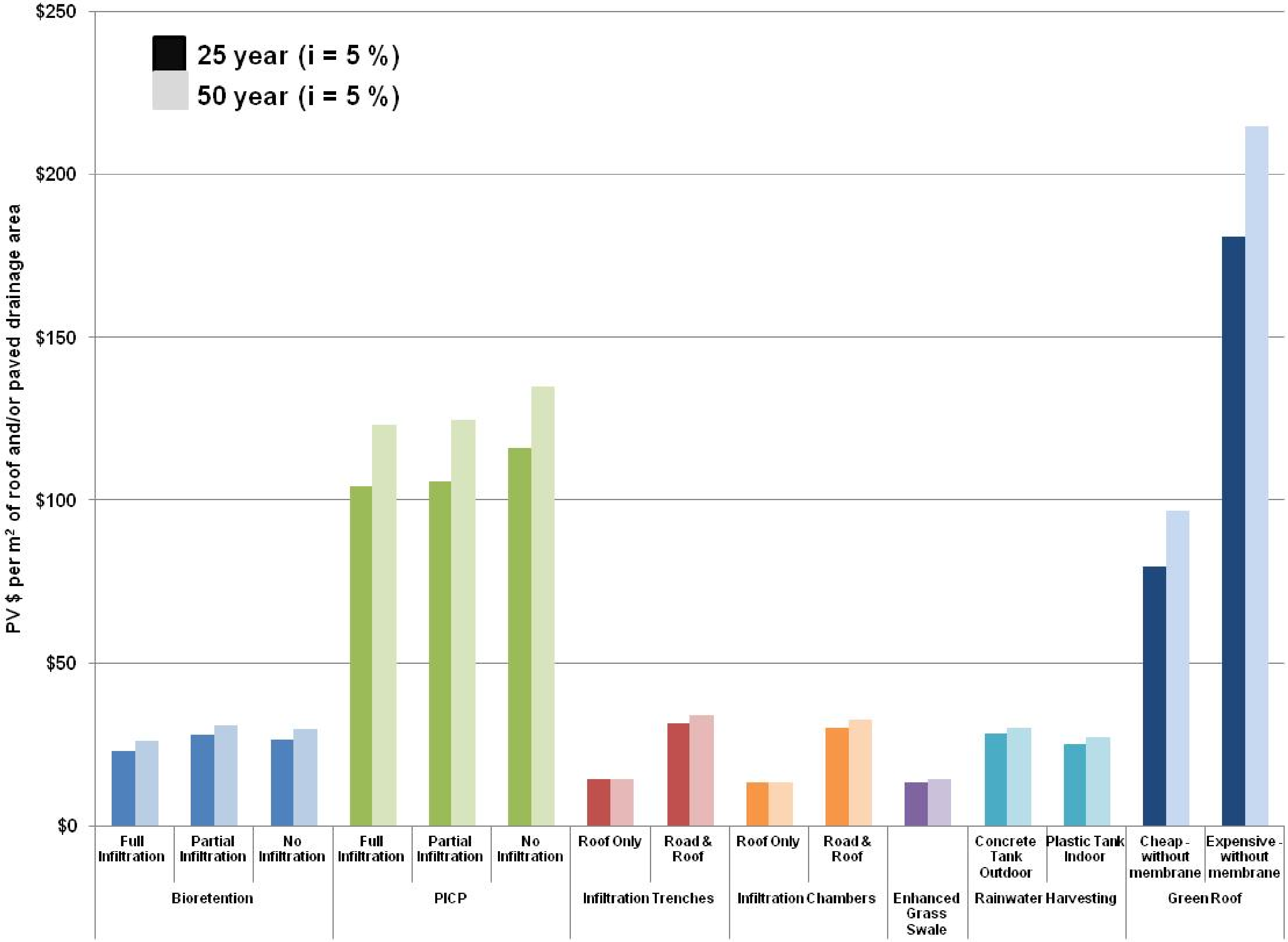

Figure 4.2: Present values for 25 year and 50 year evaluation periods for all practices per m^2 of roof and/or paved drainage area

4.3 Comparisons to Conventional Grey Infrastructure

The previous section compared the cost of LID practices to one another. In this section, the costs of selected practices are compared to conventional grey infrastructure based on the cost both of the practice and the contributing drainage area. The practice type used in the analysis is for a partial infiltration system.

The scenarios selected for comparative analysis have an asphalt drainage area of 2000 m^2 with treatment provided by different types of LID practices and a conventional oil grit separator. The scenarios were as follows:

1. Asphalt (2000 m^2) draining to a storm sewer with treatment provided by an appropriately sized **oil grit separator**
2. Asphalt (2000 m^2) draining to a 130 m^2 partial infiltration **bioretention cell** (see design and costing in section 3.1)
3. Asphalt (1000 m^2) draining to 1000 m^2 partial infiltration **permeable interlocking concrete pavement** (see design and costing in section 3.2).
4. Asphalt (2000 m^2) draining to a 100 m^2 infiltration **trench with pre-treatment provided through a 20 m^2 gravel inlet** (substituted OGS in the trench design provided in section 3.3 for a much less expensive gravel filter inlet)
5. Asphalt (2000 m^2) draining to a 100 m^2 underground **infiltration trench with pre-treatment provided by an Oil Grit Separator** (similar to model provided in section 3.3, but the OGS is larger to accommodated the larger asphalt drainage area).
6. Asphalt (2000 m^2) draining to a 200 m^2 **enhanced swale** (see design and costing in section 3.5)

It should be noted that the bioretention cell, infiltration trench with gravel filter, and enhanced swale take up 130, 20 and 200 m^2 more space than the other scenarios, respectively. The conventional scenario with OGS treatment also differs significantly from the others as it is the only practice that does not reduce runoff volumes and contaminant loads through infiltration and/or evapotranspiration. The enhanced swale would also be expected to infiltrate less runoff than the other LID practices since it is designed to convey runoff.

Figure 4.3 presents the initial capital and present value costs of the scenarios (asphalt + treatment option) over the 50 year evaluation period at a discount rate of 5%. The initial capital costs of the different treatment scenarios are relatively similar, ranging from $54 to $73 per square meter of paved drainage area. The conventional OGS treatment scenario had the second lowest initial cost, at $57 per m^2 of paved drainage. When routine maintenance and rehabilitation/replacement costs are added, and expressed as net present value, the conventional OGS treatment scenario has the third highest cost, at $114 per m^2 of paved drainage.

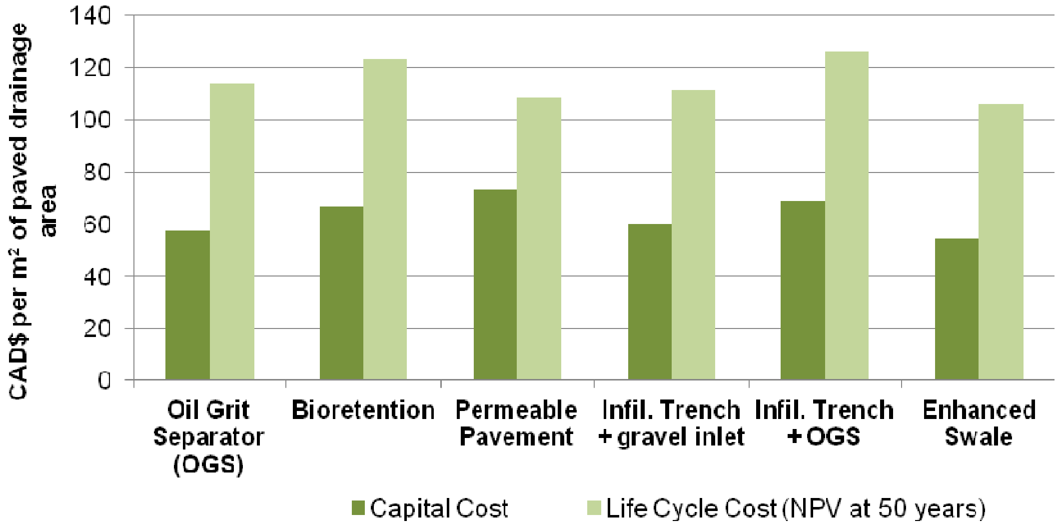

Figure 4.3: Capital and life cycle costs for different asphalt runoff treatment scenarios

The costs presented in Figure 4.3 do not consider differences in the stormwater management benefits of the practices. These differences are shown in Table 4.2 in relation to estimated reductions in runoff, total suspended solids (TSS) concentrations and TSS loads. The runoff reduction estimates are based on literature values provided in the *LID Guide*. TSS concentration reductions are based on literature reviews and local studies (*e.g.* STEP, 2008; Drake et al, 2012). To show the value of these benefits, the capital and life cycle costs of the scenarios are expressed in Figure 4.4 as dollars per kilograms of TSS reduced annually, assuming an average influent concentration of 200 mg/L, annual precipitation of 800 mm (based on climate 'normals' in Ontario) and an asphalt runoff coefficient of 0.98.

Table 4.2: Estimated reductions in runoff, TSS concentrations and loads for six asphalt treatment scenarios

Treatment Scenario	Runoff Reduction (%)	TSS Concentration Reduction (%)	Load Reduction (%)
Oil Grit Separator	0	50	50
Partial Infiltration Bioretention	45	80	89
Partial Infiltration Permeable Pavement	45	80	89
Infiltration Trench with gravel inlet	45	50	73
Infiltration Trench with Oil Grit Separator	45	50	73
Enhanced Swale	20	60	68

As expected, LID practices are less expensive than traditional OGS treatment when costs are denominated in terms of their water quality benefits. The capital cost of LID scenarios was between 24 and 44% lower than conventional OGS treatment. On a life cycle cost basis, these savings increase to between 35 and 77%. The cost differences relative to conventional OGS treatment would be even greater if the native soils were sandy, as this would significantly increase the volume of runoff reduced and the practices would be cheaper to construct because of lower material and installation costs (see full infiltration scenario models in chapter 3).

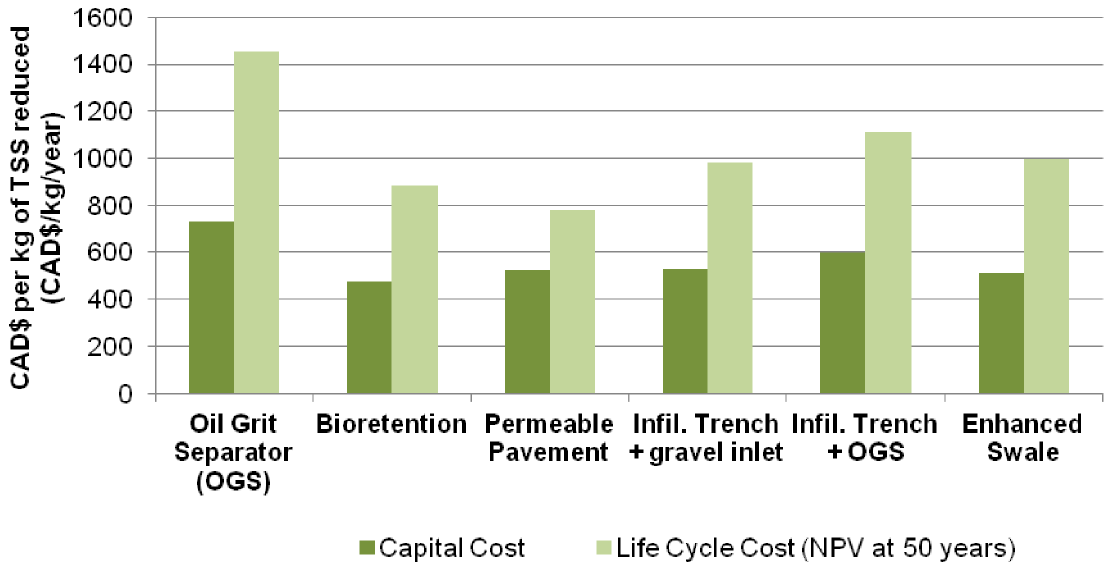

Figure 4.4: Capital and life cycle costs expressed per kilogram of total suspended solids (TSS) load reduced (see text for assumptions)

4.4 Comparison of Study Findings to Other Literature

A literature review was conducted to compare construction, maintenance and rehabilitation costs estimated in this study with those found in other studies or estimated by other models. The literature review was intended to provide an overview of key sources of LID cost information rather than a comprehensive summary of all the literature available on the topic.

Capital cost literature values are compared in the next section, followed by a comparison of maintenance and rehabilitation costs. Most literature values were converted to 2010 $CAD and to the Toronto location using RSMeans year and location conversion factors.

In reviewing the literature, every attempt was made to select a design similar to the model designs in this study in order to provide more robust comparisons. However, in several instances this was not possible as each study/model incorporated its own unique design assumptions, and included or excluded different components from the construction cost. These differences in methodologies contributed to some of the variation in costs among studies.

4.4.1 Review of literature on LID construction costs

Capital costs of LID practices included in this study are compared with other comparable literature in Table 4.3. The comparison indicates that cost estimates of bioretention and permeable pavers from this study fall on the low end of the range suggested by literature and other models when converted to 2010 $CAD. Differences in design and costing assumptions account for some of the discrepancy. For instance, WERF added 20% contingency to its permeable paver cost, which was not included in this study. The Olson et al (2010) estimate for permeable pavers provided in Table 4.3 is interpolated from detailed costing of 3 projects in Denver Colorado ranging in size from 324 m^2 to 2,671 m^2.

The cost of infiltration trenches in this study (without the hydrodynamic separator) appears to be on the high end of the range suggested by literature. There was no literature available for Infiltration Chambers. However, the cost of the Infiltration Chamber system (without the hydrodynamic separator) matched relatively closely to that suggested by the chamber manufacturer. The cost of the hydrodynamic separator used as a pretreatment device for the chambers and trenches was lower than the Olson et al (2010) estimate.

Cost estimates in this study for rainwater harvesting were higher than the two sources reviewed, likely due to differences in the design and/or range of costs included. Costs from the STEP (2010a) study were provided by the design engineer and did not include indoor piping. WERF had higher tank and installation costs, but lower costs for the pump and piping. Filter and top-up system costs, which accounted for over 10K in the present study did not appear to be included.

Green roof costs in this study were lower than green roof industry sources, possibly due to a lower assumed mark-up. Our costs, however, did line up with those of WERF, which takes a unit costing approach similar to ours. The TRCA survey of local green roofs installed in the GTA reported slightly lower costs, in part because many of the buildings in this survey were low rises that did not require expensive equipment to move the green roof materials (STEP, 2007). .

Table 4.3: LID capital cost comparison to literature/other models. Italisized text indicates literature values are lower; bolded text indicates literature costs are higher, and normal text indicates costs are similar

LID	Model design	Capital cost in this study	Literature values			
Bioretention	Full Infiltration	$32K	$26K WERF 2009	$32K Weiss et al 2007	**$40K** Brown & Schueler 1997	**$44K** Olson et al 2010
	Partial Infiltration	$42K	**$49K** Weiss et al 2007	**$55K** WERF 2009	**$59K** Brown & Schueler 1997	**$60K** Olson et al 2010
	No Infiltration	$39K	$41K Weiss et al 2007	**$49K** Brown & Schueler 1997	**$52K** Olson et al 2010	**$55K** WERF 2009
Permeable Pavers	Full Infiltration Partial Infiltration No Infiltration	$98K $100K $110K	*$55K* (This only includes paver, bedding, base & sub-base) ICPI 2011	$99K - $198K (This includes 20% contingency, not included in our estimate) WERF 2009	**$188K** Olson et al 2010	
Infiltration Trench	Full Infiltration – $2000m^2$ roof runoff	$28K	*$14K* Brown & Schueler 1997	$25K Weiss et al 2007		
	Full Infiltration – $1500m^2$ parking lot + $500m^2$ roof runoff	$45K	This design includes a hydrodynamic separator, which is assessed below.			
Infiltration Chamber	Full Infiltration – $2000m^2$ roof runoff	$26K	*$17K* (This is lower because Stormtech is only including items directly related to the chambers) Stormtech 2012			
	Full Infiltration – $1500m^2$ parking lot + $500m^2$ roof runoff	$43K	Lit review not done. This design includes a hydrodynamic separator, which is assessed below.			
	Hydrodynamic separator	$15K	$4K - $72K USEPA 1999	**$38K** Olson et al 2010		
Rainwater Harvesting	Buried concrete tank	$47K	*$23K* *General rule of thumb $1/L*	*$24K*		
	Indoor plastic tank	$41K		*$21K* WERF 2009		

LID	Model design	Capital cost in this study	Literature values		
Green Roof (extensive)	Cheap Case (4" growing medium, sedum plugs, lower building)	$247K	*$189K* (costs are similar when design differences between studies are considered)	**$344K - $430K**	**$646K-$754K**
			WERF 2009	Bass 2012	Wylie 2012
	Expensive Case (6" growing medium, sedum mats, higher building)	$473K	*$316K* (costs are similar when design differences between studies are considered)		*$279 - $397* (based on supplier estimates for the green roof system including the base roof)
			WERF 2009		STEP 2007
	Expensive Case (no membrane, green roof only)	$339K			*$238-256K* based on actual green roof costs of projects in the GTA, not including the membrane. $228K-$360K based on supplier estimates not including the base roof)
					STEP 2007

4.4.2 Review of literature on LID maintenance and rehabilitation costs

Table 4.4 presents LID maintenance cost comparisons from various literature sources. Overall, cost estimates for maintenance provided in this study align reasonably well with literature values.

The maintenance costs for bioretention cells estimated in this study are in good agreement with most of the values from the literature or other models. None of the literature sources indicated a periodic rehabilitation cost. Incorporating the rehabilitation cost at 25 years into the annual maintenance cost would only increase it to $1,103 per year. A 134 m^2 bioretention facility installed in Vaughan, Ontario in 2010 and monitored through the TRCA's Sustainable Technologies Evaluation Program had annual maintenance costs of approximately $1200, mostly for weeding and plant maintenance (STEP, 2010b).

The annual cost estimates in this study for maintaining permeable pavers were consistent with those suggested by other literature. Higher end ranges in the literature assumed that more frequent maintenance may be required in some circumstances. Major rehabilitation costs varied among literature sources. WERF recommended removing, washing and replacing all the aggregate at a cost equal to the initial cost of installation. In the present study, it was assumed that the rehabilitation would cost only about two thirds of the initial cost because fines would be largely removed from the surface through regular cleaning, thereby preserving the integrity of the open graded base. The 2010 Olson et al study assumed rehabilitation would cost 80% of the initial installation cost, and that it would be required after only 18 years. The present study suggested a 30 year timeline for rehabilitation based on observations of the structural condition of older permeable pavement sites in the Greater Toronto Area.

Infiltration trenches and chambers were assumed to require very little maintenance if adequate pretreatment was provided based on installations monitored in Ontario (e.g. SWAMP, 2004; JF Sabourin and Associates, 2008). Hence maintenance costs for cleanout of the hydrodynamic device providing pretreatment to the infiltration trench and chamber was the primary maintenance cost for these practices. Costs for clean-out of this device agreed well with other models. The Olson et al (2010) model assumed an additional cost for replacing the hydrodynamic separator after 25 years which was deemed unnecessary in this study.

Rainwater harvesting annual maintenance costs were slightly lower than the lower end estimate by WERF. However, WERF assumed a longer replacement cost for the plastic tank. This extra replacement cost contributes significantly to the 50 year maintenance burden.

Green roof annual maintenance costs in the first two years agree well with other references (CMHC, 2003; GRHC, 2006) that consider this initial period of plant establishment to be a period of more intense maintenance. Higher end maintenance costs may be required on accessible green roofs, or roofs visible from the building windows. However, most green roofs in Ontario are not of this type. Two green roofs monitored by TRCA/STEP in the Toronto area have required very little maintenance after the first year, as plants brought to the rooftop garden by wind or animals have been allowed to thrive or replace the original plant stock.

Table 4.4: LID maintenance and rehabilitation cost comparison to literature/other models. Italisized text indicates literature values are lower; bolded text indicates literature costs are higher, and normal text indicates costs are similar

LID	Maintenance or rehabilitation	Cost in this study	Literature values			
Bioretention	Annual maintenance	$945 - $952 (2%-3% of construction cost)	0.7% - 10.9% of construction cost Weiss et al 2005	$454 - $6425 WERF 2009	$1182 Olson et al 2010	**5% - 7% of construction cost** USEPA, 1999
	Rehabilitation	$7,504 after 25 years	None of the above references mention separate rehab costs.			
Permeable Pavers	Annual maintenance	$433 -$436	*$64* Olson et al 2010	$130 - $3,550 (medium is $330) WERF 2009	**$450 - $3,400 (median of $1,900) for sediment removal only** Erickson et al 2010	
	Rehabilitation	$75K (63% - 71% of initial construction cost) after 30 years	**100% of initial construction cost** after 25, 35 or 45 years WERF 2009	**80% of initial construction cost** **every 18 years** Olson et al 2010		
Infiltration Trench						
2000m² roof runoff	Annual maintenance	$74 (all for sediment removal) (0.3% of construction cost)	**$371 - $742 for sediment removal** Erickson et al 2010	**5% - 20% of construction cost** USEPA 1999	**5.1% - 126.0% of construction cost** Weiss et al 2005	**10% - 15% of construction cost** Alberta 1999
1500m² parking lot + 500m² roof runoff	Annual maintenance	$1277 (all for sediment removal) (2.8% of construction cost)	*$370 - $740 for sediment removal* Erickson et al 2010	**5% - 20% of construction cost** USEPA 1999	**5.1% - 126.0% of construction cost** Weiss et al 2005	**10% - 15% of construction cost** Alberta 1999
Infiltration Chamber						
2000m² roof runoff	Annual maintenance	$74	Lit review not done.			
1500m² parking lot + 500m² roof runoff	Annual maintenance	$1212	This cost is mainly to clean out the hydrodynamic separator. See lit review for hydrodynamic separator below.			
Hydrodynamic separator	Annual maintenance	$1200	$420 - $1,400 WERF 2005	$1,027 Olson et al 2010	**$1,800** USEPA 1999	
	Rehabilitation	assumed to last 50	**120% of initial cost after 25 years**			

LID	Maintenance or rehabilitation	Cost in this study	Literature values		
		years	BMP-REALCOST 2010		
Rainwater Harvesting	Annual maintenance	$744	**$815 - $13K**		
	Rehabilitation	$5970 plastic tank replacement at year 40	*WERF does not replace tank.*		
			WERF 2009		
Green Roof	Annual maintenance	$1,714 - $2,022			**$2,840 - $43,400**
					WERF 2009
	First 2 years	$640 - $26,620	$2.7 - $44/m2	$13-$21/m2	
			($5.4K - $88K)	($26K - $42K)	
			GRHC 2006	CMHC 2003	
	Rehabilitation	$342K - $617K	No lit review done on rehab costs.		

5.0 CONCLUSIONS

This project has employed a robust and replicable methodology to compile capital and life cycle costs for a number of the most common low impact development practices. Results show the costs associated with construction, maintenance and rehabilitation of each practice. The broader public benefits and avoided infrastructure costs associated with applying the practices are not documented as these will vary depending on a range of factors specific to each site. Combining the cost data collected in this project with these more site specific considerations will help guide decisions on the type and combination of low impact development practices best suited to each site.

Model LID practice design costs documented in this study indicate that bioretention, infiltration chambers, infiltration trenches and enhanced swales are some of the least expensive practices to implement when only the practice cost itself is considered. The practice of rainwater harvesting provides added savings by reducing the cost of potable water supplies. Permeable pavements are comparably more expensive than most other practices, but in many instances these costs would be offset to some extent by a reduction in the need to pave the drainage area, since the pavements serve both as a parking surface and stormwater treatment practice. The practice also does not require as much land as some other practices, making it particularly well suited to retrofit contexts. Green roofs are by far the most expensive practice as they are installed in less accessible locations and need to be carefully engineered to protect the integrity of the building envelope. This practice is often selected because of its aesthetic, biodiversity and energy saving benefits, as well as its overall contribution to green building rating schemes, the value of which were not considered in our cost assessment. The costs and benefits of green roofs are best assessed in relation to those of conventional roofs over long time periods to capture the cost savings associated with the longer life of green roofs (see, for example, STEP, 2007).

Just as green roofs replace conventional roofs, other LID practices supplant more conventional treatment practices. An analysis of different treatment scenarios for an asphalt parking lot revealed that LID practices had comparable life cycle costs to conventional treatment using an oil grit separator (OGS). When the treatment costs of the scenarios were expressed in relation to the superior water quality benefits of LID, the life cycle costs of the LID practices were between 35 and 77% less expensive than conventional OGS treatment.

Capital and life cycle costs generated through this project have been scaled and programmed into a spreadsheet decision support tool for each practice that allows users to input site design information (e.g drainage area size and type) and alter unit costs in order to generate estimates of overall practice costs based on site specific data and considerations. This tool is available on the Sustainable Technologies Evaluation Program website at www.sustaianbletechnologies.ca.

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APPENDIX A:

Detailed Costing Tables

Table A.1: Bioretention

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost ($CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
Site Investigation								
Dig test pit 1	80 HP backhoe (equipment)	$24.88		$/m^3	$29.86	$99.52	$0.00	Test pit is 1 m x 1 m x 1.275 m, volume is 1.2 m^3 (For Full) Test pit is 1m x 1m x 2m and sloped 1:1 above 1.2 m depth, volume is ~ 4 m^3 (For Partial) RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$59.50	$198.32	$0.00	
Dig test pit 2	80 HP backhoe (equipment)	$24.88		$/m^3	$29.86	$99.52	$0.00	Test pit is 1 m x 1 m x 1.275 m, volume is 1.2 m^3 (For Full) Test pit is 1m x 1m x 2m and sloped 1:1 above 1.2 m depth, volume is ~ 4 m^3 (For Partial) RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$59.50	$198.52	$0.00	
Infiltration tests	Double-ring infiltrometer	$608.85		$/test	$2,435.40	$2,435.40	$0.00	2 infiltration tests per test pit
Site Preparation								
Preconstruction meeting	Part of overhead				$0.00	$0.00	$0.00	
Stakeout of utilities			$500.00	lump sum	$500.00	$500.00	$500.00	Assume no interfering utilities are found as a result.
Tree & plant protection					$0.00	$0.00	$0.00	Assume no trees
Traffic control					$0.00	$0.00	$0.00	Assume not required
Install erosion & sediment control and control drainage	2" submersible gas pump for 3 days (incl. gas)		$81.15	$/day	$243.45	$243.45	$0.00	
	Silk sack in catchbasin		$65.00	$/unit	$65.00	$65.00	$0.00	
	Silt fence 1m around perimeter of excavation		$2.21	$/m	$179.01	$191.47	$0.00	
	Silt fence labour		$1.77	$/m	$143.37	$153.35	$0.00	
Mobilization/demobilization					$0.00	$0.00	$0.00	Active construction site, so all equipment on site
Excavation								
Vegetation removal	Clearing, grubbing, haul away material				$0.00	$0.00	$0.00	Active construction site, assume already done
Topsoil salvage - Stockpile & stabilize					$0.00	$0.00	$0.00	Assume 6" of topsoil is already removed
Excavation	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.24		$/Bm^3	$181.35	$330.46	$245.94	Assume excavation rate of 100 Bm^3/hr (188 Lm^3/hr) Excavation is sloped 1:1 above 1.2 m depth
	1.5 m^3 bucket excavator (equipment)	$1.89		$/Bm^3	$276.41	$503.69	$374.86	
	Loading - 15 % of excavation cost			%	$68.66	$125.12	$93.12	
	Hauling in a 13.76 m^3 truck (including truck & driver)	$172.92		$/hr/truck	$760.85	$1,400.65	$1,037.52	Assume 20 min. cycle time to dump elsewhere on site
Safety fencing	4' high fencing, 6 m around perimeter of excavation (124 m). Assume 1 week rental.	$800.00		$/week	$800.00	$800.00	$800.00	Includes setup & takedown
Material and Installation								
Impermeable membrane	0.762 mm HDPE liner (materials)	$4.96		$/m^2	$0.00	$0.00	$1,602.08	Assume membrane extends 1 m beyond edges
	0.762 mm HDPE liner (labour)	$9.32		$/m^2	$0.00	$0.00	$3,010.36	Adjusted RSMeans labour cost of $8.88 by +5% to $9.32 because of the smaller quantity.

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost ($CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
HDPE Piping	Underdrain 200 mm diameter, perforated (material)		$16.87	$/m	$0.00	$548.28	$548.28	Pipe materials used: Armtec Boss 2000, corrugated with smooth inner wall
	Underdrain 200 mm diameter, perforated (labour)	$11.40		$/m	$0.00	$370.50	$370.50	
	Clean out pipes, 150 mm diameter (material)		$9.84	$/m	$0.00	$27.06	$27.06	
	Clean out pipes, 150 mm diameter (labour)	$10.86		$/m	$0.00	$29.87	$29.87	
	Overflow pipe 200 mm diameter (material)		$15.37	$/m	$19.60	$31.59	$25.36	
	Overflow pipe 200 mm diameter (labour)	$11.40		$/m	$14.54	$23.43	$18.81	
	Pipe to sewer - 200 mm diameter (trenching not incl.) (material)		$15.37	$/m	$76.85	$76.85	$76.85	
	Pipe to sewer - 200 mm diameter (trenching not incl.) (labour)	$11.40		$/m	$57.00	$57.00	$57.00	
	Monitoring pipes - 150 mm diameter, perforated (material)		$10.94	$/m	$27.90	$44.96	$0.00	
	Monitoring pipes - 150 mm diameter, perforated (labour)	$10.86		$/m	$27.69	$44.63	$0.00	
	Delivery for all pipes		$50 to $100	$/delivery	$50.00	$100.00	$100.00	
HDPE Pipe Fittings	Underdrain: 3 end caps (200 mm)	$5.40		$/unit	$0.00	$16.20	$16.20	
	Underdrain: 3 Tees (200 mm)	$107.58		$/unit	$0.00	$322.74	$322.74	Assume the labour for Tees are $100 ea, labour for manhole adaptor is $200
	Cleanouts: 2 caps at surface (150 mm)	$65.00		$/unit	$0.00	$130.00	$130.00	
	Cleanouts: 2 Tees (150 mm to 200 mm)	$107.58		$/unit	$0.00	$215.16	$215.16	
	Overflow pipe: 1 inlet guard (200 mm)	$25.00		$/unit	$25.00	$25.00	$25.00	
	Overflow pipe: 1 Tee	$107.58		$/unit	$107.58	$107.58	$107.58	
	Overflow Pipe: with 1 endcap/footplate (200 mm)	$5.40		$/unit	$5.40	$5.40	$5.40	
	Pipe to sewer: 1 manhole adapter (200 mm)	$36.38		$/unit	$36.38	$36.38	$36.38	
	Monitoring pipes: 2 caps at surface (150 mm)	$65.00		$/unit	$130.00	$130.00	$0.00	
	Monitoring pipes: 2 footplates	$5.40		$/unit	$10.80	$10.80	$0.00	
Pipe fittings: Labour	Underdrain: 3 end caps (200 mm)	$50.00		$/unit	$0.00	$150.00	$150.00	
	Underdrain: 3 Tees (200 mm)	$100.00		$/unit	$0.00	$300.00	$300.00	
	Cleanouts: 2 caps at surface (150 mm)	$50.00		$/unit	$0.00	$100.00	$100.00	
	Cleanouts: 2 Tees (150 mm to 200 mm)	$100.00		$/unit	$0.00	$200.00	$200.00	
	Overflow pipe: 1 inlet guard (200 mm)	$50.00		$/unit	$50.00	$50.00	$50.00	
	Overflow pipe: 1 Tee	$100.00		$/unit	$100.00	$100.00	$100.00	
	Overflow Pipe: with 1 endcap/footplate (200 mm)	$50.00		$/unit	$50.00	$50.00	$50.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost ($CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
	Pipe to sewer: 1 manhole adapter (200 mm)	$200.00		$/unit	$200.00	$200.00	$200.00	
	Monitoring pipes: 2 caps at surface (150 mm)	$50.00		$/unit	$100.00	$100.00	$0.00	
	Monitoring pipes: 2 footplates	$50.00		$/unit	$100.00	$100.00	$0.00	
Pipe to sewer trenching	Pipe trenching & backfill, 0.6 m wide, 1.2 m deep, no slope	$15.59		$/m	$77.95	$77.95	$77.95	This trench depth was chosen assuming the site is excavated already a certain amount for asphalt paving
	Pipe bedding, 0.6 m wide	$13.18		$/m	$65.90	$65.90	$65.90	
Stone	50 mm clear		$36.00	$/Cm^3	$0.00	$3,182.40	$1,287.00	
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.24		$/m^3	$0.00	$109.62	$44.33	Assumed cost is similar to cost of excavation (100 m^3/hr)
	1.5 m^3 bucket excavator (equipment)	$1.89		$/m^3	$0.00	$167.08	$67.57	
Pea Gravel	Material	$56.10		$/m^3	$0.00	$729.30	$729.30	
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.24		$/m^3	$0.00	$16.12	$16.12	
	1.5 m^3 bucket excavator (equipment)	$1.89		$/m^3	$0.00	$24.57	$24.57	
	Level by hand	$1.56		$/m^2	$0.00	$202.80	$202.80	
Geotextile	Material	$3.10		$/m^2	$24.80	$145.70	$139.50	
	Labour	$0.40		$/m^2	$3.20	$18.80	$18.00	
Filter media	Gro-Bark (material)		$41.40	$/Lm^3	$6,727.50	$6,727.50	$6,727.50	
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.24		$/Cm^3	$161.20	$161.20	$161.20	Assumed cost is similar to cost of excavation (100 m^3/hr)
	1.5 m^3 bucket excavator (equipment)	$1.89		$/Cm^3	$245.70	$245.70	$245.70	
	Delivery	$900.00		$/delivery	$900.00	$900.00	$900.00	
Backfill sides of excavation	80 HP dozer + 0.5 labourer (labour)	$1.02		$/Lm^3	$0.00	$26.72	$4.69	Assume swell factor of 25% and compaction factor of 0.9 (US Army 2000*)
	80 HP dozer (equipment)	$0.66		$/Lm^3	$0.00	$17.29	$3.04	
Curbs & gutter with curb inlets	150 mm high curb, 150 mm thick gutter & 600 mm wide	$88.35		$/m	$6,449.55	$6,449.55	$6,449.55	Assume cost is same with or without inlets
	Labour	$26.26		$/m	$1,916.98	$1,916.98	$1,916.98	
Vegetation	Mixture of Shrubs, grasses & broadleaf/herb. Includes delivery and labour	$50.20		$/m^2	$4,367.40	$4,367.40	$4,367.40	Assume vegetation covers 2/3 of cell area = 87 m^2 Assume 50% shrub, 40% grasses, 10% broadleaf/herb.
Wood mulch	75 mm deep (material)	$2.72		$/m^2	$337.28	$337.28	$337.28	130 m^2 area minus 6 m^2 stone inlets
	Labour	$5.18		$/m^2	$642.32	$642.32	$642.32	
Stone inlets	50 mm clear (material)		$36.00	$/Cm^3	$21.60	$21.60	$21.60	Assume 50 mm clear, 100 mm deep. Area = 0.5 m^2 x 12 inlets = 6 m^2. Vol = 6 m^2 x 100 mm = 0.6 m^3.
	Spread by hand (labour)	$173.11		$/m^3	$103.87	$103.87	$103.87	
SUBTOTAL					**$29,066**	**$37,706**	**$35,480**	
Fees								
Project Overhead		10%		% of subtotal	$2,906.62	$3,770.55	$3,548.02	
TOTAL					**$31,973**	**$41,476**	**$39,028**	

Table A2. Permeable pavement

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (2010$CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
Site Investigation								
Dig test pit 1	80 HP backhoe (equipment)	$24.88		$/m^3	$10.70	$10.70	$0.00	Assume test pit is 1 m x 1 m x 430 mm. RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$21.32	$21.32	$0.00	
Dig test pit 2	80 HP backhoe (equipment)	$24.88		$/m^3	$10.70	$10.70	$0.00	
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$21.32	$21.32	$0.00	
Infiltration tests		$608.85		$/test	$2,435.40	$2,435.40	$0.00	2 infiltration tests per test pit.
Soil strength testing					$0.00	$0.00	$0.00	Not costed; assumed geotech tests done previously
Soil quality testing					$0.00	$0.00	$0.00	Not costed; assumed soil dumped elsewhere on site
Site Preparation								
Pre-construction meeting	Part of overhead				$0.00	$0.00	$0.00	
Stakeout of utilities			$500.00	lump sum	$500.00	$500.00	$500.00	
Erosion and sediment controls	8" dia. FilterSoxx along 60 m edge along asphalt		$10.00	$/m	$600.00	$600.00	$0.00	Assume items already on site, labour negligible
Mobilization/demobilization					$0.00	$0.00	$0.00	Active construction site, so all equipment on site
Excavation								
Vegetation removal	Clearing, grubbing, haul away material				$0.00	$0.00	$0.00	Active construction site, assume already done
Topsoil salvage, haul to stockpile	6" removed, 60 m travel to stockpile, 200 HP dozer + 0.5 labourer (labour)	$1.15		$/m^3	$175.26	$175.26	$175.26	
	6" removed, 60 m travel to stockpile, 200 HP dozer (equipment)	$2.06		$/m^3	$313.94	$313.94	$313.94	Assumed this equipment is not too heavy
Excavate	1.5 m^3 bucket excavator + 1 labourer, productivity 100 Bm^3/hr (labour)	$1.24		$/Bm^3	$347.20	$347.20	$347.20	Assumed 100 Bm^3/hr as for Bioretention excavation. Assumed 6" of topsoil has already been removed, so do not need to excavate full depth.
	1.5 m^3 bucket excavator, productivity 100 Bm^3/hr (equipment)	$1.89		$/Bm^3	$529.20	$529.20	$529.20	
	Loading - 15% of excavation cost			%	$131.46	$131.46	$131.46	
	Hauling in a 13.76 m^3 truck (including truck & driver)	$172.92		$/hr	$1,466.36	$1,466.19	1466.36	Assumed swell factor of 25%, cycle time of 20 min.
Compaction of native soil	30,000 lb grader + 25T vibratory roller + 1 labourer (labour)	$1.16		$/m^2	$1,160.00	$1,160.00	$1,160.00	Assumed this equipment is not too heavy
	30,000 lb grader + 25T vibratory roller (equipment)	$1.14		$/m^2	$1,140.00	$1,140.00	$1,140.00	
	Proctor test	$149.45		$/test	$149.45	$149.45	$149.45	1 test required
	Nuclear density test	$42.81		$/test	$171.24	$171.24	$171.24	Average of 4 tests required - test is done to check compaction.
Materials and Installation								
Impermeable membrane	0.762 mm HDPE liner (materials)	$4.96		$/m^2	$0.00	$0.00	$5,720.86	Assume membrane extends 0.57 m beyond edges
	0.762 mm HDPE liner - 3 skilled workers (labour)	$9.32		$/m^2	$0.00	$0.00	$10,745.96	
Geotextile	Polypropylene filtration fabric (materials)	$3.10		$/m^2	$3,100.00	$3,100.00	$0.00	
	Polypropylene filtration fabric - 2 labourers	$0.40		$/m^2	$400.00	$400.00	$0.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (2010$CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
	(labour)							
HDPE Piping	Underdrain, 150 mm diameter perforated pipe (materials)		$10.94	$/m	$0.00	$176.13	$176.13	Piping materials used: HDPE Armtec Boss 2000 pipe
	Underdrain, 150 mm diameter perforated pipe (labour)	$10.86		$/m	$0.00	$174.85	$174.85	
	Clean out pipes, 100 mm diameter pipe (materials)		$4.79	$/m	$0.00	$1.10	$1.34	
	Clean out pipes, 100 mm diameter pipe (labour)	$10.19		$/m	$0.00	$2.34	$2.85	
	Pipe to catchbasin, 150 mm diameter pipe (materials)		$9.84	$/m	$0.00	$4.92	$4.92	
	Pipe to catchbasin, 150 mm diameter pipe (labour)	$10.86		$/m	$0.00	$5.43	$5.43	
	Monitoring pipes, 150 mm diameter, perforated pipe (materials)		$10.94	$/m	$4.70	$4.70	$0.00	
	Monitoring pipes, 150 mm diameter, perforated pipe (labour)	$10.86		$/m	$4.67	$4.67	$0.00	
	Delivery (total for all pipe)		$50.00	n/a	$0.00	$50.00	$50.00	Assume delivery negligible
Pipe fittings	Underdrain 150 mm end cap (materials)		$2.92	$/ea.	$0.00	$2.92	$2.92	
	Underdrain 150 mm end cap (labour)	$50.00		$/ea.	$0.00	$50.00	$50.00	From looking at RSMeans, assumed $50 for simplicity
	Underdrain 150 mm coupler (materials)		$1.50	$/ea.	$0.00	$1.50	$1.50	
	Underdrain 150 mm coupler (labour)	$50.00		$/ea.	$0.00	$50.00	$50.00	From looking at RSMeans, assumed $50 for simplicity
	Clean-out 100 mm surface cap (materials)		$65.00	$/ea.	$0.00	$65.00	$65.00	Cast iron cap, assumed to be suitable as a surface cap.
	Clean-out 100 mm surface cap (labour)	$50.00		$/ea.	$0.00	$50.00	$50.00	From looking at RSMeans, assumed $50 for simplicity
	Clean-out tee, 100 - 150 mm (materials)		$111.65	$/ea.	$0.00	$111.65	$111.65	
	Clean-out tee, 100 - 150 mm (labour)	$100.00		$/ea.	$0.00	$100.00	$100.00	Assumed $100 from RSMeans cost of $189 for a 300 mm tee.
	Manhole adapter for pipe to catchbasin, 150 mm (materials)		$27.58	$/ea.	$0.00	$27.58	$27.58	
	Manhole adapter for pipe to catchbasin, 150 mm (labour)		$200.00	$/ea.	$0.00	$200.00	$200.00	
	Monitoring pipe 150 mm surface cap (materials)		$65.00	$/ea.	$65.00	$65.00	$0.00	
	Monitoring pipe 150 mm surface cap (labour)	$50.00		$/ea.	$50.00	$50.00	$0.00	From looking at RSMeans, assumed $50 for simplicity
	Monitoring pipe footplate (materials)		$2.92	$/ea.	$2.92	$2.92	$0.00	Assumed same cost as an end-cap
	Monitoring pipe footplate (labour)	$50.00		$/ea.	$50.00	$50.00	$0.00	From looking at RSMeans, assumed $50 for simplicity
Flow restrictor	Canpipe 4" ball valve (materials)		$93.90	$/ea.	$0.00	$93.90	$0.00	
	Canpipe 4" ball valve (labour)	$50.00		$/ea.	$0.00	$50.00	$0.00	From looking at RSMeans, assumed $50 for simplicity
Sub-base, 200 mm deep	50 mm clear limestone (materials)		$36.00	$/m^3	$7,200.00	$7,200.00	$7,200.00	
	30,000 lb grader, 1.5 cy front-end loader, 300 HP dozer, 25 T vibratory roller, truck tractor & water tank trailer + 1 labour foreman + 2 labourers (labour)	$1.00		$/m^2	$1,000.00	$1,000.00	$1,000.00	Assume equip not too heavy. These RSMeans costs are for 40 mm stone. Assume costs for 50 mm stone is same.
	30,000 lb grader, 1.5 cy front-end loader, 300	$1.29		$/m^2	$1,290.00	$1,290.00	$1,290.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (2010$CND) - other source	Units	Full Infiltration	Partial Infiltration	No Infiltration	Assumptions/Notes
	HP dozer, 25 T vibratory roller, truck tractor & water tank trailer (equipment)							
Base, 100 mm deep	19 mm clear limestone (materials)		$37.00	$/m^3	$3,700.00	$3,700.00	$3,700.00	
	30,000 lb grader, 300 HP dozer, 25 T vibratory roller, truck tractor & water tank trailer + 1 labour foreman (labour)	$0.58		$/m^2	$580.00	$580.00	$580.00	Assume equipment not too heavy
	30,000 lb grader, 300 HP dozer, 25 T vibratory roller, truck tractor & water tank trailer (equipment)	$1.01		$/m^2	$1,010.00	$1,010.00	$1,010.00	Assume equipment not too heavy
Compaction test	Nuclear density test	$42.81		$/test	$85.62	$85.62	$85.62	Assume 2 tests
Concrete curb along 1 edge	150 mm wide, 450 mm deep, cast-in-place (materials)	$40.64		$/m	$2,438.40	$2,438.40	$2,438.40	Assume 450 mm is sufficient to extend to the sub-base of adjacent asphalt pavement.
	150 mm wide, 450 mm deep, cast-in-place - 1 carpenter foreman, 4 carpenters, 1 labourer (labour)	$19.69		$/m	$1,181.40	$1,181.40	$1,181.40	
Plastic edge restraints along 3 edges	Snapedge® (materials)		$4.76	$/m	$444.58	$444.58	$444.58	Delivery negligible because the product is very light and can be transported with the pavers.
	Snapedge® spikes (materials)		$1.03	$/m	$96.20	$96.20	$96.20	Need 5 spikes per 8 ft (2.44 m) of Snapedge. Spikes are $0.50 each.
	Snapedge® (labour)		$1.80	$/m	$168.12	$168.12	$168.12	$52.73/hr wage, 29.3 m can be installed per hour. Installation speed (96 ft/hr)
Bedding & Pavers	80 mm interlocking pavers (materials)		$31.56	$/m^2	$31,560.00	$31,560.00	$31,560.00	Source is average of five prices
	Pavers (labour + equip only) and bedding including 50 mm layer and enough for void filling (materials, labour, equipment)		$25.30	$/m^2	$25,300.00	$25,300.00	$25,300.00	Machine installation of pavers. Price is an average of range provided ($21.30-$29.30) for union labour.
Striping		$0.46		$/m	$460.00	$460.00	$460.00	
SUBTOTAL					**$89,375**	**$90,592**	**$100,139**	
Fees								
Project overhead		10.00%		% of sub total	$8,937.52	$9,059.23	$10,013.94	
TOTAL					**$98,313**	**$99,652**	**$110,153**	

Table A3: Infiltration trenches

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost - other source ($CND)	Units	Roof Only	Road & Roof	Assumptions/Notes
Site Investigation							
Dig test pit 1	80 HP backhoe (equipment)	$24.88		$/m^3	$299.13	$299.13	Assume test pit is 1m x 1m, 2.72m deep, & sloped 1:1 above 1.2m depth. RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$596.10	$596.10	
Dig test pit 2	80 HP backhoe (equipment)	$24.88		$/m^3	$299.13	$299.13	
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$596.10	$596.10	
Infiltration tests	Double-ring infiltrometer	$608.85		$/test	$2,435.40	$2,435.40	2 infiltration tests per test pit
Soil strength testing							Not costed; assumed geotech tests done previously
Soil quality testing							Not costed; assumed soil dumped elsewhere on site.
Site Preparation							
Pre-construction meeting	Part of overhead						
Stakeout of utilities	Assume no interfering utilities found as a result		$500.00	lump sum	$500.00	$500.00	
Erosion and sediment controls	Silt fence (material)	$2.21		$/m	$112.71	$112.71	Silt fence along one edge ~ 51 m (decided by Mariko Uda, similar to approach with Infiltration Chamber)
	2 labourers	$1.77		$/m	$90.27	$90.27	
Mobilization/demobilization					$0.00	$0.00	Active construction site, so all equipment on site
Excavation							
Vegetation removal	Clearing, grubbing, haul away material				$0.00	$0.00	Active construction site, assume already done
Topsoil salvage, haul to stockpile	200 HP dozer (equipment)	$2.06		$/m^3	$31.93	$31.93	6" removed, 60 m travel to stockpile. 101.76 m^2 x 152 mm = 15.5 m^3
	200 HP dozer + 0.5 labourer (labour)	$1.15		$/m^3	$17.83	$17.83	
Excavate trench with trench box	Trench 2-3 m deep with trench box; 1.9 m^3 bucket excavator (equipment)	$3.01		$/Bm^3	$787.12	$787.12	Use a trench box. Assumed common earth. 1.9 m^3 bucket was used. Depth is 2.57m (2.72 m - 0.15 m topsoil already removed). Therefore vol = 2.57m x 101.76 m^2 = 261.5 m^3
	Trench 2-3 m deep with trench box; 1.9 m^3 bucket excavator + 1 labourer (labour)	$1.39		$/Bm^3	$363.49	$363.49	
	Loading - 15% of excavation cost			%	$172.59	$172.59	
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$1,017.39	$1,017.39	Assumed some soil not hauled away (used later for backfill). Assumed swell factor of 25% and 20 min. cycle time to dump elsewhere on site. Assumed 13.76 m^3 truck size. Backfill (trench) = 660 mm x 2 m x 50.88 m = 67.162 Bm^3; Therefore vol to haul away = 261.5 Bm^3 - 67.2 Bm^3 = 194.3 Bm^3.
Level subgrade	Assume this can be done as part of excavation step, as assumed with Infiltration Chambers						
Safety fencing	4' high, 1 week rental, including setup & takedown		$251.75	lump sum	$251.75	$251.75	Assume 1m length of excavation left open (hole of 1 m x 2 m). Put a safety fence 1 m around it, total 14 m.
Materials and Installation							
Manhole	Precast concrete, 4' dia., 8' deep (includes excavation of 34.2 Bm^3, formed concrete footing, frame & cover, steps, compacted backfill) (material)	$2,837.00		lump sum	$2,837.00	$2,837.00	
	Labour & equipment	$2,354.00		lump sum	$2,354.00	$2,354.00	
	Loading excavated soil	15%		% of excavation cost	$53.10	$53.10	Used 15% of RSMeans cost for 4' dia., 8' deep manhole includes an excavation cost of $354 to excavate 34.2 Bm^3
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$179.08	$179.08	Assumed swell factor of 25% (*US Army 2000) and 20 min. cycle time to dump elsewhere on site. Assume all 34.2 Bm^3 excavated is hauled away
Geotextile - bottom, sides & top	Polypropylene filtration fabric (materials)	$3.10		$/m^2	$1,162.50	$1,162.50	Assumed this RSMeans line is suitable. Area = 101.8 m^2 (top) + 101.8 m^2 (bottom) + [2 sides x (50.88 m x 1.62 m deep)] + [2

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost - other source ($CND)	Units	Roof Only	Road & Roof	Assumptions/Notes
							ends x (2 m x 1.62 m deep)] = 375 m^2 total area.
	2 labourers	$0.40		$/m^2	$150.00	$150.00	
Hydrodynamic Separator	Downstream Defender - 4' wide (material + delivery)		$12,000.00	lump sum	$0.00	$12,000.00	
	Assume installation cost is roughly similar to that of 4' dia., 10' deep precast manhole in RSMeans that includes 47.9 Bm^3 excavation (labour & equipment)	$2,883.00		lump sum	$0.00	$2,883.00	
	Loading excavated soil	15%		% of excavation cost	$0.00	$432.45	
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$0.00	$250.81	Assumed swell factor of 25% (*US Army 2000) and 20 min. cycle time to dump elsewhere on site. Assume all 47.9 Bm^3 excavated is hauled away
Pipe from separator to manhole - 2 m long trench	Trenching, common earth, no slope, 2' wide, 6' deep; 3/8 cy bucket hydraulic track-mounted backhoe, backfill, compaction, removal of spoil by truck; the backfill has been reduced to take into account pipe of suitable size & bedding (labour)	$15.12		m	$0.00	$30.24	
	Equipment	$5.58		m	$0.00	$11.16	
Pipe from separator to manhole - attach 300 mm pipe to both separator & manhole	Armtec Boss 2000 solid pipe, 300 mm dia. (material)		$22.81	m	$0.00	$45.62	
	Armtec Boss 2000 solid pipe, 300 mm manhole adaptor (material)		$46.00	ea.	$0.00	$46.00	
	Labour		$200.00	ea.	$0.00	$400.00	Assume cost is similar to attaching pipe to separator
Pipe from separator to manhole - pipe bedding	Pipe bedding, side slope 0 to 1, 2' wide, pipe size 10" dia., compacted sand for bedding & 12" above pipe; pipe, trench, backfill not included (material)	$8.22		m	$0.00	$16.44	
	Labour & equipment	$5.10		m	$0.00	$10.20	
Attachment for pipe from parking lot to separator (do not cost pipe/trench, just cost out the attachment)	Labour		$200.00	ea	$0.00	$200.00	Assume cost is similar to attaching pipe to a separator
Attachment for pipe from roof to control manhole (do not cost pipe/trench, just cost out the attachment)	Armtec Boss 2000 solid pipe, 200 or 300 mm manhole adaptor (material)		$42.08	ea	$42.08	$42.08	Assume close to cost of 250 mm adaptor ($42.08).
	Labour		$200.00	ea	$200.00	$200.00	
Attach overflow pipe to control manhole (do not cost pipe/trench, just cost out the attachment)	Armtec Boss 2000 solid pipe, 300 mm manhole adaptor (material)		$46.00	ea	$46.00	$46.00	
	Labour		$200.00	ea	$200.00	$200.00	
Inlet pipe - attach pipe to both control manhole & perforated pipe	Armtec Boss 2000 solid pipe, 300 mm dia. (material)		$22.81	m	$6.84	$6.84	
	Armtec Boss 2000 300 mm manhole adaptor (material)		$46.00	ea	$46.00	$46.00	
	Labour to attach pipe to manhole		$200.00	ea	$200.00	$200.00	
	Labour to attach pipe to perforated pipe		$50.00	ea	$50.00	$50.00	
Perforated pipe	Armtec Boss 2000 perforated pipe, 300 mm dia. (material)		$23.75	m	$1,194.15	$1,194.15	Assumed length of pipe is 2' (0.6m) less than length of trench.
	Installation of storm drainage piping, HDPE, 300 mm dia.; 1 foreman, 1 skilled labourer, 1 labourer (labour)	$12.52		m	$629.51	$629.51	
	Armtec Boss 2000 end cap, belled (300 mm) (material)		$11.46	ea	$11.46	$11.46	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost - other source ($CND)	Units	Roof Only	Road & Roof	Assumptions/Notes
	Labour		$50.00	ea	$50.00	$50.00	
Line inside of pipe with filter cloth & expandable rings	Assume polypropylene filtration fabric (materials)	$3.10		$/m^2	$148.80	$148.80	Assumed this RSMeans line is suitable. Area = 50.58 m (length) x 3.14 x 0.3 m = 48 m^2.
	Labour	$50.00		hr	$200.00	$200.00	Assume 2 labourers, 2 hours
Monitoring wells	Armtec Boss 2000 perforated pipe, 150 mm dia. (material)		$10.94	m	$59.51	$59.51	
	Installation of storm drainage piping, HDPE, 150 mm dia.; 1 foreman, 1 skilled labourer, 1 labourer (labour)	$10.86		m	$59.08	$59.08	Each monitoring well is 2.72 m deep. There are 2 wells.
	Cast iron cap (assume these can be used for caps at surface)		$65.00	ea	$130.00	$130.00	
	Labour		$50.00	ea	$100.00	$100.00	
	Footplate - assume we can use Armtec Boss 2000 endcap, 150 mm dia., although this may be an underestimate.		$2.92	ea	$5.84	$5.84	
	Labour		$50.00	ea	$100.00	$100.00	
50 mm stone	50 mm clear limestone (materials)		$36.00	$/Cm^3	$5,806.80	$5,806.80	Calculated volume as follows: total vol = 101.8 m^2 area x 1.62 m depth = 164.9 m^3; vol of pipe = π(0.15 m)(0.15 m) x 50.28 m = 3.6 m^3; thus, vol of stone req'd = 164.9 m^3 - 3.6 m^3 = 161.3 m^3.
	1.5 m^3 excavator + 1 labourer (labour)	$1.23		$/Bm^3	$198.40	$198.40	Assumed cost to place stone is similar to that of excavating soil (100 Bm^3/hr).
	1.5 m^3 excavator	$1.88		$/Bm^3	$303.24	$303.24	
Compact stone	21" wide walk-behind vibrating plate compactor, 2 passes, 12" lifts (equipment)	$0.11		$/Em^3	$17.74	$17.74	2 passes fine for light compaction and that with this stone hardly need compaction.
	21" wide walk-behind vibrating plate compactor, 2 passes, 12" lifts; 1 labourer (labour)	$1.01		$/Em^3	$162.91	$162.91	
Place fill	1.5 m^3 excavator + 1 labourer (labour)	$1.23		$/Bm^3	$93.97	$93.97	Assumed cost to place fill is similar to that of excavating soil (100 Bm^3/hr). volume = 101.8 m^2 x 0.750 m = 76.4 m^3.
	1.5 m^3 excavator	$1.88		$/Bm^3	$143.63	$143.63	
Compact fill in 6" lifts to 95% Proctor density	Compact in 200 mm lifts with vibrating plate compactor (labour)	$2.83		$/Cm^3	$216.21	$216.21	Assume same cost whether compacted in 200 or 150 mm lifts.
	Equipment	$0.25		$/Cm^3	$19.10	$19.10	
	Proctor test	$149.45		$/test	$149.45	$149.45	1 test required
	Nuclear density test	$42.81		$/test	$171.24	$171.24	
SUBTOTAL					**$25,069**	**$41,395**	
Fees							
Project Overhead		10.00%		% of sub total	$2,506.86	$4,139.45	
TOTAL					**$27,575**	**$45,534**	

Table A4: Infiltration chambers

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Roof Only	Road & Roof	Assumptions/Notes
Site Investigation							
Dig test pit 1	80 HP backhoe (equipment)	$24.88		$/m^3	$69.66	$69.66	Assume test pit is 1 m x 1 m, 1.8 m deep, & sloped 1:1 above 1.2 m depth. RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$138.82	$138.82	
Dig test pit 2	80 HP backhoe (equipment)	$24.88		$/m^3	$69.66	$69.66	
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$138.82	$138.82	
Infiltration tests	Double-ring infiltrometer	$608.85		$/test	$2,435.40	$2,435.40	2 infiltration tests per test pit
Soil strength testing							Not costed; assumed geotech tests done previously
Soil quality testing							Not costed; assumed soil dumped elsewhere on site
Site Preparation							
Pre-construction meeting	Part of Overhead				$0.00	$0.00	
Stakeout of utilities	Assume no interfering utilities found as a result		$500.00	lump sum	$500.00	$500.00	
Erosion and sediment controls		$2.21		$/m	$26.52	$26.52	Silt fence along one edge ~ 12 m (decided by Mariko Uda & Lisa Rocha)
	2 labourers	$1.77		$/m	$21.24	$21.24	
Mobilization/demobilization	Active construction site, so all equipment on site				$0.00	$0.00	
Excavation							
Vegetation removal	Clearing, grubbing, haul away material				$0.00	$0.00	Active construction site, assume already done
Topsoil salvage, haul to stockpile	200 HP dozer + 0.5 labourer (labour)	$1.15		$/m^3	$18.29	$18.29	6" removed, 60 m travel to stockpile
	200 HP dozer (equipment)	$2.06		$/m^3	$32.75	$32.75	6" removed, 60 m travel to stockpile
Excavate	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.23		$/Bm^3	$223.86	$223.86	Assumed common earth, 100 Bm^3/hr (interpolated in RSMeans), that depth is 1.65 m (1.8 m - 0.15 m topsoil already removed), that excavation is sloped 1:1 above 1.2 m depth.
	1.5 m^3 bucket excavator (equipment)	$1.88		$/Bm^3	$342.16	$342.16	
	Loading - 15% of excavation cost			%	$84.90	$84.90	
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$788.57	$788.57	Assumed swell factor of 25%*, assumed 20 min. cycle time to dump elsewhere on site. Assumed volume to haul away is excavated volume (182 Bm^3) minus volume to be reused as fill (300 mm x 104.7 m^2 = 31.4 Bm^3). So, haul away 150.6 Bm^3.
Level subgrade	Can be done as part of excavation step.				$0.00	$0.00	
Safety fencing	4' high, 1 week rental, including setup & takedown).	$650.00		lumpsum	$650.00	$650.00	Assume 6 m around perimeter of excavation -> total 89 m
Materials and Installation							
Manhole	Precast concrete, 4' dia., 8' deep (includes excavation of 34.2 Bm^3, formed concrete footing, frame & cover, steps, compacted backfill) (material)	$2,837.00		lump sum	$2,837.00	$2,837.00	This RSMeans cost does not include hauling away excavated soil or pipe connections
	Labour and equipment	$2,354.00		lump sum	$2,354.00	$2,354.00	
	Loading excavated soil - 15% of excavation cost			%	$53.10	$53.10	RSMeans cost for 4'dia., 8' deep manhole includes an excavation cost of $354 to excavate 34.2 Bm^3
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$179.08	$179.08	Assumed swell factor of 25% (*US Army 2000), assumed 20 min. cycle time to dump elsewhere on site. Assume all 34.2 Bm^3 excavated is hauled away.
Hydrodynamic Separator	Downstream Defender - 4' wide (material + delivery)		$12,000.00	lump sum	$0.00	$12,000.00	
	Assume installation cost is roughly similar to that of 4' dia., 10' deep precast manhole in RSMeans that includes 47.9 Bm^3 excavation (labour & equipment)	$2,883.00		lump sum	$0.00	$2,883.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Roof Only	Road & Roof	Assumptions/Notes
	Loading excavated soil - 15% of excavation cost			%	$0.00	$432.35	
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$0.00	$250.81	Assumed swell factor of 25% (*US Army), assumed 20 min. cycle time to dump elsewhere on site. Assume all 47.9 Bm^3 excavated is hauled away.
Pipe from separator to manhole - 2 m long trench	Trenching, common earth, no slope, 2' wide, 6' deep; 3/8 cy bucket hydraulic track-mounted backhoe, backfill, compaction, removal of spoil by truck; the backfill has been reduced to take into account pipe of suitable size & bedding (labour)	$15.12		m	$0.00	$30.24	
	Equipment	$5.58		m	$0.00	$11.16	
Pipe from separator to manhole - attach 300 mm pipe to both separator & manhole	Armtec Boss 2000 solid pipe, 300 mm dia. (material)		$22.81	m	$0.00	$45.62	
	Armtec Boss 2000 solid pipe, 300 mm manhole adaptor (material)		$46.00	ea.	$0.00	$46.00	
	Labour		$200.00	ea.	$0.00	$400.00	
Pipe from separator to manhole - pipe bedding	Pipe bedding, side slope 0 to 1, 2' wide, pipe size 10" dia., compacted sand for bedding & 12" above pipe; pipe, trench, backfill not included (material)	$8.22		m	$0.00	$16.44	
	Labour and equipment	$5.10		m	$0.00	$10.20	
Attach pipe from parking lot to separator (do not cost pipe/trench, just cost out the attachment)	Labour		$200.00	ea	$0.00	$200.00	
Attach pipe from roof to control manhole (do not cost pipe/trench, just cost out the attachment)	Armtec Boss 2000 solid pipe, 200 or 300 mm manhole adaptor (material)		$42.08	ea	$42.08	$42.08	Assume close to cost of 250mm adaptor ($42.08).
	Labour		$200.00	ea	$200.00	$200.00	
Attach overflow pipe to control manhole (do not cost pipe/trench, just cost out the attachment)	Armtec Boss 2000 solid pipe, 300 mm manhole adaptor (material)		$46.00	ea	$46.00	$46.00	
	Labour		$200.00	ea	$200.00	$200.00	
Inlet pipe to chamber - attach pipe to both control manhole & chamber	Armtec Boss 2000 solid pipe, 600 mm manhole adaptor (material)		$135.98	ea	$135.98	$135.98	
	Labour to attach pipe to manhole		$200.00	ea	$200.00	$200.00	
	Labour to attach pipe to chamber		$50.00	ea	$50.00	$50.00	
Geotextile surrounding stone	Polypropylene filtration fabric (materials)	$3.10		$/m^2	$784.30	$784.30	Assumed this RSMeans line is suitable for the Class 2 non-woven geotextile. Area = 104.7 m^2 (top) + 104.7 m^2 (bottom) + (41.186 m perimeter x 1.067 m deep) = 253 m^2 total area. account.
	2 labourers	$0.40		$/m^2	$101.20	$101.20	
50 mm stone, 6" (152mm) deep, place	50 mm clear limestone (materials)		$36.00	$/Cm^3	$572.76	$572.76	
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.23		$/Bm^3	$19.57	$19.57	Assumed cost is similar to cost of excavation
	1.5 m^3 bucket excavator (equipment)	$1.88		$/Bm^3	$29.91	$29.91	
Level the stone	Hand grade select gravel (2 labourers)	$1.56		$/m^2	$163.33	$163.33	
Geotextile for scour protection	Polypropylene filtration fabric (materials)	$3.10		$/m^2	$107.57	$107.57	Assumed this RSMeans line is suitable for the Class 1 woven geotextile. Area = 3.8 m x 9.138 m = 34.7 m^2 total area.
	2 labourers	$0.40		$/m^2	$13.88	$13.88	
Infiltration chambers & end caps	Stormtech SC-740 chambers		$96.00	$/m^3 storage	$6,535.68	$6,535.68	Material + delivery cost for chambers, endcaps, fittings, couplers, geotextile is approximately $100/m^3 of storage. Exclude geotextile at approximately $1/m^2. Estimated cost is $96/m^3 of storage.
	2 labourers	$50.00		$/person-hr	$100.00	$100.00	Installation rate is 30 chambers per hour by 2 labourers
Geotextile for isolator row	Polypropylene filtration fabric (materials)	$3.10		$/m^2	$0.00	$162.13	Assumed this RSMeans line is suitable for the Class 1 & 2 woven geotextile. Class 1 geotextile on bottom: area = 1.4 m x 10.9 m x 2 layers = 30.5 m^2. Class 2 geotextile on top/sides: area = perimeter of half-circle of 2 m x 10.9 m = 21.8 m^2 thus,

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Roof Only	Road & Roof	Assumptions/Notes
							total area of geotextile = 52.3 m^2.
	2 labourers	$0.40		$/$m^2$	$0.00	$20.92	
50mm stone, fill around chambers and 6" (152 mm) over top	50 mm clear limestone (materials)		$36.00	$/$Cm^3$	$2,044.80	$2,044.80	Calculated volume as follows: total vol = 104.7 m^2 area x (1.067 m depth - 152 mm stone depth below) = 95.8 m^3; vol inside chambers = 30 chambers x 1.3 m^3/chamber = 39 m^3; thus, vol of stone req'd = 95.8m^3 - 39 m^3 = 56.8 m^3.
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.23		$/$Bm^3$	$69.86	$69.86	Assumed cost is similar to cost of excavation
	1.5 m^3 bucket excavator (equipment)	$1.88		$/$Bm^3$	$106.78	$106.78	
Level the stone	Hand grade select gravel (2 labourers)	$1.56		$/$m^2$	$163.33	$163.33	
Well-graded soil, 390 mm depth, compacted	Assume native soil on-site is suitable (so no material cost)				$0.00	$0.00	
	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.23		$/$Bm^3$	$50.18	$50.18	Assumed cost is similar to cost of excavation. Compacted volume = 390 mm x 104.7 m = 40.8 Cm^3
	1.5 m^3 bucket excavator (equipment)	$1.88		$/$Bm^3$	$76.70	$76.70	
	Compact in 200 mm lifts with vibrating plate compactor (labour)	$2.83		$/$Cm^3$	$115.46	$115.46	Assume same cost whether compacted in 200 or 300mm lifts.
	Equipment	$0.25		$/$Cm^3$	$10.20	$10.20	
	Proctor test	$149.45		$/test	$149.45	$149.45	1 test required
	Nuclear density test	$42.81		$/test	$171.24	$171.24	Average of 4 tests required - test is done to check compaction.
SUBTOTAL					**$23,224**	**$39,733.10**	
Fees							
Project Overhead		10.00%		% of sub total	$2,322.41	$3,973.31	
TOTAL					**$25,547**	**$43,706**	

Table A5: Enhanced grass swale

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost - other source ($CND)	Units	Curb check dam	Filter sock check dam	Rock check dam	Assumptions/Notes
Site Investigation								
Dig test pit 1	80 HP backhoe (equip)	$24.88		$/m^3	$29.86	$29.86	$29.86	Test pit is 1m x 1m x 1.275m, therefore volume is ~ 1.2m^3 RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$59.50	$59.50	$59.50	
Dig test pit 2	80 HP backhoe (equip)	$24.88		$/m^3	$29.86	$29.86	$29.86	Test pit is 1m x 1m x 1.275m, therefore volume is ~ 1.2m^3 RSMeans costs for light & heavy soil were averaged.
	80 HP backhoe + 1 labourer (labour)	$49.58		$/m^3	$59.50	$59.50	$59.50	
Infiltration tests	Double-ring infiltrometer	$608.85		$/test	$2,435.40	$2,435.40	$2,435.40	2 infiltration tests per test pit
Soil quality testing	Not costed; assumed soil dumped elsewhere on site.							
Site Preparation								
Preconstruction meeting	Part of overhead							
Stakeout of utilities	Assume no interfering utilities are found as a result.		$500.00	lump sum	$500.00	$500.00	$500.00	
Tree & plant protection	Assume no trees							
Traffic control	Assume not required							
Install erosion & sediment control and control drainage	2" submersible gas pump (incl. gas)	$81.15		$/day	$243.45	$243.45	$243.45	Assume 3 days
	Silt sack in catchbasin		$65.00	$/unit	$65.00	$65.00	$65.00	
	Silt fence 1m around excavation (material)	$2.21		$/m	$341.00	$341.00	$341.00	Assume distance is 2x(69.9 m + 2m) + 2x(3.25 m + 2m), total is 154.3 m. Swale 61.5 m + driveway 8.4 m = 69.9 m.
	Silt fence 1m around excavation (labour)	$1.77		$/m	$273.11	$273.11	$273.11	
Mobilization/demobilization	Active construction site so all equipment on site					$0.00	$0.00	
Excavation								
Vegetation removal	Clearing, grubbing, haul away material				$0.00	$0.00	$0.00	Active construction site, assume already done
Topsoil salvage, haul to stockpile	200 HP dozer (equip)	$2.06		$/m^3	$0.00	$0.00	$0.00	Assumed already done as part of regular construction
	200 HP dozer + 0.5 labourer (labour)	$1.15		$/m^3	$0.00	$0.00	$0.00	
Excavation	1.5 m^3 bucket excavator + 1 labourer (labour)	$1.24		$/Bm^3	$88.68	$88.68	$88.68	Assume excavation rate of 100 Bm^3/hr (Mark Preston). Excavation is sloped 2.5:1 along edges 0.5 m depth. Excavation of swale (L 61.5 m, V 62.49 m^3) and driveway with additional 0.15 m depth non-sloped (L 8.4m, V 10.33 m^3), total Volume = 72.82 m^3
	1.5 m^3 bucket excavator (equipment)	$1.89		$/Bm^3	$135.17	$135.17	$135.17	Swale bottom = 23.06, sides = 38.91, Corners - 0.52, swale total = 62.49 m^3, Driveway bottom = 4.1, slopes = 5.72, corners - 0.52, Driveway total - 10.33 m^3, TOTAL EXCAVATION = 72.82 m^3
Loading excavated soil		15%		% of excavation cost	$33.58	$33.58	$33.58	
Hauling excavated soil	13.76m^3 truck (incl. driver)	$172.92		$/hr/truck	$397.72	$397.72	$397.72	71.52 m^3 x 1.25 (swell factor, US Army 2000*) = 89.4 Lm^3; thus, 6.5, so 7 truckloads. Assume 20 min. cycle time to dumb elsewhere on site; thus, 2 hours and 20 minutes /truck
Safety fencing	4' high fencing, 6m around perimeter of excavation. Assume 1 week rental (incl. setup & takedown).		$800.00	lump sum for 124m	$800.00	$800.00	$800.00	
Materials and Installation								
HDPE Pipe	Pipe to sewer - 200 mm diameter Armtec Boss 2000, corrugated with smooth inner wall (material)		$15.37	$/m	$76.85	$76.85	$76.85	
	Pipe to sewer (labour)	$11.40		$/m	$57.00	$57.00	$57.00	
	Delivery for all pipes		$50.00	lumpsum	$50.00	$50.00	$50.00	
HDPE Pipe Fittings	Pipe to sewer:-manhole adapter (200 mm)	$36.38		$/unit	$36.38	$36.38	$36.38	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost - other source ($CND)	Units	Curb check dam	Filter sock check dam	Rock check dam	Assumptions/Notes
Pipe Fittings: Labour	Pipe to sewer:manhole adapter (200 mm)	$200.00		$/unit	$200.00	$200.00	$200.00	
Pipe to sewer trenching	Pipe trenching & backfill, 0.6m wide, 1.2m deep, no slope	$15.59		$/m	$77.95	$77.95	$77.95	
	Pipe bedding, 0.6m wide	$13.18		$/m	$65.90	$65.90	$65.90	
Pipe for culvert	300 mm, 1.6 mm thickness		$40.00	$/m	$336.00	$336.00	$336.00	Smaller than recommended however small depth, 8.4 m width
	Labour	$11.40		$/m	$95.76	$95.76	$95.76	Assumed to be the same as HDPE pipe
	Delivery		$50.00	lumpsum	$50.00	$50.00	$50.00	Assumed to be the same as HDPE pipe
Curbs & gutter with curb inlets	150 mm high curb, 150 mm thick gutter, 600 mm wide (not sure if reinforced) (material)	$88.35		$/m	$5,433.53	$5,433.53	$5,433.53	Assumed perimeter along one side, not including driveway
	Labour	$26.26		$/m	$1,614.99	$1,614.99	$1,614.99	
Catchbasins	Frame and cover		$500.00	each	$500.00	$500.00	$500.00	
	Catchbasin		$367.00	m	$279.65	$279.65	$279.65	Minimum size is 0.762 m
	Installation		$500.00	each	$500.00	$500.00	$500.00	
Sod	Material		$2.00	$/m^2	$441.00	$441.00	$441.00	Sod covers bottom (46.15 m^2) and sides (174.34 m^2), total 220.5 m^2
	Labour		$1.00	$/m^2	$220.50	$220.50	$220.50	
Check dams	0.3 m curb		$150.00	$/m^2	$337.50	$0.00	$0.00	1 m long, 0.3 m high curbs, length 0.75 m bottom, then up sides 0.75 in length to reach 0.3 m height, so 0.75*3 = 2.25 m for each check dam
	Biofilter sock		$15.00	$/m	$0.00	$20.25	$0.00	1 m long, 0.3 m high for each check dam
	Rocks 50 mm clear (material)		$36.00	$/m^3	$0.00	$0.00	$19.44	Main section 0.75 m wide by 0.3 m high by minimum 0.6 m length (0.135 m^3), plus front and back slopes at 2:1 ratio (0.068 m^3 per slope), plus sides of main section (0.068 m^3 per side), plus sides of front and back slopes (0.034 m^3 per slope side), TOTAL 0.54 m^3
	Rocks 50 mm clear (labour)	$173.11		$/m^3	$0.00	$0.00	$93.48	
	Geotextile Material	$3.10		$/m^2	$0.00	$0.00	$9.77	Geotextile required under rock check dam
	Geotextile Labour	$0.40		$/m^2	$0.00	$0.00	$1.26	
Stone inlets	50 mm clear (material)		$36.00	$/Cm^3	$16.20	$16.20	$16.20	Assume 50 mm clear, 100mm deep, 1 every 6 m. Area = 0.5m^2 x 9 inlets = 4.5 m^2. Vol = 4.5 m^2 x 0.1 m = 0.45 m^3.
	Spread by hand (labour)	$173.11			$77.90	$77.90	$77.90	
	Geotextile Material	$3.10		$/m^2	$13.95	$13.95	$13.95	Assume 50 mm clear, 100mm deep. Area = 0.5m^2 x 9 inlets = 4.5 m^2.
	Geotextile Labour	$0.40		$/m^2	$1.80	$1.80	$1.80	
Headwalls for culvert	Headwall on either side of driveway		$200.00	each	$400.00	$400.00	$400.00	
50mm stone	50 mm clear limestone (materials)		$36.00	$/Cm^3	$291.60	$291.60	$291.60	Free draining backfill around pipe in culvert, surrounding pipe, 0.15 m below (rectangle trench) and 0.15 m above
	1.5 m^3 excavator + 1 labourer (labour)	$1.23		$/Bm^3	$9.96	$9.96	$9.96	Volume of pipe = 0.59 m^3, volume of backfill: flat - 3.645, slopes 5.06, total 8.708 m^3. Backfill - pipe volume - 8.1 m^3
	1.5 m^3 excavator	$1.88		$/Bm^3	$15.23	$15.23	$15.23	
Compact stone	21" wide walk-behind vibrating plate compactor, 2 passes, 6" lifts (equip)	$0.11		$/Em^3	$0.89	$0.89	$0.89	Assumed cost is the same whether compacted in 6" or 12" lifts
	21" wide walk-behind vibrating plate compactor, 2 passes, 6" lifts; 1 labourer (labour)	$1.01		$/Em^3	$8.18	$8.18	$8.18	
	Proctor test	$149.45		$/test	$149.45	$149.45	$149.45	
	Nuclear density test	$42.81		$/test	$42.81	$42.81	$42.81	Assume 1 would be sufficient with smaller area
SUBTOTAL					**$16,893**	**$16,576**	**$16,679**	
Fees								
Project Overhead		10.00%		% of subtotal	$1,689.28	$1,657.56	$1,667.92	
TOTAL					**$18,582.08**	**$18,233.11**	**$18,347.17**	

Table A6: Rainwater harvesting

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Concrete Tank Outdoor	Plastic Tank Indoor	Assumptions/Notes
Site Investigation							
Soil strength testing					$0.00	$0.00	Not costed; assumed geotech tests done previously
Soil quality testing					$0.00	$0.00	Not costed; assumed soil dumped elsewhere on site
Site Preparation							
Preconstruction meeting	Part of overhead				$0.00	$0.00	
Stakeout of utilities	Assume no interfering utilities are found as a result.		$500.00	lump sum	$500.00	$0.00	
Mobilization/demobilization	Active construction site, so all equipment on site				$0.00	$0.00	
Excavation							
Conveyance Pipe trenching & backfill	0.6 m wide, 1.2 m deep, no slope	$15.59		m	$155.90	$0.00	
Conveyance Pipe Excavation	1.5 m^3 bucket excavator + 1 labourer (labour)	$2.48		Bm^3	$62.25	$0.00	Assumed common earth, 50 Bm^3/hr (guesstimate by Mariko Uda because this is a small excavation), excavation is 18" around tank (assume same clearance as for rainwater harvesting tank; see below) and sloped 1:1 about 1.2 m depth, and that tank is buried 0.5 m with 6" of bedding underneath
	1.5 m^3 bucket excavator (equipment)	$3.78		Bm^3	$94.88	$0.00	
	Loading - 15% of excavation cost			%	$5.85	$0.00	Assume only 6.3 Bm^3 of soil (vol of tank & bedding) is hauled away. Excavation cost of just 6.3 Bm^3 is ($62 + $95) * 6.3 Bm^3 / 25.1 Bm^3 = $39
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		hr	$32.85	$0.00	Assume only 6.3 Bm^3 of soil (vol of tank & bedding) is hauled away. 6.3 Bm^3 x 1.25 (swell factor, US Army 2000*) = 7.88 Lm^3; thus, 0.57 truckload. Assume 20 min. cycle time to dump elsewhere on site. Thus, 0.19 truck-hours
Tank Excavation	1.5 m^3 bucket excavator + 1 labourer (labour)	$2.48		Bm^3	$277.51	$0.00	Assumed common earth, 50 Bm^3/hr (guesstimate by Mariko Uda because this is a small excavation), excavation is 18" around tank (according to Technical Advisory Council for Onsite Wastewater Treatment 2006*, put min 18" clearance on all sides of precast concrete septic tank) and sloped 1:1 above 1.2 m depth, and that tank is buried 0.75 m with 6" of bedding underneath.
	1.5 m^3 bucket excavator (equipment)	$3.78		Bm^3	$422.98	$0.00	
	Loading - 15% of excavation cost			%	$29.10	$0.00	Assume only 31.0 Bm^3 of soil (vol of tank & bedding) is hauled away. Excavation cost of just 31.0 Bm^3 is ($278 + $423) * 31.0 Bm^3 / 111.9 Bm^3 = $194.
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		hr	$162.54	$0.00	Assume only 31.0 Bm^3 of soil (vol of tank & bedding) is hauled away. 31.0 Bm^3 x 1.25 (swell factor, US Army 2000*) = 38.75 Lm^3; thus, 2.82 truckload. Assume 20 min. cycle time to dump elsewhere on site. Thus, 0.94 truck-hours.
Service pipe: burying					$0.00	$0.00	Buried with conveyance pipe
Top-up pipe: burying					$0.00	$0.00	Assume for simplicity that top-up pipe is buried in same trench as conveyance & service pipes
Overflow pipe trenching & backfill	0.6 m wide, 1.2 m deep, no slope	$15.59		m	$0.00	$0.00	Do not cost as would be needed even without rainwater harvesting
Materials and Installation							
Conveyance Pipe							
PVC SDR 35	300 mm diameter (material)	$75.31		m	$753.10	$0.00	Just costed length from exterior of building to tank
	300 mm diameter (labour)	$16.20		m	$162.00	$0.00	
	300 mm diameter	$1.62		m	$16.20	$0.00	
Pipe bedding	0.6 m wide	$13.18		m	$131.80	$0.00	
Inline German-style filter	3P VF4 by 3P Technik, which is suitable for a		$5,825.00	ea	$5,825.00	$5,825.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Concrete Tank Outdoor	Plastic Tank Indoor	Assumptions/Notes
	2000 m^2 catchment						
Precast concrete tank to put filter in	2.1 m long x 1.5 m wide x 1.7 m deep		$3,000.00	ea	$3,000.00	$3,000.00	
Installation of filter into tank and delivery of combined tank/filter	RH20 provides service to install 3P VF4 filter into tank		$2,000.00	ea	$2,000.00	$2,000.00	
Bedding	20 mm clear (material)		$37.00	m^3	$33.74	$0.00	Concrete tanks usually have bedding of 6" of 20-25 mm clean stone. Vol = 6" (152 mm) x 3 m x 2 m = 0.912 m^3
	1.5 m^3 bucket excavator + 1 labourer (labour)	$2.11		m^3	$1.92	$0.00	Assumed cost is similar to cost of excavation but for gravel. Used RSMeans bost for excavationi but deducted 15% as suggested by RSMeans for soft soil or sand. Assumed similar for gravel
	1.5 m^3 bucket excavator (equipment)	$3.21		m^3	$2.93	$0.00	
Attach inflow, outflow and overflow pipes to tank			$100.00	ea	$300.00	$300.00	
Backfill	80 HP dozer + 0.5 labourer (labour)	$1.02		Lm^3	$26.62	$0.00	Vol of backfill = vol of excavated (25.06 Bm^3) - vol of tank (5.355 m^3) - vol of bedding (0.912 Cm^3) = 18.8 Cm^3. Assuming swell factor of 25% and compaction factor of 0.9 (US Army 2000*), 18.8 Cm^3 would equal 26.1 Lm^3 (18.8 Cm^3 * 1.25 / 0.9).
	80 HP dozer (equipment)	$0.66		Lm^3	$17.23	$0.00	
Compact backfill	Walk-behind vibrating plate (labour)	$3.07		Cm^3	$57.72	$0.00	
	Walk-behind vibrating plate (equipment)	$0.28		Cm^3	$5.26	$0.00	
<u>Tank</u>							
Pre-cast concrete (below ground)			$0.30	L	$6,900.00	$0.00	
Standard tank access riser			$418.00	ea	$418.00	$0.00	
Plastic tank (above-ground)			$0.29	L	$0.00	$6,670.00	
Concrete tank delivery			$233.00	tank	$233.00	$0.00	
Bedding	20 mm clear (material)		$37.00	m^3	$106.19	$0.00	Concrete tanks usually have bedding of 6" of 20-25 mm clean stone. Vol = 6" (152 mm) x 3.2 m x 5.9 m = 2.87 m^3.
	1.5 m^3 bucket excavator + 1 labourer (labour)	$2.11		m^3	$6.06	$0.00	Assumed cost is similar to cost of excavation but for gravel. Used RSMeans cost for excavation but deducted 15% as suggested by RSMeans for soft soil or sand. Assumed similar for gravel.
	1.5 m^3 bucket excavator + 1 labourer (equipment)	$3.21		m^3	$9.21	$0.00	
Installation/craning	For precast concrete tanks > 20,000 L		$155.00	hr	$620.00	$0.00	
Attach connections (conveyance pipe, service pipe, overflow pipe, fill pipe, wiring)			$100.00	ea	$500.00	$500.00	
Backfill	80 HP dozer + 0.5 labourer (labour)	$1.02		Lm^3	$114.65	$0.00	Vol of backfill = vol of excav (111.94 Bm^3) - vol of tank (28.175 m^3) - vol of bedding (2.87 Cm^3) = 80.895 Cm^3. Assuming swell factor of 25% and compaction factor of 0.9 (US Army 2000*), 80.895 Cm^3 would equal 112.4 Lm^3 (80.895 Cm^3 * 1.25 / 0.9)
	80 HP dozer (equipment)	$0.66		Lm^3	$74.18	$0.00	
Compact backfill	Walk-behind vibrating plate (labour)	$3.07		Cm^3	$248.35	$0.00	
	Walk-behind vibrating plate (equipment)	$0.28		Cm^3	$22.65	$0.00	
<u>Plumbing Accessories</u>							
Submersible pump	81.2 lpm fountain pump with controls (material)	$2,485.00		ea	$2,485.00	$2,485.00	3/4 hp costs $2234.05 (material); thus $30.60 (material)/lpm. Thus for 81.2 lpm --> $2485 (material).
	81.2 lpm fountain pump with controls (labour)	$245.00		ea	$245.00	$245.00	3/4 hp costs $220.33 (labour); thus $3.02 (labour)/lpm. Thus for 81.2 lpm --> $245 (labour).
Pressure tank	439 L (116 gallons) potable water tank (material)	$3,362.49		ea	$3,362.49	$3,362.49	Steel water tanks can be used as pressure tanks

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Concrete Tank Outdoor	Plastic Tank Indoor	Assumptions/Notes
	439 L (116 gallons) potable water tank (labour)	$68.62		ea	$68.62	$68.62	
Pump float switch	Approx. 1hp		97.38	ea	$97.38	$97.38	
Pump float electrical wiring	Approx. 14 gauge	$1.76		m	$26.40	$8.80	
Service pipe: Polyethylene (PE) C901	40 mm diameter (material)	$5.15		m	$87.55	$25.75	PE C901 usually comes in coils or 20' lenghts, no couplings required
	40 mm diameter (labour)	$5.58		m	$94.86	$27.90	
Service pipe: Polyethylene (PE) C901 fittings	40 mm diameter elbow (material)	$7.24		ea	$28.96	$14.48	
	40 mm diameter elbow (labour)	$14.94		ea	$59.76	$29.88	
Service pipe through wall	Pipe sleeve with link seal for 1-1/2" diameter pipe (material)	$64.09		ea	$64.09	$0.00	
	Pipe sleeve with link seal for 1-1/2" diameter pipe (labour)	$93.80		ea	$93.80	$0.00	
Service pipe: hangers every meter indoors	Hanger consisting of clamp, clevis & rod (material)	$11.81		ea	$59.05	$35.43	
	Hanger consisting of clamp, clevis & rod (labour)	$15.69		ea	$78.45	$47.07	
Supply pipe: Copper Class K	40 mm diameter, includes couplings & hangers (material)	$46.95		m	$4,436.78	$4,436.78	
	40 mm diameter, includes couplings & hangers (labour)	$37.39		m	$3,533.36	$3,533.36	
Supply pipe: Copper fittings	40 mm diameter 90 degree elbows (material)	$20.98		ea	$629.40	$629.40	Assume cost of fittings on average is the cost of an elbow
	40 mm diameter 90 degree elbows (labour)	$43.78		ea	$1,313.40	$1,313.40	
Top-up float switch	Approx. 1/2 hp		$54.16	ea	$54.16	$54.16	
Top-up float electrical wiring	Approx. 14 gauge	$1.76		m	$26.40	$8.80	
Solenoid valve	Domestic/commerical, bronze, compound, flanged, 20 mm		$309.90	ea	$309.90	$309.90	
Water hammer arrestor	20 mm (material)	$22.48		ea	$22.48	$22.48	
	20 mm (labour)	$47.42		ea	$47.42	$47.42	
Water meter	40 mm (material)	$305.90		ea	$305.90	$305.90	
	40 mm (labour)	$75.88		ea	$75.88	$75.88	
Air gap (tundish)	3P Tundish by 3P Technik (material)		$75.00	ea	$75.00	$75.00	
	Tundish (labour)		$50.00	ea	$50.00	$50.00	
Top-up pipe: ABS (int. installation)	50 mm diameter, including couplings and hangers (material)	$8.49		m	$42.45	$42.45	
	50 mm diamter, including couplings and hangers (labour)	$54.26		m	$271.30	$271.30	
Top-up pipe: ABS elbow	50 mm diameter (material)	$2.53		ea	$2.53	$2.53	Assumed need atleast 1 elbow
	50 mm diameter (labour)	$31.01		ea	$31.01	$31.01	
Top-up pipe through wall	Pipe sleeve with link seal for 2" diameter pipe (material)	$75.05		ea	$75.05		Method used to bring pipes through walls in commercial applications
	Pipe sleeve with link seal for 2" diameter pipe (labour)	$106.68		ea	$106.68	$0.00	
Top-up pipe: ABS (ext.installation)	50 mm diameter (does not include coupling or hangers) (material)	$4.84		m	$48.40	$0.00	
	50 mm diameter (does not include coupling or hangers) (labour)	$28.22		m	$282.20	$0.00	
Top-up pipe: ABS couplings	50 mm diameter (material)	$1.06		ea	$1.06	$0.00	Assume 1 coupling required
	50 mm diameter (labour)	$31.01		ea	$31.01	$0.00	
Reduced pressure backflow preventer	50 mm (material)	$909.09		ea	$909.09	$909.09	
	50 mm (labour)	$81.17		ea	$81.17	$81.17	
Overflow							

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost (CND) - other source	Units	Concrete Tank Outdoor	Plastic Tank Indoor	Assumptions/Notes
PVC SDR 35	300 mm diameter	$93.13		m	$0.00	$0.00	Do not cost as would be needed even without rainwater harvesting
Pipe bedding	0.6 m wide	$13.18		m	$0.00	$0.00	
1 bend	PVC SDR 35, 300 mm diameter elbow (material)	$279.73		ea	$0.00	$0.00	
	PVC SDR 35, 300 mm diameter elbow (labour)	$101.85		ea	$0.00	$0.00	
SUBTOTAL					**$42,943.11**	**$36,942.82**	
Fees							
Project Overhead		10.00%		% of sub total	$4,294.31	$3,694.28	
TOTAL					**$47,237**	**$40,637**	

Table A7: Extensive greenroof

Item	Item detail	RSMeans Unit Cost (2010 or 2011$CND)	Unit cost ($CND) - other source	Units	Cheap	Expensive	Assumptions/Notes
Site Preparation							
Pre-construction meeting	Part of construction mgmt fee				$0.00	$0.00	
Mobilization/demobilization	Crane, 55 ton	$158.00		2-way	$316.00	$0.00	Assumed for 2 mobilizations/demobilization's because crane is initially needed to lift membrane, then is not needed until later for the rest of the materials.
Mobilization/demobilization	Crane, 100 ton	$453.00		way	$0.00	$1,812.00	Assumed for 2 mobilizations/demobilization's because crane is initially needed to lift membrane, then is not needed until later for the rest of the materials.
Crane							
55T crane to lift membrane, drainage layer, stone, edging, cuttings to under 5 storeys	Equipment & labour	$4,632.38		day	$13,897.14	$0.00	55T crane does 28 picks per day, will need it for 2.6 days - round up to 3 days.
100T crane to lift membrane, root barrier, drainage layer, stone, edging, sedum mats to 6-10 storeys	Equipment & labour	$5,152.38		day	$0.00	$56,676.18	100T crane does 21 picks per day will need it fo 11.2 days - round down to 11 days.
Materials and Installation							
Waterproof membrane: TPO	Material & delivery - TPO, 60mils thick, fully adhered	$12.48		m^2	$24,960.00	$0.00	
	Lift onto roof - equipment & labour	See above -Crane					
	Labour	$10.14		m^2	$20,280.00	$0.00	
	Equipment	$0.83		m^2	$1,660.00	$0.00	
	Extra labour for flashing around parapets & roof penetrations - assume labour cost similar to PVC sheet flashing	$17.22		m^2	$1,248.45	$0.00	Assume 330 mm of flashing around parapets, mechanical units and drains.
Waterproof membrane: EPDM	Material & delivery - EPDM, 60 mils thick, fully adhered	$18.21		m^2	$0.00	$36,420.00	
	Lift onto roof - equipment & labour	See above -Crane					
	Labour	$9.74		m^2	$0.00	$19,480.00	
	Equipment	$0.79		m^2	$0.00	$1,580.00	
	Extra labour for flashing around parapets & roof penetrations - assume labour cost similar to PVC sheet flashing	$17.22		m^2	$0.00	$1,248.45	Assume 330 mm of flashing around parapets, mechanical units and drains.
Water leakage test: EFVM	EFVM by International Leak Detection - cost to install grid & conduct initial test		$13.99	m^2	$0.00	$27,980.00	Tested in one visit
Water leakage test: other option more cheaper than EFVM	Applied potential electrical method or water lance method by I-CORP International - cost to do initial test		$3,000.00	lump sum	$3,000.00	$0.00	Conductive material is required below the waterproof membrane, assumed a concrete structure. These methods cannot be used for black EPDM, which has too much carbon content.
Root barrier (not needed for TPO, possibly needed for EPDM)	Material		$4.30	m^2	$0.00	$8,600.00	Average of quotes
	Lift onto roof - equipment & labour	See above -Crane					
	Labour - assume similar to laying drainage mat.	$4.16		m^2	$0.00	$8,320.00	
R20 insulation	Material - Dow Roofmate		$23.68	m^2	$47,360.00	$47,360.00	
	Lift onto roof - equipment & labour	See above -Crane					
	Labour	$4.95		m^2	$9,900.00	$9,900.00	
Drainage layer + filter cloth (combined):	Material + delivery: average cost of 3 different drainage layers (3RFoam, dimple board, and another dimple board).		$11.09	m^2	$22,180.00	$22,180.00	Average cost for drainage layer
	Onto roof - equipment & labour	See above -Crane					

Item	Item detail	RSMeans Unit Cost (2010 or 2011$CND)	Unit cost ($CND) - other source	Units	Cheap	Expensive	Assumptions/Notes
	Labour - similar to laying drainage mat	$4.16		m^2	$8,320.00	$8,320.00	
Irrigation system	Total installed cost		$10.76	m^2	$0.00	$21,520.00	Assumed irrigation cost costs approx. $1/sf.
Edging: aluminium	Permaloc's GeoEdge 4-1/2" aluminum edging		$30.70	m	$7,521.50	$0.00	
	Permaloc's GeoEdge 4-1/2" aluminum corners		$43.06	corner	$1,033.44	$0.00	No delivery cost included, assumed not significant. Assume pre-made corners for the 4 perimeter corners and the corners around the 5 mechanical units (4 corners each), but not for the drains.
	Permaloc's GeoEdge 6-1/2" aluminum edging		$46.05	m	$0.00	$11,282.25	
	Permaloc's GeoEdge 6-1/2" aluminum corners		$57.46	corner	$0.00	$1,379.04	No delivery cost included, assumed not significant. Assume pre-made corners for the 4 perimeter corners and the corners around the 5 mechanical units (4 corners each), but not for the drains.
	Onto roof - equipment & labour	See above -Crane					
	Labour - assume similar to installing lumber edging	$8.89		m	$2,311.40	$2,311.40	
Vegetation-free zone - 3" of 1-1/2" washed round stone	Material + delivery: average cost of 3 different suppliers		$7.93	m^2	$958.34	$958.34	
	Onto roof - equipment & labour	See above -Crane					
	Labour - assume similar to spreading same volume of pea gravel	$62.13		m^3	$1,568.38	$1,568.38	
4" growing medium - in bulk, not in sacks	Material - average of 3 suppliers		$13.00	m^2	$24,206.00	$0.00	
	Delivery in bulk		$0.85	m^2	$1,582.70	$0.00	
	Blowing onto roof with blower truck		$7.10	m^2	$13,220.20	$0.00	
6" growing medium - in sacks	Material		$23.40	m^2	$0.00	$43,570.80	
	Delivery of sacks		$1.99	m^2	$0.00	$3,705.38	
	Lifting onto roof with crane 6-10 stories & spreading - equipment & labour	$20.77		m^2	$0.00	$38,673.74	
Plants; sedum cuttings	Material		$2.12	m^2	$3,947.44	$0.00	
	Delivery		$0.11	m^2	$204.82	$0.00	
	Onto roof - equipment & labour	See above -Crane					
	Labour - assume similar to applying 2 bushels/1000 sf of sprigs	$0.31		m^2	$577.22	$0.00	Assumed an application rate of 25lb/1000 sf.
Plants; sedum plugs	Material		$4.30	m^2	$0.00	$0.00	Toronto's Green Roof Bylaw says min. 1 plug/sf.
	Delivery		$0.61	m^2	$0.00	$0.00	Assume truck cost of $500 plus $160 per rack. 4 racks would be needed. Therefore, total delivery charge is $1140, or $0.61/m2.
	Onto roof - equipment & labour	See above -Crane					
	Labour - assume similar to planting 2-1/4" potted plants at 1/sf.	$5.49		m^2	$0.00	$0.00	
Plants; sedum mats	Material		$31.22	m^2	$0.00	$58,131.64	This material includes 1" of growing medium, so we can minus 1" of growing medium.
	Delivery		$1.42	m^2	$0.00	$2,644.04	3 trucks needed at a cost of $750 each. Pallets are required for $390. Therefore total cost is $2640, or $1.42/$m^2$.
	Onto roof - equipment & labour	See above -Crane					
	Labour	$4.63		m^2	$0.00	$8,621.06	
	SAVINGS because can reduce growing medium by 1"		-$14,325.00	lump sum	$0.00	-$14,325.00	The savings are estimated at $14,325 if growing medium is in sacks & craned up 6-10 stories.
SUBTOTAL with membranes					**$210,253.03**	**$429,917.70**	
Fees							

Item	Item detail	RSMeans Unit Cost (2010 or 2011$CND)	Unit cost ($CND) - other source	Units	Cheap	Expensive	Assumptions/Notes
Project Overhead (10%)		10.00%		% of sub total	$21,025.30	$42,991.77	
TOTAL					**$231,278**	**$472,909**	
SUBTOTAL without membranes [1]							
Fees					**$100,054**	**$307,871**	
Project Overhead (10%)		10.00%			**$10,005**	**$30,787**	
TOTAL					**$110,060**	**$338,658**	

Notes: [1]Subtotal without membranes excluded costs for membranes and R20 insulation, as well craning was reduced to 1 day for cheap, and 2 days for expensive.

Table A8: Asphalt (used for comparative analysis)

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost ($CND) - other source	Units	Total ($CND)	Assumptions/Notes
Site Investigation						
Soil strength testing						Not costed; assumed geotech tests done previously
Soil quality testing						Not costed; assumed soil dumped elsewhere on site
Site Preparation						
Pre-construction meeting	Part of overhead					
Stakeout of utilities	Assume no interfering utilities found as a result		$500.00	lump sum	$500.00	
Mobilization/demobilization						Active construction site, so all equipment on site
Excavation						
Vegetation removal	Clearing, grubbing, haul away material				$0.00	Active construction site, assume already done
Topsoil salvage, haul to stockpile	6" removed, 60 m travel to stockpile, 200 HP dozer + 0.5 labourer (labour)	$1.15		$/m^3	$175.26	
	6" removed, 60 m travel to stockpile, 200 HP dozer (equipment)	$2.06		$/m^3	$313.94	
Excavate	1.5 m^3 bucket excavator + 1 labourer, productivity 100 Bm^3/hr (labour)	$1.24		$/Bm^3	$248.50	Assumed a productivity of 100 Bm^3/hr. Assumed common earth. 6" of topsoil has already been removed, so do not need to excavate full depth, plus catchbasins and pipe
	1.5 m^3 bucket excavator, productivity 100 Bm^3/hr (equipment)	$1.89		$/Bm^3	$378.76	60 m x 16.7 m x 0.2 m = 200.4 m3 for parking lot
	Loading	15%		% of excavation cost	$94.09	
	Hauling in a 13.76 m^3 truck (including truck & driver)	$172.92		$/hr	$1,038.84	Assumed swell factor of 25% (*US Army 2000), cycle time of 20 min.
Compaction of native soil	30,000 lb grader + 25T vibratory roller + 1 labourer (labour)	$1.16		$/m^2	$1,160.00	
	30,000 lb grader + 25T vibratory roller (equipment)	$1.14		$/m^2	$1,140.00	
	Proctor test	$149.45		$/test	$149.45	1 test required
	Nuclear density test	$42.81		$/test	$171.24	Avg. 4 tests required - test is done to check compaction.
Hydrodynamic Separator	-					
Hydrodynamic Separator	Downstream Defender - 4' wide (mat + delivery)		$12,000.00	lump sum	$0.00	
	Assume installation cost is roughly similar to that of 4' dia., 10' deep precast manhole in RSMeans that includes 47.9 Bm^3 excavation (labour & equip)	$2,883.00		lump sum	$0.00	
	Loading excavated soil	15%		% of excavation cost	$0.00	
	Hauling in a 13.76 m^3 truck (includes driver)	$172.92		$/hr	$0.00	
Materials and Installation						
Catchbasins	Frame and cover		$500.00	each	$0.00	
	Catchbasin		$367.00	m	$0.00	Minimum size is 0.762, two catchbasins = 1.524 m
	Installation		$500.00	each	$0.00	
Conveyance pipes from catchbasins to HDS	Armtec Boss 2000 solid pipe, 300 mm dia. (material)		$22.81	m	$0.00	Catchbasins on either end of parking lot at halfway point, drain to HDS at halfway along other end, so 2 x 30 m = 60 m, plus 2 x 8.335 m = 16.67 m, TOTAL 66.67 m
	(labour & equip)	$5.10		m	$0.00	
Base, 300 mm deep	20 mm crusher run (material)		$43.00	$/Cm^3	$12,900.00	
	30,000 lb grader, 300 HP dozer, 25 T vibratory roller, truck tractor & water tank trailer + 1 labour foreman (labour)	$0.75		$/m^2	$750.00	

Item	Item detail	RSMeans Unit Cost (2010$CND)	Unit cost ($CND) - other source	Units	Total ($CND)	Assumptions/Notes
	30,000 lb grader, 300 HP dozer, 25 T vibratory roller, truck tractor & water tank trailer (equipment)	$1.20		$/m^2	$1,200.00	
Compaction test	Proctor test				$0.00	Assume supplier provides curve, so not required.
	Nuclear density test	$42.81		$/test	$214.05	Assume 5 tests
Asphalt	Plant mix asphalt, wearing course, 50 mm thick (material)	$18.37		$/m^2	$18,370.00	60 m x 33.34 m = 2000 m2
	1 foreman, 7 labourers, 4 equipment operators (labour)	$1.02		$/m^2	$1,020.00	
	130 HP asphalt paver, 2 10T tandem rollers, 1 12T pneumatic whl roller (equipment)	$0.61		$/m^2	$610.00	
	Hauling in a 13.76 m^3 truck (including truck & driver)	$172.92		$/hr	$864.60	Assume cycle time of 1h, assumed a 18 cy (13.76 m^3) / 25T ton truck. The vol of asphalt required is 50 mm x 1000 m^2 = 50 m^3. If the compacted density of asphalt is 145 lb/cu ft (2322 kg/m^3), then we need 50 m^3 x 2322 kg/m^3 = 116.1 T. If each truck load takes 25 T, we need 4.6 (i.e. 5) truck loads. Therefore 5 truck hours.
	Asphalt lab test		$200.00	$/test	$200.00	For the 1000 m^2 parking lot, we need 116.1 T. Thus, assume just 1 test.
	Asphalt nuclear density tests		$60.00	$/hr	$180.00	For this 1000 m^2 parking lot, the asphalt paving productivity is 5305m^2 per day according to RSMeans which is lower than other sources. Assume 3 hours.
Striping		$0.46		$/m^2	$460.00	
SUBTOTAL					**$42,138.72**	
Fees						
Project overhead		10.00%		% of sub total	$4,213.87	
TOTAL					**$46,353**	

APPENDIX B:

Maintenance Costs

Table B1: Bioretention maintenance yearly costs

Maintenance Task	Frequency	Full Infiltration	Partial or No Infiltration
Watering	Year 1: Weekly first 2 months, bi-weekly May to August	$302	$302
	Year 2: 10% of plants that are new, weekly for first 2 months, biweekly May-August	$212	$212
	Year 3: Biweekly May-August	$20	$20
Inspection	Years 1 & 2: 4.5 times per year	$212	$212
	2.5 times per year in subsequent years	$118	$118
Remove litter and debris	6 times per year	$120	$120
Remove Sediment	Every 2 years, or as needed	$912	$912
	After year 2	$362	$362
Prune	Annually or as needed	$58	$58
Weed	6 times per year	$120	$120
Add mulch to maintain 75 mm	Replace every 3 years	$980	$980
Restore lost vegetation	10% in year 2	$437	$437
Unclog underdrain	Every 10 years	$0	$77
Average per year		**$945**	**$952**

Table B2: Bioretention rehabilitation

Item	Full, Partial or No Infiltration
Remove all plants	$137
Install new plants	$4,367
Install new filter media	$1,738
Till	$103
TOTAL	**$6,345**

Table B3: Permeable pavement maintenance yearly costs

Maintenance Task	Frequency	Full Infiltration	Partial or No Infiltration
Surface sweeping with vacuum	Every 2 years	$582	$582
Restriping	Every 3 years	$460	$460
Pave replacement (10 pavers)	Every 8 years	$57	$57
Clean out pipes	Every 10 years	$0	$38
Average per year		**$433**	**$436**

Table B4: Permeable pavement rehabilitation

Item	Full, Partial or No Infiltration
Removal of Pavers and Stone	
Remove pavers	$1,625
Remove No. 8, and top 2" of No.57 stone	$2,057
Cost of removal at year 30	**$3,682**
Installation of New Pavers and Stone	
Erosion and sediment control	$600
Mobilization & demobilization	$1,516
Base, 50 mm deep	$3,440
Compaction test	$86
Plastic edge restraints	$709
Bedding & pavers	$56,860
Striping	$460
Cost of installation at year 30	**$63,670**
SUBTOTAL	$67,35
Clean up	$6,735
TOTAL	**$74,088**

Table B5: Infiltration trenches yearly costs

Maintenance Task	Frequency	Roof Only	Road & Roof
Catchbasin cleanout	Once a year for roof runoff only design	$75	$0
Vacuum sediment & oil from hydrodynamic separator	Annually for parking lot runoff design	$0	$1,200
Soil Test	At 8 years for parking lot runoff design	$0	$550
Remove & replace filter cloth inner lining from perforated pipe. Test & dispose of sediment.	Once every 8 years for parking lot runoff design	$0	$750
Average per year		**$74**	**$1,277**

Table B6: Infiltration chambers yearly costs

Maintenance task	Frequency	Roof Only	Road & Roof
Catchbasin cleanout	Once a year for Roof Runoff only design	$75	$0
Vacuum sediment & oil from hydrodynamic separator	Annually	$0	$1,200
Jet vac & vacuum sediment from isolator row of infiltration chambers	Once every 8 years	$0	$300
Average per year		**$74**	**$1,212**

Table B7: Enhanced grass swales yearly costs

Maintenance task	Frequency	Curb/Filter sock/Rock check dam
Watering	Year 1: Weekly first 2 months, bi-weekly May to August	$767
	Year 2: 10% of plants that are new, weekly for first 2 months, biweekly May-August	$534
	Year 3: Biweekly May-August	$51
Inspection	Years 1 & 2: 4.5 times per year	$212
	2.5 times per year in subsequent years	$118
Remove litter and debris	Years 1 & 2: 4.5 times per year	$90
	2.5 times per year in subsequent years	$50
Remove sediment	Every 2 years, or as needed	$912
	After year 2	$362
Restore lost vegetation	In Year 2	$66
Mowing	Once a month, as as needed May to September	$106
Average per year		**$500**

Table B8: Rainwater harvesting yearly costs

Maintenance Task	Frequency	Concrete Tank Outdoor	Plastic Tank Indoor
Cleaning in-line filter	Annually	$75	$75
Inspection	Annually	$100	$100
Cleaning out tank	Every 10 years	$1,200	$1,200
Replacing pump	Every 10 years	$2,485	$2,485
Replacing pressure tank	Every 10 years	$3,431	$3,431
Average per year		**$744**	**$863**
Rehabilitation (replace plastic tank)	Every 40 years	n/a	$7,170

Table B9: Extensive greenroof maintenance yearly costs

Maintenance Task	Frequency	Cheap	Expensive
Watering	Year 1: Cheap case – once or twice a day until establishment (14 weeks), then once a week for 2.5 months	$15,800	$0
	Year 2: Cheap case – once every 2-3 weeks for 4 months	$700	$0
	Year 3: Cheap case – once every 2-3 weeks for 4 months	$700	$0
Weeding	Year 1: Cheap case – every other week for 2 months, then once a month for 4 months Expensive case - Once	$8,640	$1,080
	Year 2: Cheap case – once a month for 6 months Expensive case – ½ of area once	$6,480	$540
	Year 3: Cheap case – three times Expensive case – ½ of area once	$3,240	$540
	Subsequent years: Both case – ½ of area once	$540	$540
Plant replacement (10%)	Every 40 years	$2,080	$2,080
Check drains, flashing, membrane	Twice a year	$100	$100
Test Membrane	Every 5 years	$3,000	$5,000
Membrane repair of small leak	Every 5 years after 10 years	$762	$762
Average per year		**$9495**	**$13.985**

Table B10: Extensive greenroof rehabilitation

Item	Cheap	Expensive
Remove sedum, growing medium & stone[1]	$45,470	$68,205
Remove drainage layer[1]	$10,505	$10,505
Remove insulation[1]	$27,034	$27,034
Remove TPO/EPDM[1]	$13,036	$13,036
Chute	$4,731	$12,617
Cost of demolition	**$100,776**	**$131,397**
Cost of new greenroof	**$210,253**	**$429,918**
Subtotal	$311,029	$561,315
Project overhead	$31,103	$56,131
TOTAL	**$342,132**	**$617,446**

Notes: [1]Includes carrying across roof and disposal

Table B11: Asphalt yearly costs (used for comparative analysis)

Maintenance Task	**Frequency**	**Yearly cost**
Sealcoat	Every 3 years	$2,900
Cleaning surface prior to sealcoating	Every 3 years	$220
Restriping (after sealcoat)	Every 3 years	$460
Crack filling, pothole filling, patches	Ongoing as needed	$1,000
Average per year		$2,146

Table B12: Asphalt rehabilitation (used for comparative analysis)

Item	**Total cost**
Remove asphalt	$6,470
Regrading, compacting as necessary	$490
New asphalt	$21,245
Striping	$460
Cost of rehabilitation at 25 years	**$28,665**
Project overhead	$2,867
Overall cost of rehabilitation at 25 years	**$31,532**

APPENDIX C:

Life Cycle Maintenance Costs

Table C1: Bioretention

Maintenance Task	Full Infiltration	Partial or No Infiltration
Water	$534	$534
Inspection	$6,088	$6,088
Litter	$6,000	$6,000
Sediment	$9,600	$9,600
Prune	$2,900	$2,900
Weed	$6,000	$6,000
Mulch	$15,680	$15,680
Vegetation	$437	$437
Underdrain	$0	$385
Rehab	$7504	$7504
TOTAL	**$54,743**	**$55,128**

Table C2: Permeable pavement

Maintenance Task	Full Infiltration	Partial or No Infiltration
Vacuum sweep	$13,968	$13,968
Replace pavers	$339	$339
Clean out pipes	$0	$154
Restriping	$7,360	$7,360
Rehab	$72,990	$72,990
TOTAL	**$94,657**	**$94,811**

Table C3: Infiltration trenches

Maintenance Task	Roof Only	Road & Roof
Cleanout catchbasin	$3,675	$0
Clean-out hydrodynamic separator	$0	$58,800
Replace filter cloth & dispose sediment	$0	$4,500
Test sediment	$0	$550
TOTAL	**$3,675**	**$63,850**

Table C4: Infiltration chambers

Maintenance Task	Roof Only	Road & Roof
Cleanout catchbasin	$3,675	$0
Clean-out separator	$0	$58,800
Clean-out infiltration chamber	$0	$1,800
TOTAL	**$3,675**	**$60,600**

Table C5: Enhanced grass swales

Maintenance Task	Curb/Filter sock/Rock check dam
Water	$1,351
Inspection	$6,088
Litter	$2,580
Remove sediment	$9,600
Restore vegetation	$66
Mowing	$5,300
TOTAL	**$24,985**

Table C6: Rainwater harvesting

Maintenance Task	Concrete Tank	Plastic Tank
Cleaning in-line filter	$3,750	$3,750
Inspection	$5,000	$5,000
Cleaning out tank	$4,800	$4,800
Replacing pump & pressure tank	$23,664	$23,664
Replacement	n/a	$5,970
TOTAL	**$37,214**	**$43,184**

Table C7: Extensive greenroof

Maintenance Task	Cheap	Expensive
Water	$17,200	$0
Weeding	$43,740	$27,540
Plant replacement	$2,080	$2,080
Check drains, flashing, membrane	$5,000	$5,000
Test membrane	$27,000	$45,000
Repair membrane, small leak	$6,096	$6,096
Replacement	$373,628	$613,542
TOTAL	**$474,744**	**$699,258**

Table C8: Asphalt (used for comparative analysis)

Maintenance Task	Asphalt
Clean, sealcoat and restriping	$57,280
Crack filling, pothole filling and patching	$50,000
Rehabilitation	$26,951
TOTAL	**$134,231**