

Freshwater Management Tool

August 2021

FWMT Report 2021/9



Report 9 A Total Economic Valuation Approach to Understanding Costs and Benefits of Intervention Scenarios – Part 1 Urban Devices



Freshwater Management Tool: Report 9. A Total Economic Valuation Approach to Understanding Costs and Benefits of Intervention Scenarios – Part 1 Urban Devices

August 2021

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Healthy Waters Department, FWMT Report 2021/9

ISSN 2815-9772

ISBN 978-1-99-100279-2 (PDF)

Recommended citation

Auckland Council (2021). Freshwater management tool: report 9. A total economic valuation approach to understanding costs and benefits of intervention scenarios – part 1 urban devices. FWMT report, 2021/9. Prepared by Koru Environmental Consultants Limited, Manaaki Whenua Landcare Research and Batstone Associates for Auckland Council.

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Costs presented in this report are non-financial indicative life cycle cost estimates and are based on current available information and should be read in the context of the assumptions presented in this report. Cost information has been gathered and modelled in order to gain an understanding of the relative difference in cost between different solutions, not the actual cost of each solution.

Any decision that is made after using this data must be based solely on the decision-makers own evaluation of the information available to them, their circumstances and objectives.

Executive summary

Background and purpose

Auckland Council's Healthy Waters Department is developing a Freshwater Management Tool (FWMT) to assist with decision-making around the development of freshwater management outcomes required by the National Policy Statement for Freshwater Management (NPS-FM) (e.g., both regulatory and operational programmes). A key part of this assessment is understanding the costs and benefits of implementing different intervention scenarios for future planning and decision making.

The purpose of this report is to document the cost data sources, assumptions and process undertaken to generate indicative life cycle cost (LCC) estimates for urban stormwater device interventions for use within the FWMT, within the context of a total economic valuation assessment. The report recommends how the cost results should be interpreted and how they should be considered alongside our understanding of the indirect costs and the benefits associated with alternative intervention scenarios. Recommendations are also made to overcome identified challenges and to refine future costs assessments.

The "Total Economic Valuation" assessment framework

The report recommends that Auckland Council undertake a Total Economic Valuation (TEV) assessment framework for decision-making within the FWMT. A TEV framework assists in assessing alternative approaches in a way which acknowledges direct, indirect and avoided costs, as well as direct, indirect and other ancillary community benefits. A toolkit approach to better understanding these costs and benefits is recommended and illustrated in Figure ES-1.

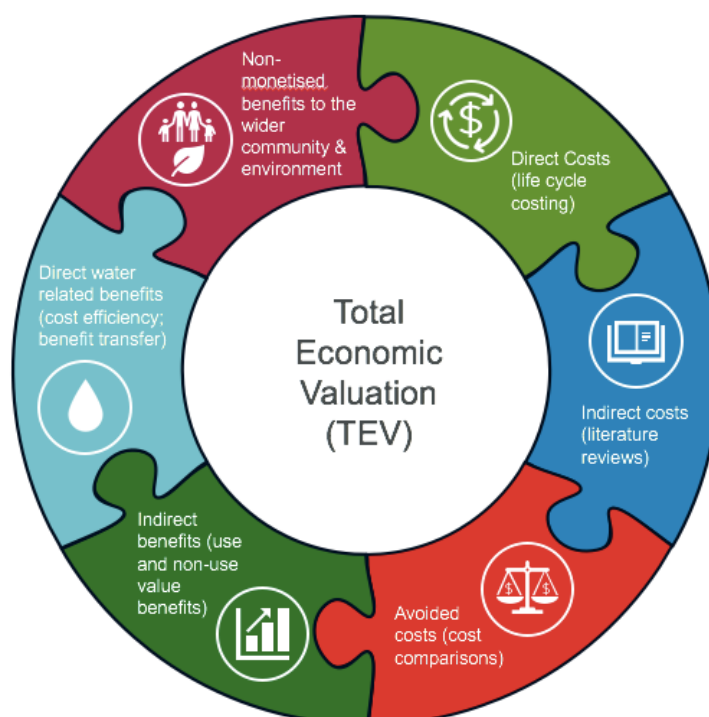


Figure ES-1 A TEV assessment framework, as applied to the Auckland Council FWMT.

In order to provide a comprehensive TEV framework assessment for the FWMT, the authors recommend that the following studies could be undertaken:

1. Assessment of direct costs via life cycle costing (this report)
2. An initial qualitative screening assessment of benefits and avoided costs using the New Zealand developed “More Than Water” tool.
3. An initial quantitative assessment of benefits and costs based on BEST, an internationally recognised and reviewed cost and benefits assessment tool.
4. Finally, the results of the various assessment methods would then need to be brought together in a holistic assessment of benefits and costs by updating the qualitative and quantitative assessments undertaken in points 1, 2 and 3 above.

Direct costs – Life Cycle Costing

A life cycle costing (LCC) approach has been used to assess the direct costs associated with urban stormwater interventions. The LCC is the sum of the acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage and maintenance through to disposal. A cradle-to-grave time frame is warranted because future costs associated with the use and ownership of an asset are often greater than the initial acquisition cost and may vary significantly between alternative solutions to a given operational need (Australian National Audit Office, 2001). The LCC process undertaken for this study has been done in accordance with the Australian/New Zealand Standard 4536:1999 (1999) for LCC.

Cost data was collected for stormwater wetlands, ponds, rain tanks, permeable pavement, rain gardens, tree pits, green roofs, filter systems, swales and infiltration basins. LCCs of urban source control interventions is reported in Ira (2020). Over the course of this project, workshops and cost data collection meetings were held with AC Healthy Waters officers to collect cost data. This data was used to supplement existing cost databases generated via previous costing studies (Ira and Simcock, 2019; Ira, 2017; Ira *et al.*, 2015 and 2009).

Sections 3.6 and 3.7 describe the data in-puts, methodology and assumptions of the LCC process, as represented in **Figure ES-2** overleaf.

With respect to the total acquisition costs (TACs) used within the models, where possible, the cost data is based on actual devices which were designed to achieve, in general, a 75% total suspended solids removal over a long term average basis (Auckland Council, 2003; Auckland Council, 2017). Low, average and high TACs are provided in Section 4, for use in the LCC models.

The maintenance costs (MCs) used within the models are based on best practice maintenance guideline documents (Auckland Council, 2003; NZTA, 2010 and Healy *et al.*, 2010), along with the expert opinion of maintenance operators and green infrastructure specialists. The activities and frequencies assume that the device which is being maintained (and therefore costed) has been designed and constructed according to best practice standards, and is functioning as designed. The costs are best estimates for any given maintenance activity, however, the models may not be fully reflective of “on-the-ground” maintenance which is currently occurring for a range of existing devices.

Using the new LCC models built for this study, over 120 model runs were undertaken for a range of devices (wetlands, rain gardens, tree pits, infiltration basins, filter systems, permeable paving rain tanks, swales and green roofs), surface area sizes, catchment areas, unit cost rates and discount rates in order to generate low and high LCC indicative estimates.

As shown in **Figure ES-2**, the LCC results are presented in Section 6 of this report. Appendix B tabulates the LCC results, Appendix C summarises the LCC results for specific device sizes for use in

SUSTAIN, and Appendix D provides a summary of the nonlinear relationships which can be used to estimate LCCs for future catchment planning purposes.

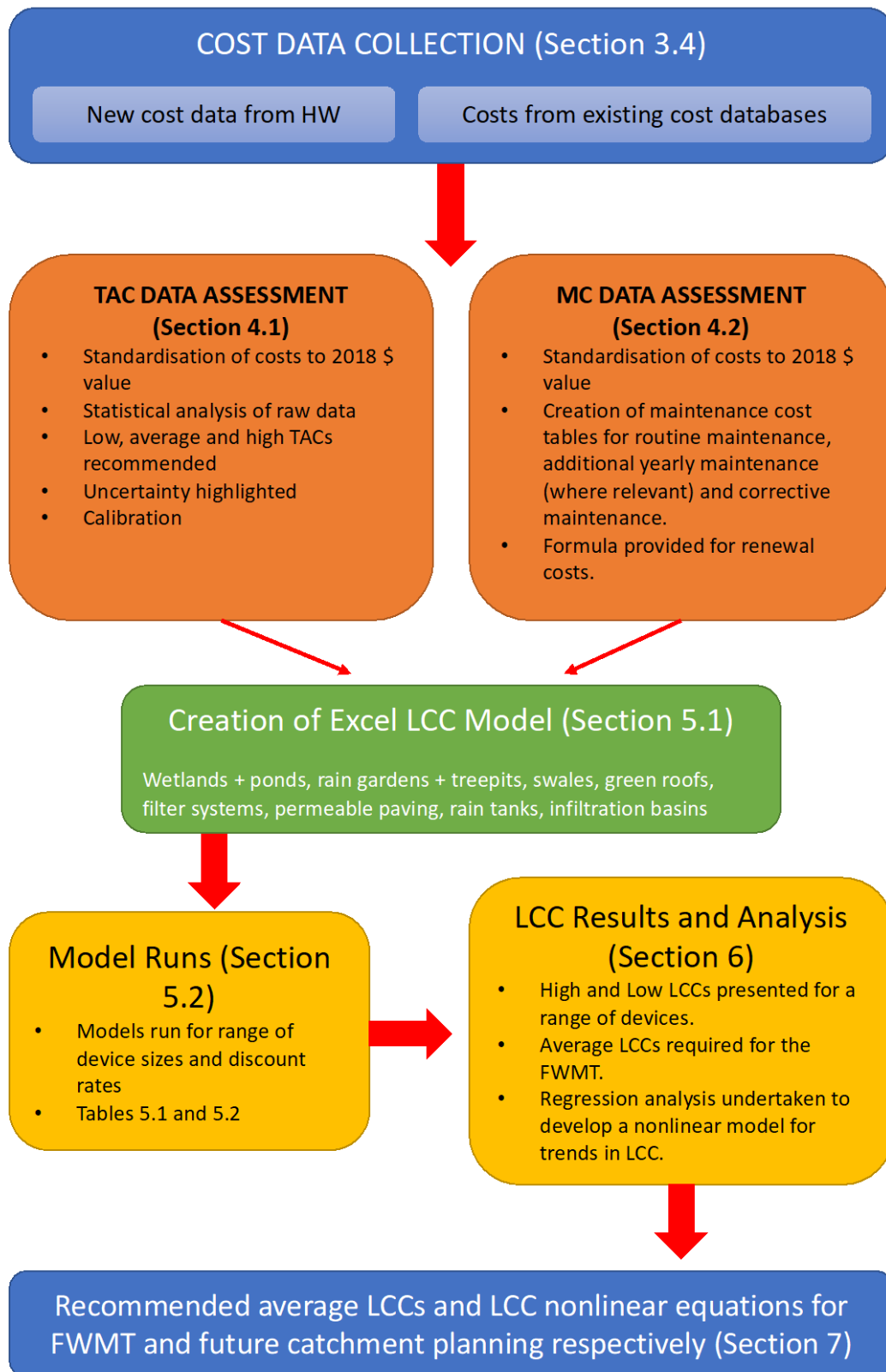


Figure ES-2 Data collection, modelling and analysis process

LCC models were run for 2%, 4% and 6% discount rates. Discounting is one of the most debatable and controversial aspects of a LCC assessment, and the effect of the discount rate on the LCC results was clearly evident. As expected, the higher discount rate (6%) places less emphasis on the long-term maintenance costs and leads to a reduction in the annualised average LCCs. Conversely, the 2% discount rate costs are the highest and can therefore be taken as a more conservative assessment of long-term costs. This re-enforces findings noted in Ira *et al.*, 2012 and 2015. When comparing discount rates across the full range of devices modelled it is evident that the relative cost difference between these interventions is similar for all discount rates.

The LCC results highlight that there is a strong inverse relationship between device surface area size and unit cost (i.e. LCCs decrease as the size of a device increases (Section 6)). This relationship is likely caused by the dominance of the long term maintenance costs for each device. Maintenance costs become more efficient as the size of a device increases, as much of the maintenance needs to be undertaken regardless of device size (e.g. inspections or traffic management). This leads to clear economies of scale being achieved for larger devices. Although the FWMT Stage 1 requires a single “average” cost per intervention, further analysis (regression analysis undertaken in Stata – version 16) was undertaken in order to develop nonlinear models for the variation in LCC with device scale. The purpose for that being to help ensure greater variation in device LCC can be incorporated into the FWMT over its staged development programme (e.g., enable the same device to be included within the FWMT optimisation tool, at varying sizes).

The LCC results have re-enforced prior research undertaken (Ira *et al.*, 2008; 2012 and 2015; Ira and Simcock, 2019) that emphasised two components of LCC are most important for urban devices:

1. the area which the device treats;
2. the frequency and type of maintenance undertaken.

The previous research referenced above found that the 3rd most important component which influences costs is the level of treatment provided (this cost driver has not been further explored through this project since devices have been designed according to GD01 standards). Device design, construction methodology, topography, geographical location, soils and availability of materials all also have an affect cost. Unfortunately the lack of meaningful cost data and the poor resolution of the data means that these secondary cost drivers could not be identified within the data and are therefore not represented in the LCC relationships developed (e.g., are generalised).

Recommendations

The study has highlighted a number of areas where further research is needed to refine the underlying cost information which is used in the LCC models. Key areas for further work include:

- Using the cost data collection templates developed in this project to collect Auckland-specific total acquisition and maintenance costs in order to refine the LCC estimates and to further investigate the effect of the secondary cost drivers mentioned above.
- Building on the above data collection process, further work is needed to better understand the relationship between secondary cost drivers, such as device design, topography, geographical location, soils and availability of materials. Having more than one explanatory variable will assist in ensuring future models provide enhanced and more consistent replication to the current model.
- Understanding LCCs is only one part of the decision-making process and other factors, such as resilience, ease of adaptation and institutional frameworks (i.e. ownership models) would also need to be considered. For example resilience theory indicates that distributed systems of smaller devices are considered more resilient in the long term than catchment scale devices (Moores and Semadeni-Davies, 2015). Further research is needed to

investigate the relationship between cost and different device considerations (e.g. device shape (which leads to edge effects, or economies of scale that could be realised by having devices in series, such as in green streets applications).

- Very little cost information is available for infiltration basins - further cost information needs to be collected in order to refine the LCC estimates.
- Further modelling could be undertaken to increase the relevant surface or catchment area size range limitations for the LCCs provided.
- Further work could be undertaken to estimate the indirect costs, avoided costs and cost efficiency of particular stormwater devices in order to present a more balanced economic assessment of the long term cost of a particular solution.
- Finally, it is recommended that SUSTAIN does not LCCs which have been averaged across a range of surface area sizes. The cost module in SUSTAIN could be developed to undertake a more sophisticated statistical analysis for the reasons explained in the report.

Table of contents

Disclaimer	iv
Executive summary	v
Cost definitions	xii
1. Introduction.....	1
1.1 Background.....	1
1.2 The importance of cost and understanding challenges	1
1.3 Purpose of this report	2
1.4 Structure	2
2 Economic analysis framework.....	4
2.1 Total economic valuation.....	4
2.2 A TEV approach for stormwater infrastructure in Auckland	4
3 Life cycle costing	7
3.1 Life Cycle Costing Analysis	7
3.2 Limitations	8
3.3 Mitigations to be costed	8
3.4 Cost data sources	9
3.5 New cost data	10
3.6 Data in-puts, assumptions and the LCC process	11
3.7 Methods and outputs: completing the costing puzzle.....	13
4. Assessment of unit costs	15
4.1 Total acquisition costs.....	15
4.1.1 Non-device specific TAC assumptions.....	15
4.1.2 Data analysis	16
4.1.3 Wetlands	17
4.1.4 Rain gardens.....	18
4.1.5 Tree pits	18
4.1.6 Swales.....	19
4.1.7 Green roofs	20
4.1.8 Filtration systems	21
4.1.9 Infiltration basins	21
4.1.10 Rain tanks	22
4.1.11 Permeable paving	23
4.1.12 Calibration of TACs	23
4.2 Maintenance Costs.....	25
5. Development of the LCC model and device assumptions	35
5.1 The Healthy Waters LCC models.....	35
5.2 Model assumptions for the FWMT LCCs	36
6. Life cycle cost results.....	39

6.1	Interpreting and understanding the results.....	39
6.2	LCC results – urban structural devices.....	39
6.3	Rain gardens or wetlands?.....	46
6.4	Understanding where costs fall in the urban development value chain: “Who Pays”?.....	47
7	LCC model review and incorporation into the FWMT	48
7.1	LCC model review and statistical analysis	48
7.2	Incorporation of the LCC results into the FWMT	50
8.	Conclusions and recommendations.....	51
8.1	Conclusions.....	51
8.2	Recommendations	52
9.	References	54
	Appendix A – cost data collection templates	56
	Appendix B – life cycle cost results	57
	Appendix C – LCC results to be used in the pilot run of sustain	58
	Appendix D – LCC trend functions.....	59
	Appendix E – maintenance cost curves.....	60
	Appendix F – memo on updated rain garden LCC model assumptions and results for use in sustain.....	67

Cost definitions

Term	Abbreviation	Definition
Corrective Maintenance Costs	CMC	These are costs associated with large scale maintenance of the treatment device. They tend to occur infrequently over the life of a device.
Decommissioning Costs	DC	Costs associated with the decommissioning or complete removal of the treatment device at the end of its life span.
Discount Rate	DR	The discount rate is a percentage rate used to discount future costs back to their present day value. The real discount rate is used. Discounting is used to find the value at the base year of future costs, in other words, the present value.
Green Infrastructure	GI	Green infrastructure refers to stormwater assets which use soils and vegetation to restore some of the natural process used to manage stormwater and provide for healthier urban receiving water systems.
Life Cycle Cost	LCC	The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, planning, construction, usage, and maintenance and renewals through to disposal costs.
Life Cycle Costing		The process of assessing the cost of a product over its life cycle or portion thereof, as defined in the Australian/New Zealand Standard 4536:1999.
Life Span	LS	The functional life of the treatment device in years.
Life Cycle Analysis Period	LCAP	This is the period of time (in years) over which the life cycle costing analysis is conducted.
Present Value	PV	The present day value of all future costs and benefits (i.e. the value of future costs or benefits when discounted back to the present time).
Renewal Cost	RC	Costs associated with renewing the device back to its original design state at the end of its life span.
Routine Maintenance Costs	RMC	These are annual costs which relate to routine maintenance events such as mowing grassed areas, weeding, general inspections, etc.
Total Acquisition Cost	TAC	The TAC relates to the design, planning, consenting and construction costs of a device.

1. Introduction

1.1 Background

Auckland Council's Healthy Waters Department is developing a Freshwater Management Tool (FWMT) to assist with decision-making around the implementation of the National Policy Statement for Freshwater Management (NPS-FM). Implementation requirements span both regulatory decisions on objectives and limits, and operations decisions on investment for interventions and management (e.g., stormwater network, rural land use, urban land use). The FWMT includes a Stormwater Management Model (SUSTAIN) which will be used to assess a range of structural and source control interventions for improving stream hydrology and water quality in urban and rural areas within the Auckland Region. A key part of this assessment is understanding the costs and benefits of implementing different intervention scenarios. Ultimately, by doing so the FWMT can deliver evidence to underpin planning and operational responses in Auckland Council for future development, climate and national regulation.

1.2 The importance of cost and understanding challenges

Auckland Council faces stormwater infrastructure related challenges from growth, development and redevelopment of urban centres within the region. Additional challenges occur in rural environments from legacy and ongoing land clearance, drainage and use.

Within the urban environment, challenges to water management include:

- increased flooding of existing properties and infrastructure, especially where 'downstream' capacity to manage increased impervious surfaces is limited;
- increased volume and flow of stormwater which compromises existing levels of service as well as creates stressors on aquatic habitats through the process of accelerated stream channel erosion;
- deterioration of the quality of receiving waters and sediments;
- increased expectations of public for improved receiving water quality, especially where contact recreation or food gathering is affected by sewer overflows; and
- increased costs associated with long term maintenance of constructed stormwater practices.

Water Sensitive Urban Design (WSUD) and green infrastructure have been offered up as solutions to addressing the effects of stormwater discharges. However, a key impediment to implementation has been the perception that green infrastructure costs more than conventional 'grey' stormwater management practices both in the short term (i.e. design, construction and development costs) and long term (i.e. operating and maintenance costs). One of the aims of this project has been to more accurately quantify costs of traditional (grey infrastructure) and green infrastructure practices, as well as source control initiatives to better understand the relative difference in cost between various intervention scenarios. Costing of urban source control interventions for the FWMT is reported in Ira (2020).

Understanding cost is a vital part of the decision-making process, as cost estimation plays a key role in managing for development activities, from costs incurred by private developers, to on-going maintenance costs incurred by network operators. However, comprehensive and accurate quantification of initial and long term costs of infrastructure provision present many challenges:

- **Site specificity:** Green and grey infrastructure incorporates a range of approaches for managing stormwater discharges which are dependent on the characteristics of the development, location, topography, geology and climate, thus it is exceptionally difficult to estimate cost on a generic or average cost basis.

- **Design approach:** the choice of a particular device, its function and location in a treatment train, and the design objectives all affect cost. For example, a swale or filter strip whose primary function is to provide pre-treatment for infiltration practices would have differing design and cost elements to those which provide for stand-alone stormwater treatment.
- **Public/ private cost allocation:** One of the principles of green infrastructure is to treat contaminants and reduce the volume of stormwater “at source”. As a result, a large number of stormwater management devices can be located on private property (e.g. using a rain garden and rain tank to manage stormwater from a residential dwelling or commercial property). Understanding the private and public split of costs is an important part of determining where the cost will fall within the urban development value chain.
- **Emerging green technologies:** Many green infrastructure practices are relatively new, and thus actual cost data relating to long term operation and maintenance is not only scant, but often very variable.
- **GI integration with landscaping:** Green infrastructure costs are often integrated with landscaping as part of design, construction and especially maintenance. This can make it difficult to extract cost information.
- **Asset management – bulk contracts:** Green and grey infrastructure in public spaces are likely to be maintained under large, ‘bulk’ contracts that depend on the type of work and its location. It is often difficult to single out individual maintenance activities. In many instances, the cost information available relates to problematic or poorly designed practices which would require higher than usual renewal or ongoing maintenance costs.
- **Obtaining accurate cost data:** accurate cost data is notoriously difficult to obtain. Many suppliers refuse to provide estimates, developers do not like divulging sensitive cost information and many councils do not store cost data related to construction and maintenance activities in a meaningful way. Unit costs presented in this report are therefore best estimates based on available information.

1.3 Purpose of this report

The purpose of this report is to document the cost data sources, assumptions and process undertaken to generate indicative life cycle cost (LCC) estimates for urban devices configured within the FWMT Stage 1. Ensuring, a total economic valuation (TEV) assessment is supported.

The report recommends how the urban device LCC results should be aligned to devices whilst noting limitations in our understanding of the indirect costs and the benefits associated with alternative intervention scenarios. The costs developed here can also be used as an input to other Auckland Council modelling efforts, as well as in future planning. The cost data collected and the associated indicative LCC estimates are presented within the context of the challenges identified in Section 1.2. Recommendations have been made to overcome these challenges and to refine future cost assessments.

1.4 Structure

Section 2 describes the economic analysis framework and interaction between the economic workstreams with the FWMT.

Section 3 provides background to LCC: the benefits and limitations; data sources and the methodology used to collect additional cost data; and a description of the life cycle costing approach. It also summarises the key structural and source control interventions for which cost data has been collected.

Section 4 summarises the unit cost data, statistical analysis and recommended values within the LCC models for both total acquisition costs (TAC) and maintenance costs (MC).

Section 5 provides a description of the new LCC model which was developed for this project, along with key assumptions used in the models.

Section 6 summarises the life cycle cost model results which will be used in the FWMT.

Section 7 provides information on how to apply the costs; limitations of the cost data; future ownership and the circumstances where costs are incurred; and interpreting results.

Section 8 concludes the report and provides recommendations for further refining cost data assessments and reducing uncertainties in the future.

2 Economic analysis framework

2.1 Total economic valuation

Whilst understanding cost is a vital part of the decision-making process, being able to quantify and/or acknowledge the total benefits of a particular intervention is just as crucial for water quality management decisions. It is important to capture the full change of social welfare resulting from a policy or government intervention. Business cases often ignore ancillary benefits to the community or the environment, and it is common for the “value engineering” process to eliminate these benefits since they are not seen as integral to a particular project. This often leads to a different set of recommendations than if total benefits were accounted for.¹

A TEV approach provides a framework for decision-making which acknowledges the wider benefits of alternative approaches, and quantifies them where possible.² The CRC for Water Sensitive Cities (2016) outlines the key components of a TEV approach for urban water infrastructure:

1. **Direct costs:** the present value (or life cycle costs) of all upfront and ongoing expenditure required to construct and operate stormwater management interventions.
2. **Indirect costs:** other costs derived from manufacturing or transporting parts used within stormwater assets, along with administration costs to support implementation (e.g. the cost of carbon from either the manufacturing stage or transport stage of a material/ product).
3. **Avoided costs:** both local and downstream – the present value of avoided capital and operating costs associated with a particular stormwater management approach.
4. **Direct benefits:** the value that will be gained by the organisation installing stormwater management interventions (e.g. the value of water for irrigation if the scheme includes rainwater harvesting).
5. **Indirect benefits:** broader community benefits of alternative stormwater interventions, such as recreation-related benefits, or avoided sicknesses.
6. **Other environmental/ community benefits:** non-monetised benefits which are relevant and should be incorporated into decision making.

2.2 A TEV approach for stormwater infrastructure in Auckland

In order to fully integrate a TEV into the FWMT, a toolkit approach to better understanding the direct and indirect costs and benefits from different intervention methods is recommended. **Figure 2.1** provides an illustration of this approach which includes:

- using life cycle costing to quantify direct costs, and indirect costs where practical;

¹ The NZ Treasury’s guidance on Cost Benefit Analysis can be found here:

<https://treasury.govt.nz/sites/default/files/2015-07/cba-guide-jul15.pdf>. The US EPA’s guidelines contain additional useful information and references: <https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses>.

² The term “Total Economic Valuation” is typically used to refer to the combination of both use and non-use values to characterise changes in social welfare. The benefits discussed below will include several categories of non-use values. The Ministry for the Environment provides background here:

<https://www.mfe.govt.nz/publications/fresh-water-rma/option-and-existence-values-waitaki-catchment/3-total-economic-value>.

- using willingness to pay³-based estimates and benefit transfers⁴ to quantify benefits, where practical;
- using local and international studies to qualitatively assess a wider range of non-quantifiable benefits and indirect costs.

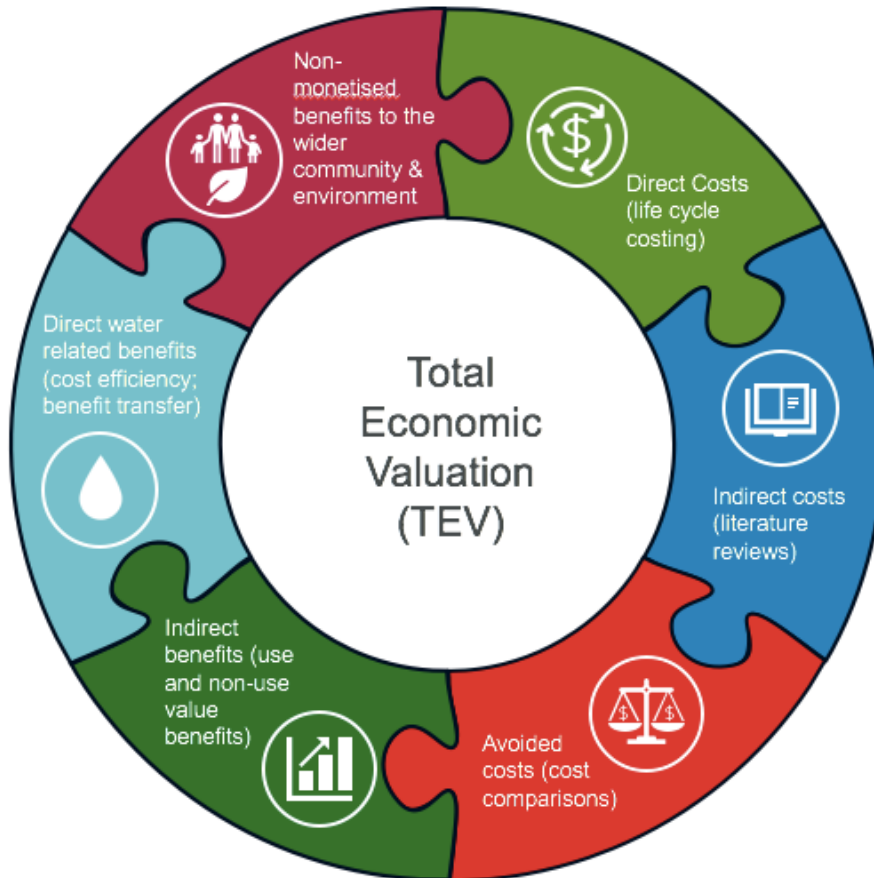


Figure 2.1 A TEV assessment framework, as applied to the Auckland Council FWMT. Each segment relates to the economic criteria described in the CRC approach (CRC for Water Sensitive Cities, 2016)

In addition to the individual LCC modelling which will be incorporated into the FWMT (this report), two methods can be used to synthesise the results of the cost and benefit studies to deliver a holistic assessment of benefits: the More Than Water (MTW) Tool (Moores, *et al.*, 2019), developed by the Activating WSUD in New Zealand research project; and the Benefits of SuDs Tool⁵ (B⁵EST), developed by the UK’s CIRIA. Further details of these tools and their use are provided in the scoping report on costs and benefits for the FWMT (Ira, *et al.*, 2019). In summary, the following approach is recommended (**Figure 2.2**):

1. An initial qualitative screening assessment of benefits and avoided costs using the New Zealand developed “More Than Water” tool.

³ When valuing many environmental amenities, where market prices do not exist, there are several methods used to estimate people’s “willingness to pay” for improvements in those amenities. These methods include stated preference surveys and revealed preference approaches like property price analysis and recreation demand approaches. See <https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses>.

⁴ Benefit transfer refers to the process of applying values estimated in previous studies to new policy cases (see the *US EPA Guidelines for Preparing Economic Analyses* referenced above).

⁵ <https://www.susdrain.org/resources/best.html>

2. An initial quantitative assessment of benefits and costs based on a “New Zealandised” version of B&EST, an internationally recognised and reviewed cost and benefits assessment tool.
3. Finally, the results of the various assessment methods brought together in a holistic assessment of benefits and costs by updating the qualitative and quantitative assessments undertaken in points 1 and 2 above.

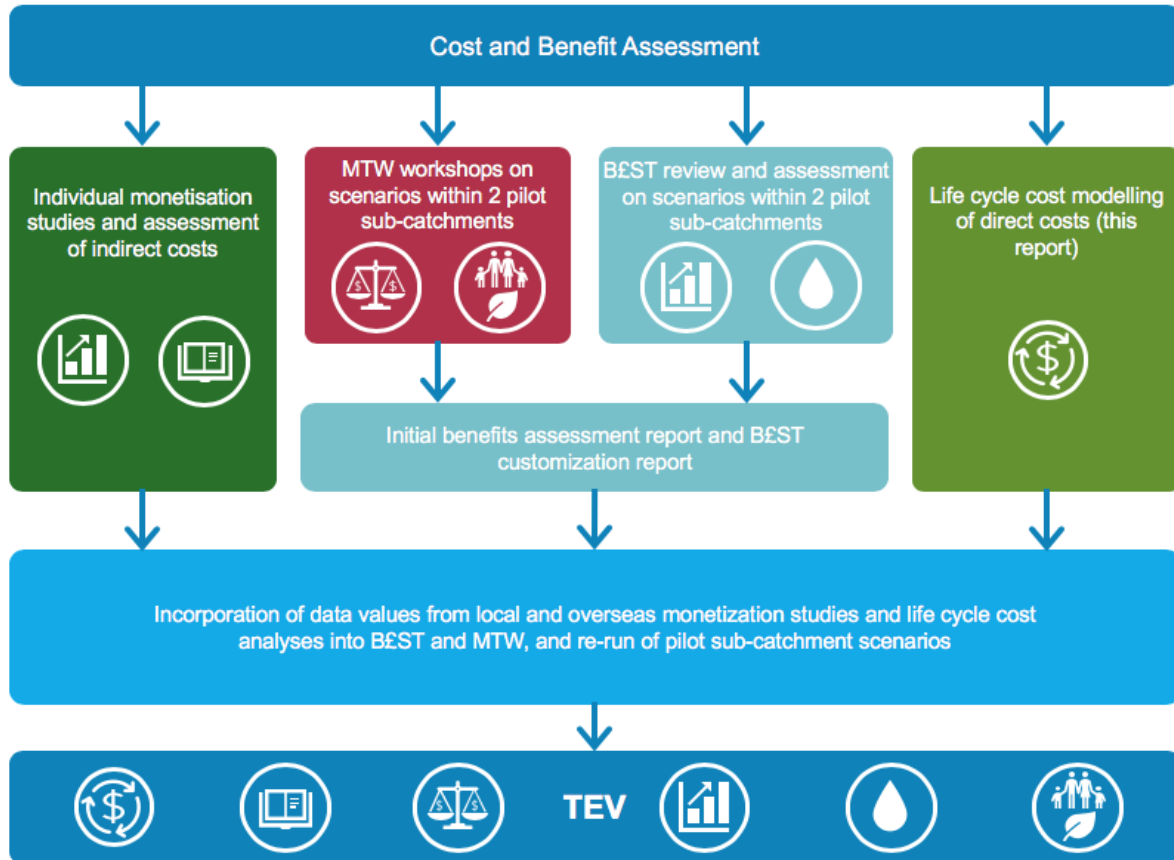


Figure 2.2 Proposed process for assessment of costs and benefits for stormwater infrastructure in the Auckland Region. The symbols provided here link to the TEV approach provided in Figure 2.1 to indicate which part of the TEV continuum each assessment represents.

The focus of this report is to document the life cycle costing approach and assumptions, for urban structural interventions, which are to be incorporated into the FWMT and used to support either a LCC approach (direct cost and benefit) or a later TEV approach.

3 Life cycle costing

3.1 Life Cycle Costing Analysis

A LCC approach has been previously used to assess costs associated with stormwater devices in Australia, the United States of America (USA) and the United Kingdom (UK) (Vesely *et al.*, 2006). The Australian/New Zealand Standard 4536:1999 (1999) defines LCC as the process of assessing the cost of a product over its life cycle or portion thereof. The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage and maintenance through to disposal (**Figure 3.1**). A cradle-to-grave time frame is warranted because future costs associated with the use and ownership of an asset are often greater than the initial acquisition cost and may vary significantly between alternative solutions to a given operational need (Australian National Audit Office, 2001).

LCC has a number of advantages and supports a number of applications and analyses (Lampe *et al.*, 2005):

- It allows for an improved understanding of long-term investment requirements.
- It helps decision-makers make more cost-effective choices at the project scoping phase.
- LCC provides for an explicit assessment of long-term risk.
- It reduces uncertainties and helps local authorities determine appropriate development contributions.
- LCC assists decision-makers understand the relative cost difference between two or more management options without the full-blown costs of detailed engineering assessments.

LCC is therefore able to describe the type, frequency and level of cost associated with a specific stormwater practice across the life span of that practice (**Figure 3.1**).

Decision making on the use of green and grey stormwater infrastructure needs accurate and comprehensive data on the technical and financial performance of these devices. The financial performance depends on the sum and distribution, over the life cycle of the device, of the acquisition and maintenance costs which include design, construction, use, maintenance, and disposal. LCC can be used for structuring and analysing this financial information. However, whilst LCC is an important tool in understanding the costs associated with infrastructure development, it is only one parameter in the evaluation process (Taylor, 2003), and needs to be considered in the context of social, cultural and environmental goals (as discussed in Section 2.2).

LCC can be done using either a statistical or unit cost approach. A statistical approach is based on developing a statistically significant regression relationship between the size of a practice, and its acquisition and/or maintenance costs. Unit costing involves identifying individual elements of the acquisition and maintenance phase, and costing them using average tender rates (Ira *et al.*, 2008). A combination of both approaches has been used to generate LCCs for Auckland (as discussed further in Section 4).

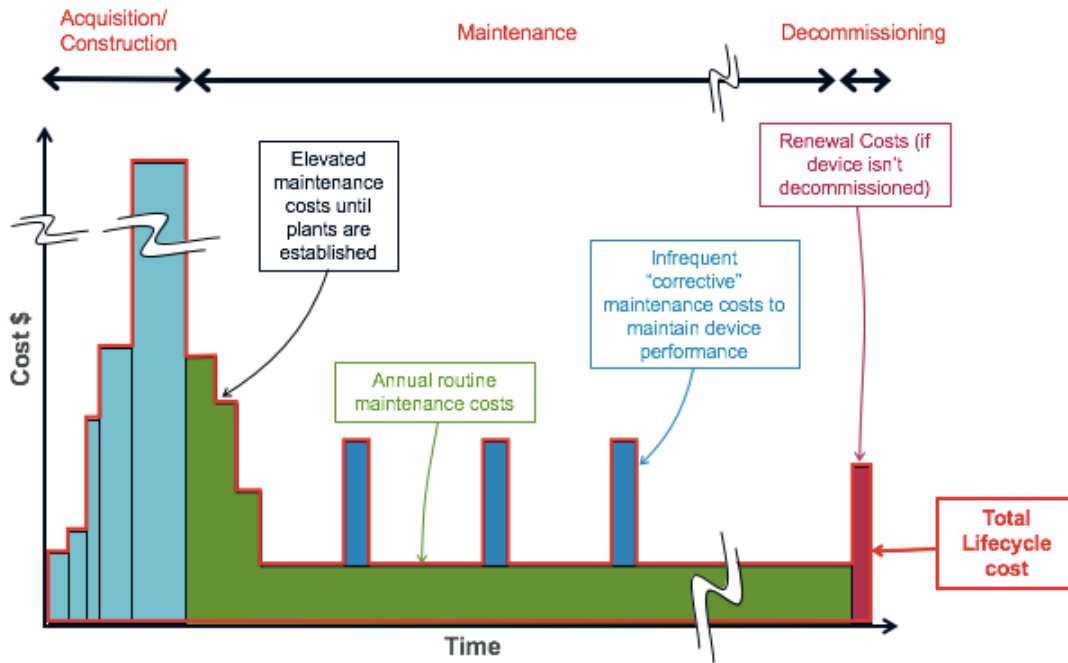


Figure 3.1 Phases in the life cycle of a stormwater practice and potentially associated costs (adapted from Taylor, 2003).

LCCs are normally expressed as either a total Net Present Value (NPV) over the life cycle of the device, or a present value per year for each year of the device life span. The total NPV LCC is the lump sum amount that a person would need today to meet all the costs of installing, maintaining and using that device over its lifetime. A LCC analysis is not a financial analysis of asset depreciation over time. It generally involves only quantifying the direct costs associated with a particular practice. LCC makes no assumptions about the feasibility, timing, uptake or optimisation of stormwater management devices, nor about financing, governance or distributions of costs for particular catchments or activities.

3.2 Limitations

Whilst LCC analyses are reasonably common, the accuracy of any analysis is dependent mainly on the quality of cost data which is used. Some challenges include:

- Cost information is notoriously variable, difficult to collect and rapidly goes out of date (Lampe, *et al.*, 2005).
- LCC analyses are complex and require an in-depth understanding of the technical design of a device, along with relevant site conditions and constraints.
- LCCs do not provide a financial analysis of asset depreciation over time.
- Depending on the discount rate chosen, LCC can underestimate costs which occur in the future.
- It needs to be combined with an analysis of the benefits of a particular stormwater management option to ensure a more informed and balanced approach to decision-making is undertaken.

3.3 Mitigations to be costed

Table 3.1 outlines the structural stormwater interventions for which LCCs have been generated. It is noted that only costs associated with the intervention itself have been quantified. Costs associated

with connections to and the existing piped network and stormwater system are outside the scope of this analysis.

Table 3.1 Structural stormwater interventions for which LCCs have been generated

Structural Intervention Type	Description
Stormwater wetlands	Flood detention and water quality treatment
Stormwater ponds	Flood detention and water quality treatment
Rain tanks	Incorporates water reuse
Permeable pavement	Designs for passive systems only
Rain gardens	Designs as per GD01 (Auckland Council, 2017)
Road rain gardens/ hybrid treepits	Designs as per GD01 (Auckland Council, 2017)
Green roofs	Extensive green roof (<150mm filter media)
Filter systems	Average costs for different types of filter systems
Swales	Conveyance and water quality treatment
Infiltration basins	

3.4 Cost data sources

In addition to collecting individual cost data from the Auckland region, a number of existing cost databases have been used to generate the TACs and MCs for urban structural devices (**Table 3.1**). These cost databases include:

1. **Activating WSUD for Healthy, Resilient Communities in New Zealand** (2019)⁶: The Building Better Homes Towns and Cities National Science Challenge (BBHTC) funded the ‘Activating Water Sensitive Urban Design (WSUD) for healthy, resilient communities’ research project. The project delivered research and enhanced capability to address critical current barriers to the uptake of WSUD in New Zealand. Two key barriers identified through the research discovery phase were that of costs (especially long term maintenance costs) associated with stormwater management and maintenance activities. Construction and maintenance cost information was collected from around New Zealand, and LCCs were modelled for a range of stormwater devices. Costs provided are in NPV \$(2018), and are based on a 50 year life span and 3.5% discount rate.
2. **Te Awarua-o-Porirua (TAoP) Whaitua Collaborative Modelling Study – Economic Models** (Ira, 2017): The TAoP Whaitua project was a collaborative modelling study with the purpose of generating information and knowledge to support the TAoP Whaitua Committee’s recommendation for land and water management within the Whaitua. As part of the economic aspects of this work, stormwater cost information was collected which was specific to the Wellington region. LCCs were generated for a number of different stormwater interventions for use in an overall “Cost Aggregation Model” which was used to compare different urban and rural stormwater and wastewater intervention scenarios. Individual LCCs were documented and these have helped to inform the cost information provided in this section. Costs are based on a 50 year life span and 3.5% discount rate.

⁶ <https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design> Relevant reports include:

- a) Ira, S.J.T. and Simcock, R. (2019). *Understanding costs and maintenance of WSUD in New Zealand*. Research report to the Building Better Homes, Towns and Cities National Science Challenge.
- b) Moores, J., Ira, S., Batstone, C. and Simcock, R. (2019). *The ‘More than Water’ WSUD Assessment Tool*. Research report to the Building Better Homes, Towns and Cities National Science Challenge.

3. **The NIWA-Cawthron UPSW Spatial Decision Support System** (Ira *et al.*, 2015): This model was prepared under the “Urban Planning that Sustains Waterbodies” research (funded by the Ministry for Business Innovation and Employment). It is a computer-based spatial decision support system which evaluated the effects of urban development on freshwater and estuarine urban waterbodies in terms of the four well-beings (environmental, cultural, social and economic). An economic costing methodology, based on a LCC approach, was used to contribute to the overall economic indicator in the model. The LCC module used numerous COSTnz model runs to determine NPV \$/ha/yr costs based on a 50 year life cycle analysis period and a 3.5% discount rate.
4. **The Landcare Research COSTnz Model** (Ira *et al.*, 2009): The COSTnz Model is a LCC model that allows users to quantify the relative costs of individual stormwater management devices. The model was completed in 2009 and is based on a unit costing approach. The model provides default low, medium and high costing values which can be used, and also recommends frequencies for maintenance activities. In the absence of more recent and available cost data, default unit costs from COSTnz were used.

3.5 New cost data

Over the course of this project, workshops and cost data collection meetings were held with AC Healthy Waters officers to supplement the cost data sources documented in Section 3.4 for the structural mitigations. The cost data collection protocol used is included in **Appendix A. Table 3.2** provides a summary of this data collection process.

Table 3.2 Summary of the cost data collection process for structural interventions

Workshop/ Meeting Date	Purpose	Team
7/3/2019	Start-up workshop to discuss cost data needs and gaps. Also discussion around HW objectives for cost data and how it will be used.	Attendees from the following Healthy Water Teams: Lifecycle Management; Asset Management; Development and Negotiations; Waterways Planning; Regional Planning
3/4/2019	Meeting to collect data relating to TACs. Cost information for 9 rain gardens and 1 wetland received. Indirect and overhead costs discussed and the “Unit Rate Analysis for 2018 Stormwater Asset Revaluation” (Draft 2 for Audit Review – 6-22-2018) was tabled as good approach for estimating these costs in Auckland.	Asset Management
10/4/2019	Meeting to collect MC information. Information received on catchpit cleaning, street sweeping, cleanout of proprietary devices, rain garden maintenance.	Lifecycle Management – Central

Workshop/ Meeting Date	Purpose	Team
10/5/2019	Meeting to collect MC information. Information received on pond, wetland and rain garden maintenance. Schedule of maintenance costs received for northern area.	Lifecycle Management - North
4/7/2019	Cost workshop to present TACs and MCs to be used in the life cycle assessment. Scope of cost data collection expanded to include proprietary devices such as GPTs and ponds.	Attendees from the following Healthy Water Teams: Lifecycle Management; Asset Management; Development and Negotiations; Waterways Planning; Regional Planning
2/9/2019	Meeting with PDP to obtain TAC and MC information relating to proprietary filters and GPTs.	PDP Consultants
31/10/2019	Meeting with Healthy Waters (Jackie Zhou and Sally Be) – discussion around TAC and review of individual LCC models.	Healthy Waters (Waterways Planning)

3.6 Data in-puts, assumptions and the LCC process

Conducting a life cycle analysis is a step-by-step process which includes making assumptions around the life span, the life cycle analysis period, the base date of the costs, discount rate, and the costs themselves. It is considered to be a robust method of estimating non-financial indicative costs.

Table 3.3 documents this process and the assumptions used in the LCC models. It is noted that this process is in accordance with the Australian/New Zealand Standard 4536:1999 for LCC modelling.

Table 3.3 Life cycle costing assumptions

Step	Assumptions / Parameters
Design parameters	Design based on the structural intervention options report (Morphum Environmental, 2019).
Life span	The life span varies depending on the type of stormwater treatment device, and is the functional life of the device. In order to be consistent with previous life cycle costing work in NZ, a life span of 50 years be used for all devices (e.g., Ira <i>et al.</i> , 2009, 2015; Ira, 2017; Ira and Simcock, 2019). For devices with a shorter life span (e.g. rain tanks) ‘resets’ are included as part of the corrective maintenance costs to account for renewal-type costs.
Life cycle analysis period (LCAP)	This is the number of years over which the analysis will run. It is can sometimes equal the life span. If multiple devices are being modelled as part of a treatment train approach then the LCAP needs to be consistent so that the results across devices are comparable. The Activating WSUD in NZ, Porirua Whaitua and UPSW NIWA costing work used a LCAP of 50 years. This fits well with the life spans recommended and has been used.

Step	Assumptions / Parameters
Base date and inflation rate	The base date for all costs is 2018. No inflation is incorporated in LCC analysis (Auckland Council, 2013; NZ Treasury, 2015), rather a discount rate is used to calculate the net present value. Any cost information collected which was not from 2018, was inflated to a base date of 2018.
Discount rate (used for the Net Present Value LCC calculation)	<p>The discount rate (DR) is a function of the cost of capital, an inflation factor and a risk adjustment factor. It can be real or nominal. The real discount rate is use for LCC and doesn't include an inflation component⁷. The total NPV LCC is the lump sum amount that a person would need today to meet all the costs of installing, maintaining and using that device over its lifetime. In other words, costs which occur later in time within the LCC cycle are given less weight than those which occur sooner. The DR is therefore used to bring future costs back to today's dollar values. By discounting the costs we are able to determine the total buying power (cash value) needed over the total life cycle.</p> <p>Discounting is one of the most debatable and controversial aspects of a LCC assessment. Although, the DR used is less important than ensuring a consistent DR is used for all devices (NZ Treasury, 2015). The public sector discount rate is published by the NZ Treasury and set at 8%:</p> <p>https://treasury.govt.nz/sites/default/files/2015-07/cba-guide-jul15.pdf</p> <p>A discount rate of 3.5% was used in the Activating WSUD in NZ, Porirua Whaitua and UPSW NIWA costing work. COSTnz provides an option of either a 3% or 6% discount rate, or users can specify their own rate. A lower discount rate avoids/ mitigates a distortionary focus on distant future costs (and benefits). The Auckland Council "Cost Benefit Primer" report (Auckland Council, 2013) recommends a discount rate of 4%, with sensitivity analyses being undertaken on 2%, 6% and 8%. An 8% discount rate is not recommended for infrastructure projects which have a long life and potentially significant long term maintenance expenditure (such a high discount rate underestimates the importance of near-end or end-of-life maintenance). This approach has been endorsed by Auckland Council's Chief Economist (pers comm. 12 December 2019).</p>
Calculate the Total acquisition costs (TAC)	The TAC relates to the design, planning, consenting, land acquisition and construction costs of a device. The TAC is calculated based on cost sources identified in Sections 3.4 and 3.5, and as presented in Section 4.1.
Calculate the routine maintenance costs (RMC)	<p>These are regular (annual) costs which relate to routine maintenance activities such as general inspections, mowing grassed areas, weeding, cleaning out debris, making good from vandalism, etc.</p> <p>The RMC is calculated based on cost sources identified in Sections 3.4 and 3.5, and as presented in Section 4.2.</p>

⁷ For more information about the real discount rate, please see the Australian/New Zealand Standard *Life Cycle Costing: An Application Guide, AS/NZ 4536:1999*.

Step	Assumptions / Parameters
Calculate the corrective maintenance costs (CMC)	These are intermittent (multi-annual) large scale costs associated with marked, infrequent maintenance activities. They include repairing parts, cleaning out sediments and disposal of them, replacing filter media, etc. Renewals can also form part of the corrective maintenance costs. The CMC is based on cost sources identified in Sections 3.4 and 3.5, and as presented in Section 4.2.
Decommissioning costs (DC)	Decommissioning costs are not included in the analysis, as it is very unlikely that the devices would be decommissioned at the end of the 50 year period. Instead, a renewal cost is scheduled for the final year of the life span.
Determine the LCC (Cost Outputs)	Based on the step-by-step process documented in this table, LCC models have been built and used to calculate the NPV cost. Total LCCs results are given in Section 6. LCC results for use in SUSTAIN are in the form of an annualised LCC.

3.7 Methods and outputs: completing the costing puzzle

Table 3.3 shows that there are many inputs and parts to the LCC process. Once the unit cost data had been collected, it was analysed separately to develop suitable low and high TACs and MCs for use in an LCC model (Section 4). New, purpose-built LCC models were built (Section 5) for a range of stormwater practices, and low and high LCCs generated (Section 6). Separate low and high LCC model runs are recommended as the cost data presented is based on either actual construction costs or actual cost estimates for parts, labour and installation of constructed devices. Given that construction costs and estimates for parts, labour and installation vary depending on engineer estimates, topography, soils, construction methodology, availability of materials and procurement methods, a LCC “envelope” between the low and high cost scenario runs assists in accounting for and encompassing this inherent variability in cost. Given that the FWMT requires a single LCC for each intervention, an average LCC has been generated from the low and high LCC model runs. Section 7.1 provides an explanation of how the LCCs should be implemented in SUSTAIN. Additionally, the LCCs were subjected to a regression analysis and non-linear relationships were established (Section 7.2). The purpose of the regression analysis was to account for the variation in LCC which corresponds to variations in device surface area. The relationships provide a more accurate LCC per surface area across a range of surface area sizes than simply using average costs. The non-linear relationship was generated in order to aid future catchment planning work which could be done outside of the FWMT. The flow chart in **Figure 3.2** documents this process.

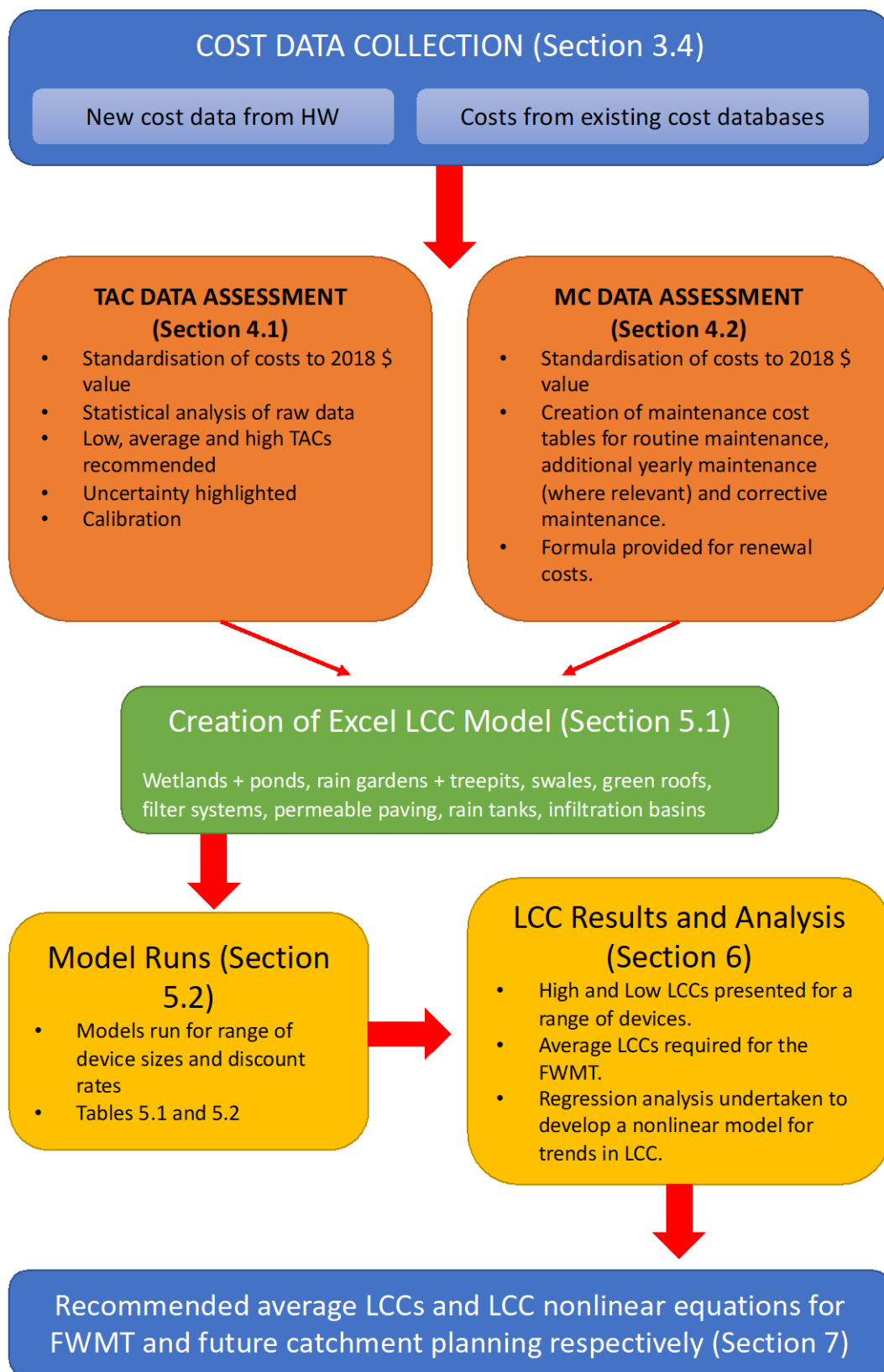


Figure 3.2 Data collection, modelling and analysis process

4. Assessment of unit costs

4.1 Total acquisition costs

Total acquisition costs (TAC) are costs that relate to the design, consenting, planning, project management, land purchase and construction of a specific intervention. All TACs provided in this report have a base date of 2018.

4.1.1 Non-device specific TAC assumptions

In general, the majority of cost data collected and recorded tends to relate solely to construction costs. The upfront planning, design and consenting costs, as well as project management costs (sometimes referred to as overhead and indirect costs), generally required estimation by the authors.

The following assumptions guided derivation of non-construction costs for devices. The indirect and overhead costs have been calculated, but vary depending on the data source:

- Data collected through the Activating WSUD in NZ project (Ira and Simcock, 2019) includes an overhead and indirect cost of 45% of the construction cost. This was based on work undertaken through the ToAP Waitua project (Ira, 2017), as well as discussions with network operators, developers and consultants. The estimated 45% overhead and indirect costs comprises 30% which relates to professional fees and costs associated with planning, design, consenting and project management costs and 15% which relates to construction contingency costs.
- Additional data collected for this project from Healthy Waters uses the "Unit Rate Analysis for 2018 Stormwater Asset Revaluation" (Auckland Council, 2018), as shown in **Table 4.1**. Cost information for the unit rate analysis (Auckland Council, 2018) was derived from asset schedules of capital projects managed by Council as well as assets vested from subdivision development for a range of assets (from pipes and manholes to soakage systems, treatment devices and pump stations). The indirect asset and overhead cost did not vary by asset, but rather via geographical zones relating to construction cost complexity.

Table 4.1 Indirect and overhead costs as determined by Auckland Council. Indirect asset costs refer to physical costs which cannot be traced to an asset (such as health and safety, traffic management, preliminary and general costs), whilst overhead costs refer to the design cost and project management services (Auckland Council, 2018).

Indirect Cost

Cost Complexity Zone	
Low	25% of construction cost
Medium	55% of construction cost
High	91% of construction cost

Overhead Cost

Cost Complexity Zone	
Low	15% of construction cost
Medium	18% of construction cost
High	20% of construction cost

Land costs are excluded from the TACs provided in Sections 4.1.3 – 4.1.11. Land costs are expected to be generated separately by Healthy Waters and added to the LCCs provided⁸.

Whether a stormwater intervention is being built in a greenfields or brownfields catchment, or if it is a retrofit solution, can have a significant effect on the construction cost. Breaking into existing services, connections to existing services and working within brownfield/ retrofit site constraints tend to lead to increased construction costs over greenfield subdivisions. A cost adjustment factor for brownfields and retrofit scenarios is therefore recommended by the authors. Unfortunately there has been little research nationally and internationally into quantifying this cost differential, and thus it is recommended that the LCC models use the cost adjustment factors recommended by the USEPA System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN)⁹ model (Table 4.2).

Table 4.2 Cost adjustment factor based on SUSTAIN recommendations⁹

BMP/ Intervention	Factor
New BMP in undeveloped (greenfields) area	1
New BMP in partially developed (brownfields area)	1.5
New BMP in developed area (retrofit)	2
New BMP – difficult installation in highly urban settings	3

4.1.2 Data analysis

Once individual TAC data was collected and collated into a consistent format, it was standardized to 2018 NZ dollar values. Statistical analyses was undertaken on all stormwater interventions where actual TAC data was available. Regression analyses were performed in order to find the best fit relationship.

The analyses highlighted that none of the relationships fit the data particularly well, although the linear and exponential best-fit regressions did highlight that an increase in surface area corresponded to a decrease in cost. In the case of swales and green roofs, the poor fit is likely due to the lack of cost data. With respect to wetlands and rain gardens, whilst surface area is a primary cost driver, the data set also displayed sensitivity to secondary cost drivers such as construction methodology, topography, geographical location, soil type and availability of materials. Further construction cost data is needed in order to further refine these relationships.

Given that further data collection and statistical analyses was outside the scope of this project, descriptive statistics were run using Excel in order to generate low and high TACs to be used in the LCC analysis (as described further in Sections 4.1.3 – 4.1.11).

⁸ Healthy Waters have estimated TAC for each property within the 5,465 sub-catchments using February 2020 rates assessment information.

⁹ Memo from Karen Mateleska, EPA Region-I to Opti-Tool TAC, 20 February 2016. SUSTAIN Model details can be found at: <https://www.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain>

4.1.3 Wetlands

TAC data was available for 28 urban stormwater wetlands with an additional urban stormwater wetland TAC estimated provided by Healthy Waters officers. The 29 urban stormwater wetlands were designed and constructed over a period of 10 years, and were all either designed in accordance with the design standard laid out in the former Auckland Regional Council's Technical Publication 10 (Auckland Regional Council, 2003), or to achieve an average of 75% total suspended solids removal, or Auckland Council's Guideline Document 01 (Auckland Council, 2017).

As stated in Section 4.1.2, descriptive statistics were run for the dataset using Excel (**Table 4.3**). The error margin in **Table 4.3** relates to the 95% confidence interval, with the upper and lower bounds being the average cost +/- the error margin.

Table 4.3 Descriptive statistics for wetlands

Descriptive Statistics	TAC\$/m ²
Average	\$362
Standard Deviation	284
Sample Size	26
Margin of Error	\$115
Upper Bound	\$477
Lower Bound	\$248
Max	\$1,126
Min	\$52
Range	\$1,074
Median	\$319

The average TAC for an urban stormwater wetland is \$360/m² surface area with an error margin of +/- 32%. The FWMT includes 3 different types of urban wetlands as part of the intervention scenarios. Based on professional judgement, and using the upper and lower bounds of the TAC dataset, the recommended TACs for urban wetlands is shown in **Table 4.4**.

Subsequent to completion of this assessment, TACs were also requested for urban stormwater ponds. No additional data collection was undertaken for urban stormwater ponds. Previous modelling undertaken using COSTnz (Ira *et al.*, 2009) has demonstrated that ponds are generally cheaper to design and construct than wetlands. Based on professional judgement and the previous COSTnz modelling, the urban wetland lower bound TAC is suggested to be used to represent ponds.

Table 4.4 Recommended TACs for the wetland and pond LCC models

TOTAL ACQUISITION COSTS	Low Cost (\$/m ²)	High Cost (\$/m ²)
TAC per m ² surface area: TYPE 1: FLOOD DETENTION WETLAND	\$250	\$320
TAC per m ² surface area: TYPE 2: WQ WETLAND	\$320	\$360
TAC per m ² surface area: TYPE 3: WQ AND DETENTION WETLAND	\$360	\$470
TAC per m ² surface area: TYPE 4: POND	\$250	\$320

4.1.4 Rain gardens

TAC data was available for 43 urban rain gardens, inclusive of 7 rain gardens costed by Healthy Waters officers. The 43 urban rain gardens were designed and constructed over a period of 8 years, and were all either designed in accordance with the design standard laid out in the former Auckland Regional Council's Technical Publication 10 (Auckland Regional Council, 2003), or to achieve an average of 75% total suspended solids removal, or Auckland Council's Guideline Document 01 (Auckland Council, 2013).

Based on the descriptive statistics (**Table 4.5**), the average TAC for a rain garden is \$520/m² surface area with a 95% confidence interval error margin of +/- 19%. Looking at the data collected for the 43 rain gardens, the low TAC estimate (\$420/m²) is more indicative of rain gardens constructed as part of greenfield subdivisions, whilst the high estimate (\$620/m²) is more indicative of concreted lined rain gardens constructed during brownfields development or retrofit situations. It is interesting to note that the high estimate equates to approximately 1.5 times the low TAC estimate which is consistent with the development factor recommended for use in brownfields situations. Based on these results, it is recommended that the LCC models use a low TAC of \$420 and a high TAC of \$520.

Table 4.5 Descriptive statistics for rain gardens

Descriptive Statistics	TAC \$/m ²
Average	\$521
Standard Deviation	300
Sample Size	38
Margin of Error	\$98
Upper Bound	\$620
Lower Bound	\$423
Max	\$1,206
Min	\$89
Range	\$1,117
Median	\$530

4.1.5 Tree pits

No cost data was available for existing tree pits, so TACs have been extrapolated from rain gardens which have a surface area of less than 10m². Only eleven <10m² rain gardens were available for analysis (**Table 4.6**).

Table 4.6 Descriptive statistics for tree pits

Descriptive Statistics	TAC \$/m ²
Average	\$1,840
Standard Deviation	827
Sample Size	11
Margin of Error	\$555
Upper Bound	\$2,395
Lower Bound	\$1,285

Descriptive Statistics	TAC \$/m ²
Max	\$2,940
Min	\$653
Range	\$2,287
Median	\$1,708

The average TAC for a treepit is \$1,840/m² surface area with a 95% confidence interval error margin of +/- 30% (**Table 4.6**). For production runs of treepits (potentially greater than 10 treepits within a green streets scenario), a lower bound cost of \$1,290/m² should be used for the LCC models. This allows for economies of scale to be accounted for (i.e. savings resulting from 'bulk' orders). Although, such efficiencies might not be achieved except for a single costed party (e.g., except for Auckland Council or Auckland Transport). Discussions with Healthy Waters engineers highlighted that the upper bound (\$2,395/m²) seemed excessively high.

4.1.6 Swales

Two types of urban swale devices have been documented via the data collection process (i.e. drained swales and infiltration swales):

- Drained swales are steeper ($\geq 5\%$ slope), and incorporate check dams and an underdrain
- Infiltration swales are gentler ($< 5\%$ slope) and do not incorporate any underdrainage (i.e. the underlying soils and geology allows for infiltration of stormwater).

The swales were designed and constructed over a period of 7 years, and were all either designed in accordance with the design standard laid out in the former Auckland Regional Council's Technical Publication 10 (Auckland Regional Council, 2003), or to achieve an average of 75% total suspended solids removal over a long term basis. For both types, the number of observed swales are limited, with 8 TAC estimates available for the infiltration swales (**Table 4.7**) and a further 8 TAC estimates available for the drained swales (**Table 4.8**).

Table 4.7 Descriptive statistics for infiltration swales

Descriptive Statistics (Infiltration Swales)	\$/ linear m
Average	\$75
Standard Deviation	13
Sample Size	7
Margin of Error	\$12
Upper Bound	\$87
Lower Bound	\$63
Max	\$93
Min	\$54
Range	\$39
Median	\$71

The average TAC for an infiltration swale is \$75/ linear m (a 95% confidence interval error margin of +/- 16%). Infiltration swales are not used as an option within the FWMT Stage 1.

Table 4.8 Descriptive statistics for drained swales

Descriptive Statistics (Drained Swales)	\$TAC / linear m
Average	\$312
Standard Deviation	80
Sample Size	8
Margin of Error	\$65
Upper Bound	\$378
Lower Bound	\$247
Max	\$474
Min	\$216
Range	\$258
Median	\$308

The average TAC for a drained swale of \$310/ linear m (a 95% confidence interval error margin of +/- 21%). Looking at the data collected for the 8 drained swales, the low TAC estimate (\$250/m²) is more indicative of swales constructed as part of greenfield subdivisions, whilst the high estimate (\$380/m²) is more indicative of swales constructed during brownfields development or retrofit situations. It is interesting to note that the high estimate equates to approximately 1.5 times the low TAC estimate which is consistent with the development factor recommended for use in brownfields situations. Based on these results, it is recommended that the LCC models use a low TAC of \$250 and a high TAC of \$315.

4.1.7 Green roofs

Only 4 cost estimates are available for urban green roofs (Ira and Simcock, 2019). It should be noted that these costs relate to the 'green roof' components of the roof, not the underlying structure of the building. The average TAC for green roofs is \$370/m² (**Table 4.9**), with a low TAC of \$300 and high TAC of \$440 recommended for the LCC models.

Table 4.9 Descriptive statistics for green roofs

Descriptive Statistics	TAC \$/m ²
Average	\$369
Standard Deviation	75
Sample Size	4
Margin of Error	\$73
Upper Bound	\$442
Lower Bound	\$296
Max	\$467
Min	\$284
Range	\$183
Median	\$363

4.1.8 Filtration systems

Filtration systems are a broad category comprising different types of underground constructed filter systems. The TAC provided in this section are generally based on cost information provided by PDP Consultants Ltd, as collected for Healthy Waters FWMT (Pattle Delamore Partners Ltd, 2019). They comprise a range of different filter systems and are average, indicative cost estimates for the category as a whole. They are not representative of any particular proprietary product, and the descriptive statistics (**Figure 4.10**) relate solely to the filtration system itself.

Table 4.10 Descriptive statistics for filtration systems

Descriptive Statistics	\$/ ha area treated
Average	\$38,337
Standard Deviation	14792
Sample Size	13
Margin of Error	\$8862
Upper Bound	\$46,378
Lower Bound	\$30,296
Max	\$63,824
Min	\$13,780
range	\$50,043
Median	\$37,380

A low TAC for an urban filtration system of \$79,370/ ha of impervious area treated (this includes the filtration system plus pre-treatment, earthworks, pipes and connections, reinstatement, overhead and indirect costs) is recommended for use in the LCC models, with a high TAC of \$95,000. The analysis provided in this report relates solely to the cost of different types of filter systems. The recommended TAC includes an estimate for pre-treatment (gross pollutant trap or similar), installation and reinstatement costs, as well as overhead and indirect costs.

4.1.9 Infiltration basins

No new data has been collected for urban infiltration basins since the development of COSTnz in 2007. Even during the development of COSTnz, scant cost information on infiltration basins was available. This is likely due to their limited use within the Auckland Region.

For this project, it is recommended that the relationship developed within COSTnz for dry ponds be used as a surrogate cost for infiltration basins (Vesely, et al., 2006). The relationships developed for COSTnz are shown in **Figure 4.1**.

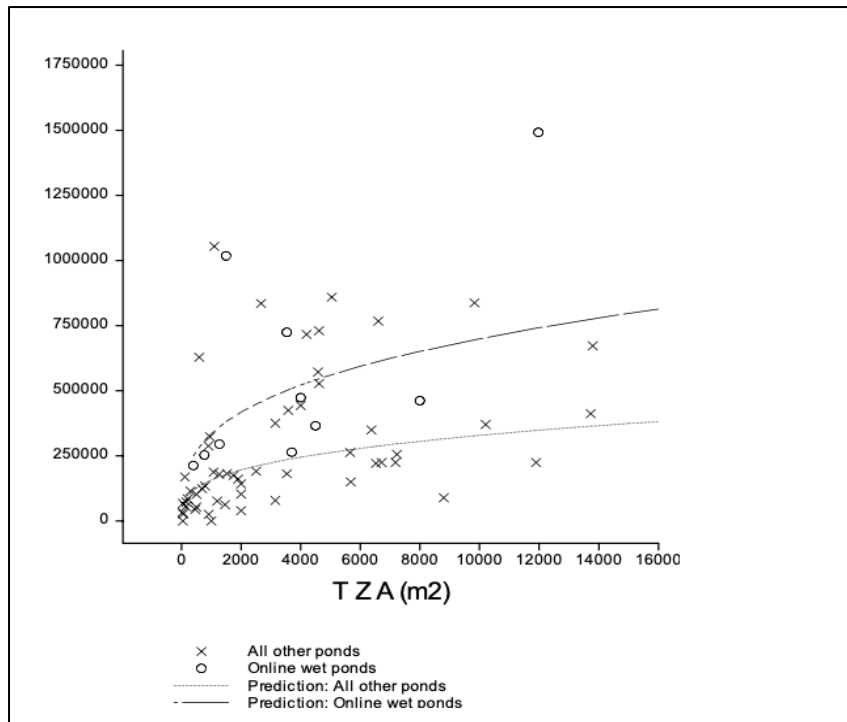


Figure 4.1 TAC (\$) plotted against Treatment Zone Area (TZA) (m²) for online wet and other ponds with model prediction curves

The recommended equation for dry pond TACs equates to the low pond TAC estimate for off-line ponds, as developed in COSTnz. It is recommended that this equation be used for the relationship between TAC and surface area for infiltration basins within LCC models:

$$TAC = \left(\frac{6802 * PondSurfaceArea^{0.4436}}{1.76} \right) * (1 + 0.048^3)$$

Further work (data collection and analysis) would be needed to more accurately define the design, consenting and construction costs of infiltration basins, however, due to their low level of use in the Auckland Region, this is not deemed a priority for Stage 1 of the FWMT.

4.1.10 Rain tanks

TACs for urban rain tanks are based on work undertaken for COSTnz (Ira *et al.*, 2009) and the Activating WSUD in New Zealand project (Ira and Simcock, 2019). One of the main cost drivers within the TAC for urban rain tanks is the size of the tank (see **Table 4.11**), and the recommended TAC equations below provide a low and high estimate of the cost. The costs are based on actual cost estimates for parts, labour and installation of the rain tanks and the low and high estimates encompass the spread of cost estimates received from rain tank suppliers. The constant within the equations account for costs associated with electrical connections, pump, pipework, concrete slab for base, water filters, first flush diverters and shut off valves, and reinstatement. The percentage in each case (i.e. low – 15% and high – 20%) relates to overhead and indirect costs associated with the design and construction process.

$$\begin{aligned} \text{Low TAC} &= (4800 + TankCost) + [(4800 + TankCost) * 0.15] \\ \text{High TAC} &= (6500 + TankCost) + [(6500 + TankCost) * 0.2] \end{aligned}$$

Table 4.11 Costs of rain tanks (as taken from COSTnz and inflated to 2018 \$ values), and ground-truthed via rain tank costs from supplier websites (accessed in December 2019). Costs relate to above ground, round polyethylene storage tanks and include an installation cost component.

Tank Size	Low TAC (\$)	High TAC (\$)
1000 Litre	672	738
3000 Litre	1,384	1,410
5000 Litre	1,964	2,056
9000 Litre	2,768	3,203
10000 Litre	3,361	3,756
15000 Litre	3,954	4,376
30000 Litre	4,547	4,863

4.1.11 Permeable paving

TACs for urban permeable paving are based on work undertaken for the Activating WSUD in New Zealand project (Ira and Simcock, 2019). One of the main cost factors within the TAC for permeable paving is the type of paver (**Table 4.12**), and the equations provide a low and high estimate of the cost. The constant within the equations accounts for costs associated with the installation and construction activities, and materials needed to prepare the ground to lay pavers. The percentage in each case (i.e. low – 15% and high – 20%) relates to overhead and indirect costs associated with the design and construction process.

$$\begin{aligned} \text{Low TAC} &= (85 + m^2 \text{ of paver cost}) + [(85 + m^2 \text{ of paver cost}) * 0.15] \\ \text{High TAC} &= (120 + m^2 \text{ of paver cost}) + [(120 + m^2 \text{ of paver cost}) * 0.20] \end{aligned}$$

Table 4.12 Costs of different types of permeable pavers (as taken from COSTnz and inflated to 2018 \$ values and from supplier websites, accessed in December 2019).

Estimate of Permeable Paver Costs	2018 \$
Solid block paver with gaps between or similar	\$89
Gobi block or similar	\$100
Grass pavers or similar	\$70
COSTnz paver costs (low)	\$217

4.1.12 Calibration of TACs

Urban wetland and rain garden calculated average TACs have been compared with the actual cost data collected in order to ensure that the proposed average costs for use in the LCC model are generally representative across a range of surface area sizes. **Figures 4.2** and **4.3** show the fit for both devices across range of observed sizes. It is noted that, in both, the use of an average urban device TAC likely over-estimates TACs of large devices and underestimates TACs of smaller devices. A better fit could be achieved if more explanatory variables were available in the underlying datasets, but the resolution of the cost data (i.e. lump sum construction cost information) did not

allow for this analysis. Further work is recommended (Section 6.2) to collect detailed design and construction cost information for a range of GI devices. Our recommendation is that should optimisation outputs from the FWMT proceed to become increasingly important to decision-makers, that targeted investigation of TAC for devices is prioritised by Healthy Waters.

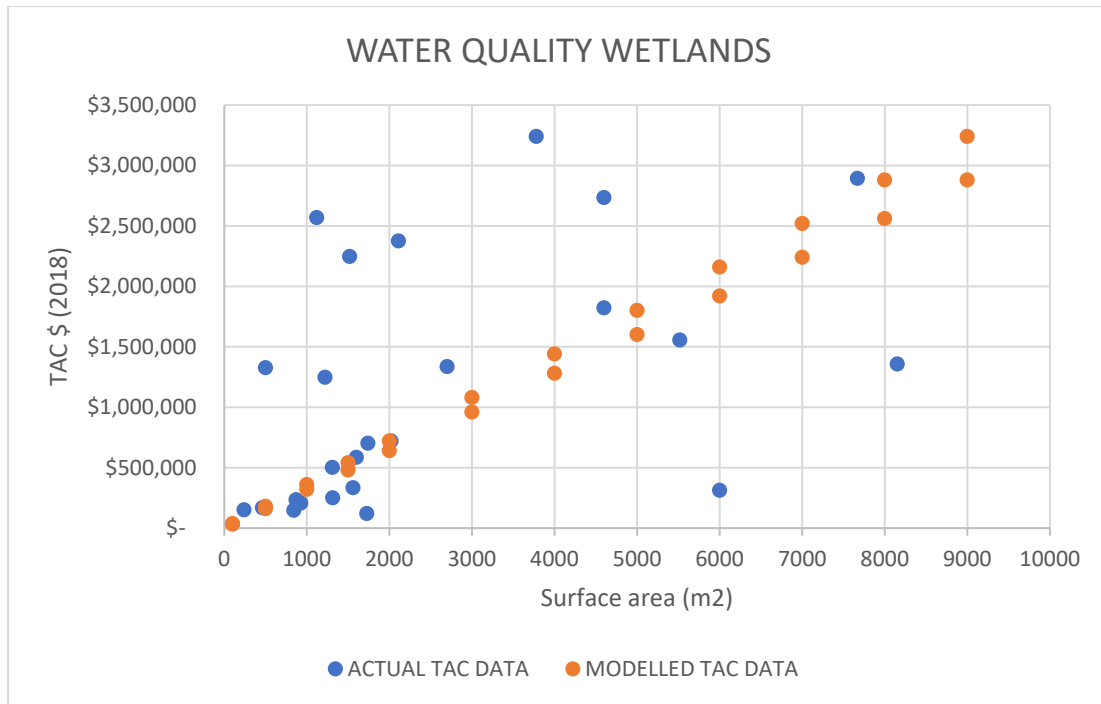


Figure 4.2 Comparison between actual (collected) TACs and proposed unit cost TAC values for life cycle cost assessments for urban water quality wetlands

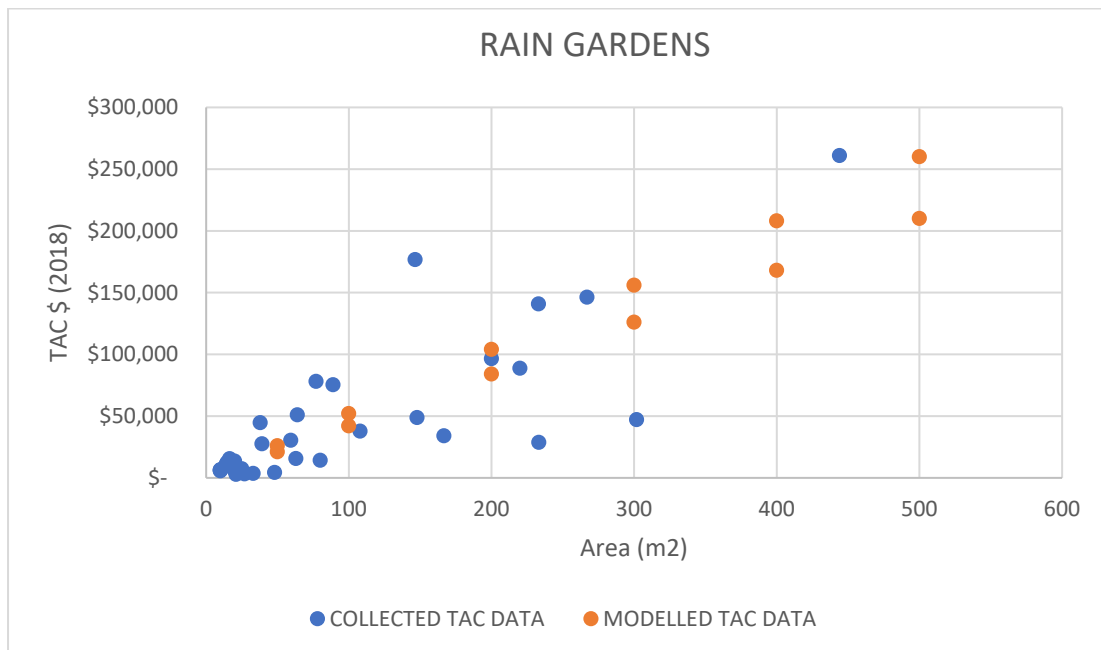


Figure 4.3 Comparison between actual (collected) TACs and proposed unit cost TAC values for life cycle cost assessments for urban rain gardens

4.2 Maintenance Costs

Maintenance costs are generally a function of the types of activities needed to ensure a structural stormwater practice functions as designed, along with the frequency of that activity and the unit cost. **Tables 4.13 to 4.20** provide a summary of the proposed maintenance activities, frequency of those activities and unit costs for the structural interventions discussed in Section 3.3.

Whilst every effort has been made to ensure that the activities and costs are reflective of “on-the-ground” maintenance, it should be noted that the tables are indicative of the average level of maintenance needed on a device that has been appropriately designed and constructed. This is compatible with the broader use of average device TAC by the FWMT Stage 1.

Maintenance costs do not account for “exceptional maintenance” (i.e., failure of a new pond embankment or needing to rebuild/ correct rain garden overflow structures). In addition, unit costs provided are best estimates at the time of writing with a base date of 2018. It is likely that maintenance costs are relatively more accurate – that is relative variation therein between devices is more accurate than absolute differences.

The frequencies provided in the tables are based on the Activating WSUD maintenance tables (Ira and Simcock, 2019) which were developed from the former Auckland Regional Council’s Technical Publication 10 (Auckland Regional Council, 2003), the NZTA Stormwater Treatment Standard (NZTA, 2010) and Auckland Council’s TR2010/053 (Healy *et al.*, 2010), as well as advice from Auckland Council engineers, maintenance engineers and landscape maintenance experts.

Non-routine maintenance costs, such as botulism in wetlands and ponds, are challenging to quantify (e.g., irregular, infrequent and widely varying). Thus an “indicative” cost for non-routine maintenance has been included in the relevant tables. The cost associated with botulism can vary greatly from pond to pond and season to season. As such, the overall cost over a period of 50 years for a theoretical pond or wetland intervention is almost impossible to accurately predict.

Traffic management costs can be significant, but also vary greatly and it is difficult to predict the types of traffic management measures which will be implemented for various theoretical GI interventions into the future. As for botulism, an indicative cost for traffic management is included.

Finally, GI devices are generally not decommissioned at the end of their lives. No decommissioning cost is therefore included in the maintenance analysis. Rather, a renewal cost will be included at the end of the life span for each GI practice. This renewal cost will be calculated as follows:

$$\text{Renewal cost} = \text{TAC} - \text{land costs}$$

Table 4.13 Routine and corrective wetland and pond maintenance schedule

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Routine General Maintenance (line trimming/lifting, mowing, maintaining healthy vegetation cover, removing litter)	4	per visit	\$50	\$55
Removing debris (e.g. litter, dead vegetation) from outlet and inlet /forebay structures	4	per wetland	\$50	\$165
Inspections (Weeds, QA, inspection of embankments, spillways, outfalls, overall functioning of facility, integrity of fences if present)	12	per visit	\$40	\$95
Scheduled Mechanical Inspections (pumps, outlets, removing mosquito breeding areas)	1	per wetland	\$65	\$145
Additional inspections (significant events)	0.5	per visit	\$60	\$125
Aquatic weed management	1	m ²	\$0.29	\$0.53

Additional Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Additional visits for initial Aftercare of Plants (for first 5 years): includes initial tree form prune and canopy lift to retain dense groundcover	2	m ²	\$0.30	\$0.35
Asset handover maintenance (for first 2 years)	2	per visit	\$475	\$1,050

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Cleaning of debris/ litter after significant events	10	per wetland	\$5,000	\$10,000
Botulism related costs	10	per wetland	\$50,000	\$100,000
Terrestrial weed management	10	per wetland	\$80,000	\$100,000
Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments/baffles, erosion)	10	per wetland	\$12,000	\$18,800
Replacement of parts (grates, trash screens)	20	per wetland	\$1,200	\$7,200
Replanting the wetland zone	50	m ²	\$10.80	\$15.00
Reseeding/ landscaping disturbed terrestrial area	25	m ²	\$7.25	\$10.80
Desilting and disposal of sediment from forebay	25	m ³	\$105	\$310
Desilting and disposal of sediment from main pond	50	m ³	\$105	\$310

Table 4.14 Routine and corrective rain garden and tree pit maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Routine Landscape Maintenance:				
Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.	9	m ²	\$0.50	\$1.30
It includes up to 5% replanting or re-mulching (especially at inlets and edges).				
It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity.				
Functional Drainage Maintenance:	12	per RG	\$120	\$175
Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.				
Flush out drainage.				
Traffic Control Costs:	9	m ²	\$1.00	\$3.20
TMPs and traffic lane closure (static or mobile works)				
Minor repairs:	1	per RG	\$120	\$175
Repairs to grills on outlets/ inlets; additional soil/ mulch needed; erosion				
Make good following vandalism:	2	per RG	\$120	\$175
Relates to primarily vegetation and graffiti removal				

Additional RMC	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Initial aftercare of plants (first 3 years)	4	m ²	\$1.20	\$3.48
Initial aftercare of tree pits (first 3 years)				
Checking stakes/supports and then their removal where required	3	m ²	\$0.75	\$1.00
May need fertilisation in sandy and large rain gardens in clean catchments (note: if high-fertility-requiring trees less than 4 m tall are planted, then double to twice per year, using slow-release fertilisers/ organic mulch amended with compost)	1	m ²	\$0.75	\$1.00
24 monthly pruning for first 6 years to develop healthy structural form and lift canopy to required sight lines	1	m ²	\$1.00	\$1.40

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Additional mitigative actions: - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Additional trimming of vegetation around signs or lights (services and signage should not be placed in raingardens). - Removing dead vegetation due to ponding because of incorrect rain garden mix or poor outlet design.	5	m ²	\$2.60	\$6.00
Fixing erosion of outlets due to poor slope control or undersized rain gardens.	5	m ²	\$0.50	\$0.75
TMPs and traffic lane closure (static or mobile works)	5	m ²	\$1.00	\$3.20
Infiltration Testing (if needed)	4	per test	\$100	\$520
Removal & disposal of sediments (including replacement with new media) + cartage	50	m ³	\$55	\$147
Complete replanting	50	m ²	\$1.50	\$7.20
Major maintenance of drainage system, e.g. replacement of parts	15	per RG	\$1,200	\$3,900

Table 4.15 Routine and corrective swale maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Routine General Maintenance for grass swale (tractor mowing, edge-spraying or trimming, weeding).	6	m ²	\$0.43	\$0.76
Routine General Maintenance for planted swale in perennial vegetation (maintaining healthy vegetation cover, weeding, edge trimming, mulch replacement).	3	hr	\$45	\$60
Routine General Maintenance - as above but needs road or lane closures to allow for maintenance (for major arterial roads use this item)	4	m ²	\$0.60	\$3.50
Routine General Maintenance - mowing requiring hand mowing or weed whacking rather than tractor mowing.	6	m ²	\$15	\$20
Inspections (inlets for scour, ruts and preferential flow, debris, outlets, integrity of swale/ dispersed flow) and removing debris/ litter and sediment (e.g. From inlet or overflow structures)	2	per swale	\$35	\$50
Deciduous Trees - sweep and remove leaves	2	per hr	\$45	\$60
Make good following vandalism (bollards, repair of barriers, re-staking trees) Note: where trees are in grassed swales use protection against weed whackers to avoid trunk damage	1	per swale	\$120	\$175

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Maintaining even, dispersed flow - removing accumulated sediment; regrading, filling and decompaction to remove tyre ruts or scoured areas	25	per swale	\$300	\$600
Disposal of sediment to landfill	25	m ³	\$55	\$150
Re-grassing (assume turf mat or coir/wool seeded mats used given swale is online)	25	m ²	\$0.66	\$0.90
Replanting - plugs with coir/wool erosion mat (high amenity has 9 plugs/m ² or larger plants, low amenity has 4 plugs/m ² with no large plants)	25	m ²	\$15	\$20
Replanting/ grassing (where road closures are required)	25	m ²	\$0.83	\$2.55
Minor repairs to inlet or outlet structures	10	per swale	\$48	\$240
Replacement of bollards (discontinuous kerbing)	10	per 10m	\$60	\$180
Replacement of underdrain	25	per m	\$20	\$30
Replacement of specimen trees following death or damage (e.g. from vandalism. Mowers, weed whackers, storm damage, drought or water logging)	10	per tree	\$250	\$400

Table 4.16 Routine and corrective green roof maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Inspections (planted zone including all edges; overflows and drainage points, irrigation) (allows for working at heights certification).	3	labour cost per hr	\$20	\$45
Mowing of sedum-based roof garden (not lawn mowing)	2	per m ²	\$0.43	\$0.76
Weeding / pruning / fertilizing/ edge, drain and overflow clearance (low rate - standard landscaper)	1	labour cost per day	\$160	\$360
Weeding pruning /fertilizing/ edge, drain and overflow clearance (high rate - working at heights certification)	2	labour cost per day	\$400	\$720

Additional Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Additional visits for initial Aftercare of Plants (for first 3 years):	3	per m ²	\$8	\$30

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Corrective Maintenance Repair Costs (plants/ media)	25	per m ²	\$2	\$50
Corrective maintenance Repair Costs (perimeter drainage edges and overflow mulch topping up/replacement) (estimate based on roof perimeter)	15	lump sum	\$1,000	\$3,000
Corrective Maintenance Repair Costs (under-drainage layer) (estimate 0.25 of roof)	25	per m ²	\$100	\$120
Working at Heights Certification	3	per course	\$2,000	\$2,500
Council Inspections – cost to private green roofs	3	per inspection	\$105	\$120

Table 4.17 Routine and corrective filter systems maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Inspections	2	per device	\$220	\$400
Cleanout of pre-treatment/ catchpit	2	per device	\$220	\$270
Yearly maintenance clean	1	per ha impervious	\$8,400	\$9,000
TM solutions (road closure - mobile solution)	1	per device	\$560	\$870

Additional Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Additional inspection	1	per device	\$220	\$400
Initial maintenance clean	1	per ha impervious	\$8,600	\$9,200

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
For sand filters: Cleaning of treatment devices (sediment removal (top layer); disposal; etc)	10	per device	\$1,900	\$3,400
TM solutions (road closure - mobile solution)	25	per device	\$560	\$870
Replacement of Unit*	25	per ha impervious	\$30,300	\$46,400
Indirect replacement costs	25	per ha impervious	\$6,900	\$13,800
Overhead replacement costs	25	per ha impervious	\$4,100	\$8,300

Table 4.18 Routine and corrective infiltration basin maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
General Maintenance: removing debris, clearing inlets, checking sediment traps, forebays/ swales, etc	12	per basin	\$120	\$160
Inspections (sediment traps/ forebays, pre-treatment swales, inlets, outlets/ overflow spillway, overall functioning of facility)	4	per basin	\$40	\$95
Maintaining healthy vegetation around device, weeding, mowing, etc	6	m ²	\$0.35	\$0.70
Minor repairs	1	per basin	\$135	\$680
Make good following vandalism	1	per basin	\$200	\$325
Additional inspections (significant events)	0.5	per visit	\$60	\$125

Additional Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Asset handover maintenance (for first 2 years)	2	per visit	\$475	\$1,045

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Cleanout sediment, oils, etc and removal of top layer of stone and re-establishment/ cleaning of debris after significant events	5	per basin	\$1,000	\$5,000
Replacement of parts (grates, trash screens)	20	per basin	\$1,200	\$7,200
Erosion repair	2	per visit	\$475	\$1,045
Repairs to structural components	10	per basin	\$680	\$1,355
Removal and disposal of sediments	10	m ³	\$105	\$310
Rehabilitation of trench/ basin	10	m ³	\$135	\$490

Table 4.19 Routine and corrective above ground rain tank maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Inspection of tank, orifice outlet, pipework, first flush device, pest screens, erosion protection. Inspection of electrical parts. Maintenance of screens/ filters. Clean out as necessary. Check surrounding area for overhanging branches/ nuisance potential.	1	per inspection	\$195	\$290

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Maintenance of filters, pumps, etc	5	per tank	\$100	\$130
Replacement of water supply pump	15	per pump	\$1,200	\$3,000
Minor Repairs to concrete and structural components (e.g. sealing cracks; tank stand; etc)	15	per tank	\$130	\$690
Council Inspections – cost to private rain tanks	3	per inspection	\$105	\$120

Table 4.20 Routine and corrective permeable paving maintenance

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Inspections and regular cleaning of organic sediments and debris. Includes yearly clean for weed/ moss control. NB to ensure inspections coincide with storm events to check drainage function.	4	per driveway	\$175	\$180
Minor repairs	1	per driveway	\$120	\$360

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Cleanout sediment, oils, etc and removal of top layer of stone and re-establishment (top up joint chip or sand between pavers)	5	m ³	\$160	\$185
Top-up of low fines joint mix	5	m ²	\$10	\$16
Disposal of unsuitables	5	m ³	\$55	\$147
Replacement of permeable pavers (if necessary)	15	m ²	\$110	\$250
Uplift pavers, replace sand and bedding	15	m ²	\$90	\$110
Erosion repair	5	per driveway	\$300	\$600

5. Development of the LCC model and device assumptions

5.1 The Healthy Waters LCC models

As part of this project, individual LCC models have been built for each of the urban stormwater devices previously noted in this report and for operation under GD01 (Auckland Council, 2017). The models are “easy-to-use” Excel based models. Data collected and included in the models have been described in Section 4.

The purpose of the LCC models is to provide an indicative non-financial estimate of LCC, related either to the surface area of the device or the catchment area treated. It is considered that the models will be most useful for undertaking a comparison of costs of different types of devices, and can be used for catchment planning purposes.

Key LCC features of each model include:

- Users can use the default cost information provided in the model or they can input their own unit cost data
- Additional rows are provided under the routine and corrective maintenance tables to allow for additional maintenance activities to be included.
- The default discount rate set in the model is 4%, however, this parameter can be changed so that sensitivity of the effect of the discount rate on long term costs can be modelled. Discounting is used to find the value at the base year of future costs associated with a stormwater device. Future costs are discounted by a discount rate that reflects an opportunity cost comprising time preference (utility of current consumption versus future consumption) and compensation for risk (uncertainty about the future requires greater expected return). Real costs are used in a life cycle cost analysis and are discounted by the real discount rate, so they do not include an inflation component. Because of the potentially significant impact of the discount rate on the estimated LCC (e.g., a cost that is accrued 10 years from the base year is reduced by 29% if the discount rate is 3.5% per annum but by 61% if the rate is 10%), sensitivity analysis is recommended using different discount rates. Auckland Council’s Chief Economist Unit recommends sensitivity analysis be undertaken using 2%, 4% and 6% discount rates (pers. comm. 12 December 2019).
- The total life cycle analysis period (LCAP) for all models is 50 years.
- The models include a “Renewals” function which is linked to the life span of a device. If the life span is less than 50 years, then more than 1 renewal cost will be included in the life cycle analysis.
- The base date of the default cost data is 2018. If users enter their own unit cost data in places, this information should be inflated or deflated to 2018 to ensure it is comparable with the default cost information (if used).
- No default values are provided for land costs. This information needs to be obtained separately on a ‘case-by-case’ basis and added to the total LCC.
- The model includes a “cost development factor” as it is more expensive to design and construct stormwater mitigation measures in brownfields than in greenfields areas (i.e., primarily because of the need to break into existing services, increased traffic management controls and work in restricted spaces in brownfield locations). Previous LCC undertaken to date (i.e. the UPSW model - Ira *et al.*, 2015) has included a land cost factor for different types of stormwater devices. This factor also included the cost of the land, so is not applicable for the Healthy Waters LCC model where land costs would be directly obtained from the Council rates database. As a result (and as discussed in Section 4.1), the cost development factors recommended for use by the USEPA have been included⁹.
- All costs given are excluding GST.

The Excel LCC models have been provided to Healthy Waters as a tool for use in their catchment planning process. The models have been used to calculate low and high indicative estimate LCCs for Healthy Waters for a range of device sizes and discount rates.

5.2 Model assumptions for the FWMT LCCs

Recommended low and high TACs and MCs, as presented in Section 4, were used in the FWMT LCC models. The maintenance costs used within the LCC models are based on best practice maintenance guideline documents, along with the expert opinion of maintenance operators (Section 4.2). The activities and frequencies assume that the device which is being maintained (and therefore costed) has been designed and constructed according to best practice standards, and is also functioning normally (e.g., it excludes exceptional device failures including inappropriate design). Amongst other things, costs associated with activities such as traffic management and botulism events are widely varying and irregular. Indicative frequencies and costs have been included but should be treated as highly uncertain. Whilst a best estimate of combined costs is provided, the LCC models are generalised and unlikely to be accurate for individual devices in any particular FWMT sub-catchment.

The effective area (device area available for stormwater treatment) is directly related to the total surface area (effective and ineffective) of the device. As a result, a range of likely surface areas were modelled for each device (**Table 5.1**) based on the unit costs provided in Section 4. The range of likely surface areas were based on the opportunity screening and device sizing work undertaken by Morphum Environmental (2019).

Table 5.1 Model runs undertaken based on device size

Device Type	Size Range	Number of LCC model runs
Wetlands	100 – 10,000 m ² surface area	26 models per discount rate
Rain gardens	20 – 1,000 m ² surface area	28 models per discount rate
Tree pits	5 – 10 m ² surface area	4 models per discount rate
Infiltration basins	1,000 – 9,000m ² surface area	10 models per discount rate
Filter systems	1 – 30 ha impervious area treated	24 models per discount rate
Permeable paving	50 – 600 m ² surface area	26 models per discount rate
Rain tanks	1,000 – 30,000 Litre tank sizes	14 models per discount rate
Ponds	2,000 – 6,000 m ² surface area	10 models per discount rate
Swales	100 – 5000m linear swale	12 models per discount rate
Green roofs	200 – 400 m ² roof area	10 models per discount rate

When building the LCC models for each of the different devices, a number of design and/ or assumptions had to be made. These assumptions are documented in Table 5-2 below.

Table 5-2 Design or maintenance assumptions made within each of the LCC models for the purposes of generating average LCC values for the FWMT.

Device Type	Assumptions	Source/ Comment
Wetlands	<ul style="list-style-type: none"> The landscaped area surrounding the wetland is estimated to be one third of surface area size. 	Assumptions based on previous LCC modelling work and are best estimates.

Device Type	Assumptions	Source/ Comment
	<ul style="list-style-type: none"> • Costs related to botulism have been excluded as this issue relates primarily to open water ponds. • For the maintenance cleanout, the volume of sediment removed has to be estimated. It was assumed that: <ul style="list-style-type: none"> ○ 1m depth of forebay sediment would be removed, and ○ 0.5m depth of main pond sediment would be removed. • The life span of the wetlands is assumed to be 50 years. 	
Ponds	<ul style="list-style-type: none"> • Assumptions as per wetlands except that a “placeholder cost” has been included to represent potential future botulism costs. The placeholder cost is based on discussions with HW operations engineers. • The life span of the ponds is assumed to be 50 years. 	Assumptions based on previous LCC modelling work and are best estimates.
Rain gardens and tree pits	<ul style="list-style-type: none"> • Rain garden depth taken as 0.9m (includes media layer, transition layer and drainage layer) • The estimated volume of sediment removed equates to the rain garden surface area multiplied by the rain garden depth. • A cost has been included for traffic management. • The life span of the rain garden and tree pits is assumed to be 50 years. 	Rain garden depth as per GD01 recommendations.
Infiltration basins	<ul style="list-style-type: none"> • The landscaped area surrounding the infiltration basin is estimated to be one third of the surface area size. • For the maintenance cleanout, the volume of sediment removed has to be estimated. It was assumed that: <ul style="list-style-type: none"> ○ 0.5m depth of sediment across the whole basin surface area would be removed. • The life span of the infiltration basins is assumed to be 50 years. 	Assumptions based on previous LCC modelling work and are best estimates.
Filter systems	<ul style="list-style-type: none"> • Filter systems is a generic category that refers to different types of underground filters, such as sand filters. • The life cycle cost models include pre-treatment of the filter systems. • A 50 year life span has been assumed for the filter systems. 	Assumptions based cost information provided by PDP (2019).

Device Type	Assumptions	Source/ Comment
Permeable paving	<ul style="list-style-type: none"> Costs relate to solid block pavers which are laid with gaps between them to provide permeability. Paver replacement is estimated to occur at 15 year intervals, and the model estimates that approximately 35% of the pavers are replaced at this frequency. 	Assumptions based on previous LCC modelling work and are best estimates.
Rain tanks	<ul style="list-style-type: none"> Tanks are assumed to be above ground, round polyethylene storage tanks. Costs allow for water reuse. The tank life span is 25 years. 	Manufacturers specifications/ guarantees.
Swales	<ul style="list-style-type: none"> Assumed to be drained swale with a 3% slope and mown grass. Base width of 0.6m, with 3:1 side slopes. It has been estimated that 0.1m of cover would be removed for the rehabilitation of swales as part of corrective maintenance works. The life span of the swales is assumed to be 50 years. 	Swale profile and cross-sectional area as per GD01 recommendations.
Green roofs	<ul style="list-style-type: none"> Extensive green roof with a media of 100mm – 150mm depth and planted with a mix of native grasses and sedum. Costs are only associated with the green roof (i.e. plants, media, waterproofing membrane and drainage components) – costs relating to the building structure are not included. Maintenance costs allow for inspections, mowing of sedum based roof and weeding, as well as repair to perimeter edges, drainage components and media top-up. The life span of the green roofs is assumed to be 50 years. 	Based on work undertaken through the Activating WSUD in NZ project (Ira and Simcock, 2019).

All models used:

- the default cost values provided in each of the Excel LCC models (e.g., as per the unit TAC and MCs provided in Section 4,);
- the maintenance activities and frequencies as documented in **Tables 4.13 to 4.20**;
- a 50 year life cycle analysis period.

The models have a base date of 2018, and exclude GST and land costs.

Because of the potentially significant impact of the discount rate on the estimated LCC (as discussed in Section 5.1), sensitivity analysis is recommended for all life cycle costing analyses using different discount rates. In alignment with recommendations provided by Auckland Council's Chief Economist (pers comm. 12 December 2019), separate model runs were conducted using a 2%, 4% and 6% discount rate.

6. Life cycle cost results

6.1 Interpreting and understanding the results

Prior to presenting the LCC estimates, it is important to reflect on the context within which the data is presented.

- The FWMT costs build on earlier LCC work (Ira and Simcock, 2018; Ira, 2017; Ira *et al.*, 2015; Ira *et al.*, 2009) and is based on generating a total LCC over a 50 year analysis period (base date of 2018).
- The costs relate to best practice design of the mitigations and target treatment performance in accordance with GD01 (Auckland Council, 2017), and are based on the best available cost data.
- The costs are presented as ranges from low to high to ensure FWMT sensitivity modelling can occur.
- When interpreting the cost results, relative differences in cost between urban devices are likely more accurate than absolute. LCC allows “like for like” comparison of additional costs between interventions (e.g., is standardized for space/length, time, cost components). The costs are indicative estimates.
- The assessment makes no assumptions about the feasibility, timing, uptake or optimisation of interventions in specific location(s), or about financing, governance or distributions of costs for particular catchments or activities – that is dealt with directly within the FWMT via configuration rules for SUSTAIN.
- The results are presented in a way such that they highlight the distribution of costs in terms of where they fall within the value chain (i.e. whether they are developer-related costs, public utility costs or house-hold costs). In reality, all costs are borne in differing proportions by private individuals via “on-charging” from developers, network utility fees or rates (targeted and other wise), or everyday household costs.
- It should be recognized that the LCCs only relate to the direct costs associated with a particular intervention. In order to obtain a full understanding of the economic implications of an intervention, a total economic valuation (TEV) approach is preferred (i.e., to balance direct costs with indirect costs, avoided costs, cost efficiency and other ancillary benefits).

6.2 LCC results – urban structural devices

Low and high LCCs are provided for each device type and for the size ranges documented in **Table 5.1**, along with the average LCC. **Appendix B** summarises the LCC\$/unit area/ year results for each device and discount rate. **Figures 6.1 to 6.8** provide a graphical representation of the LCC for a 4% discount rate.

Generally, the LCC results demonstrate a right-skewed distribution of costs (i.e., an increase in device surface area leads to a decrease in LCC). This relationship is likely caused by the predominating effect of long term maintenance costs on TAC. Much of the maintenance and associated cost is device specific (e.g. inspections) and needs to be undertaken for both small and large devices (i.e., it is independent of total device area or length, ensuring a lesser relative cost for larger devices). This leads to clear economies of scale being achieved for larger devices.

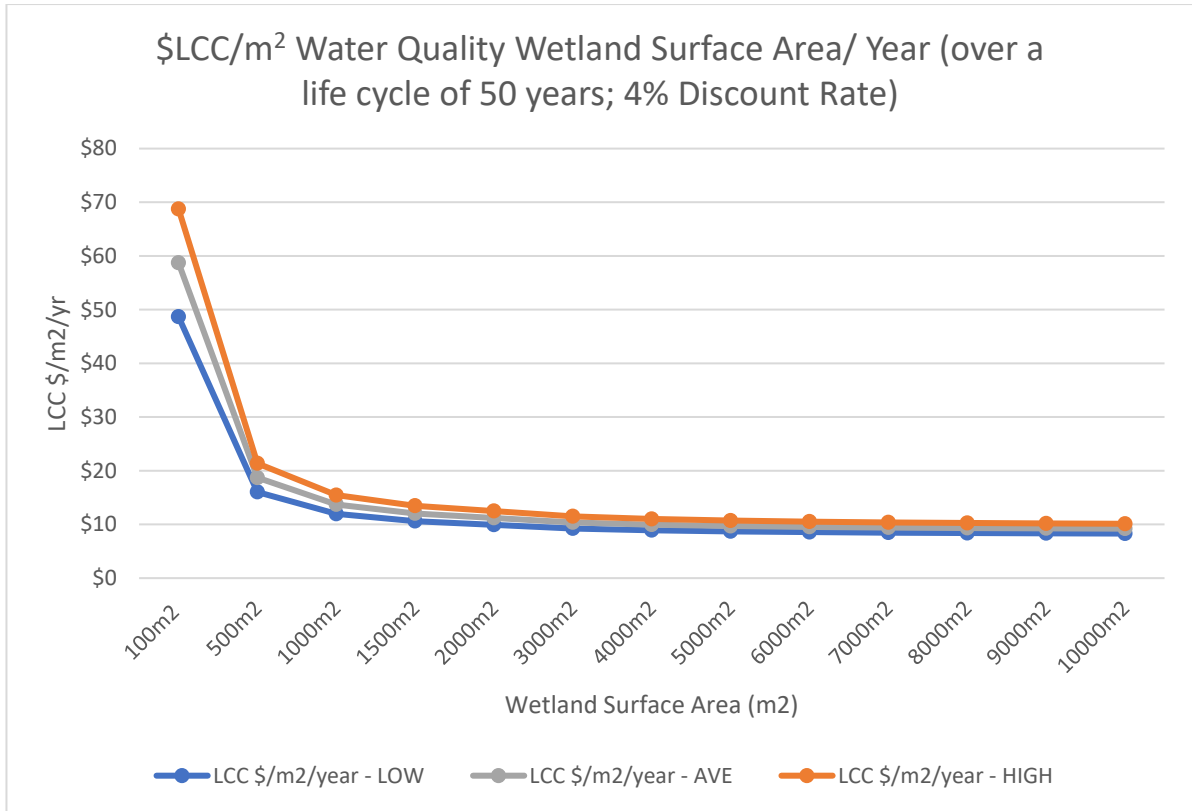


Figure 6.1 Low, average and high LCCs for urban water quality wetlands: \$LCC/m² /year over a life cycle of 50 years and 4% discount rate.

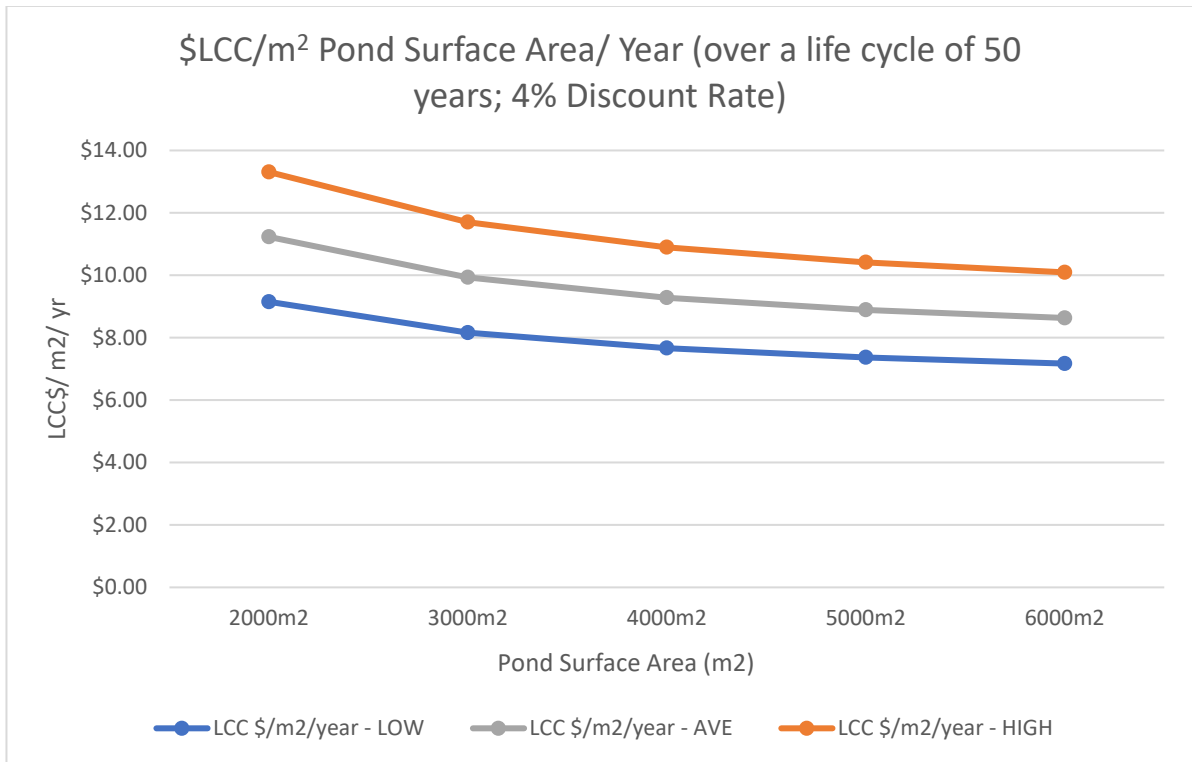


Figure 6.2 Low, average and high LCCs for urban ponds: \$LCC/m² /year over a life cycle of 50 years and 4% discount rate.

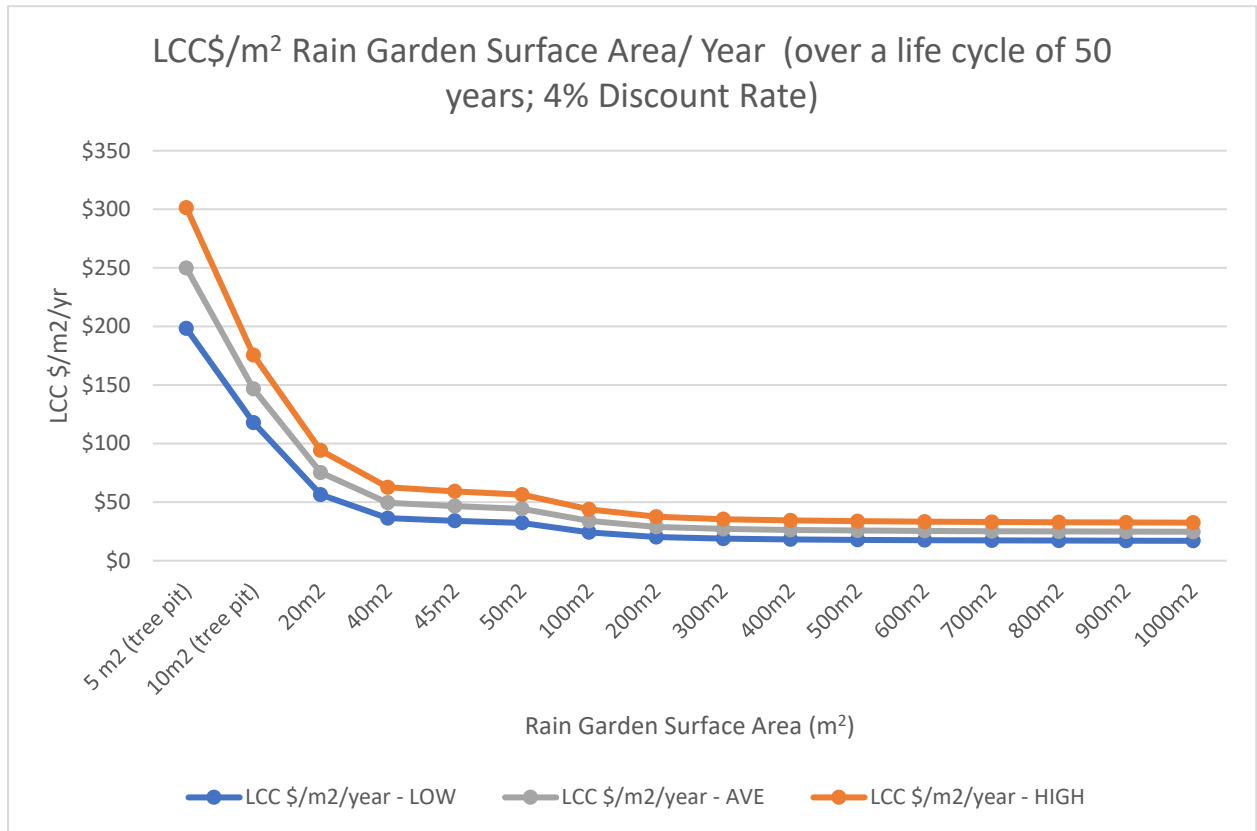


Figure 6.3 Low, average and high LCCs for urban rain gardens and tree pits: \$LCC/m²/year over a life cycle of 50 years and 4% discount rate¹⁰.

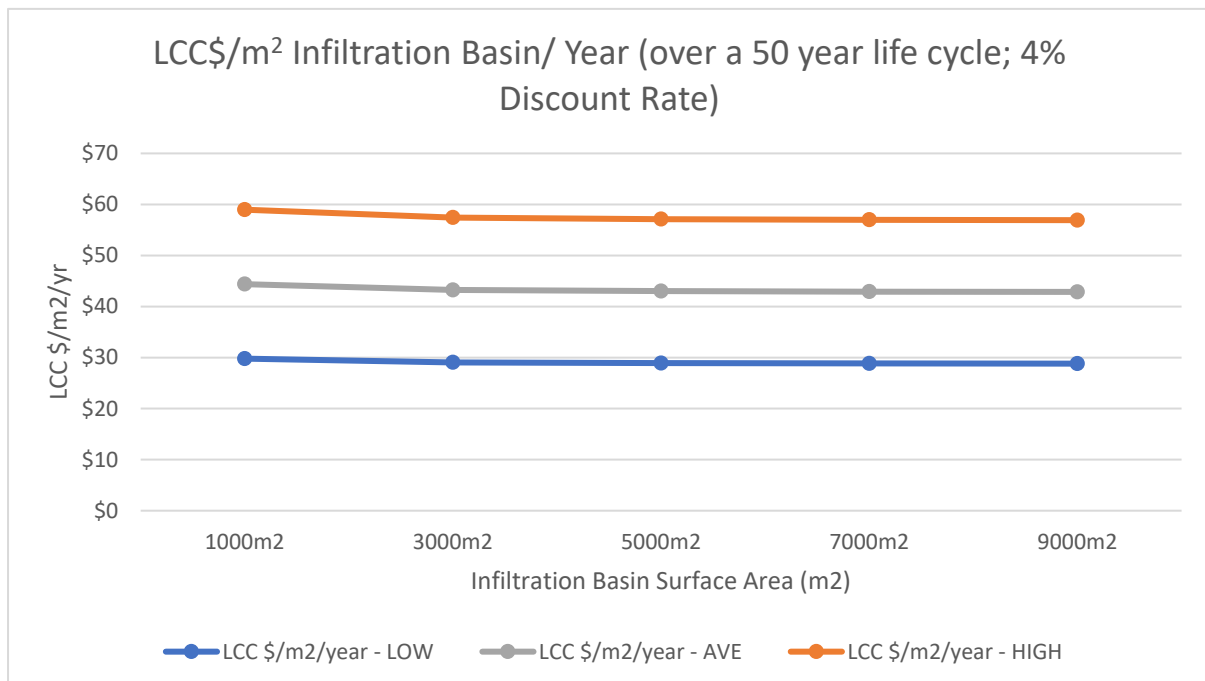


Figure 6.4 Low, average and high LCCs for urban infiltration basins: \$LCC/m²/year over a life cycle of 50 years and 4% discount rate.

¹⁰ Since the completion of this report the rain garden LCC model was refined and updated as a result of further research. The updates made to the LCC model, along with recommended rain garden LCCs are described in **Appendix F**.

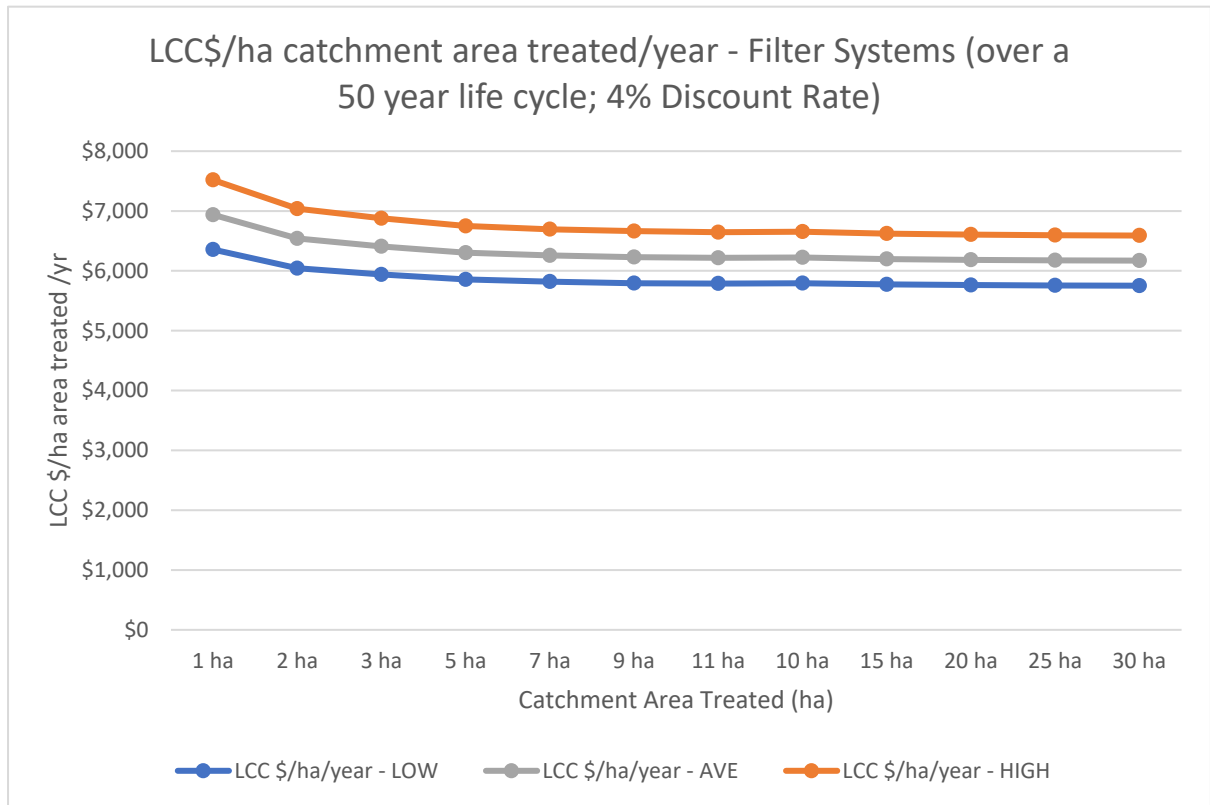


Figure 6.5 Low, average and high LCCs for urban filter systems: \$LCC/ha area treated /year over a life cycle of 50 years and 4% discount rate.

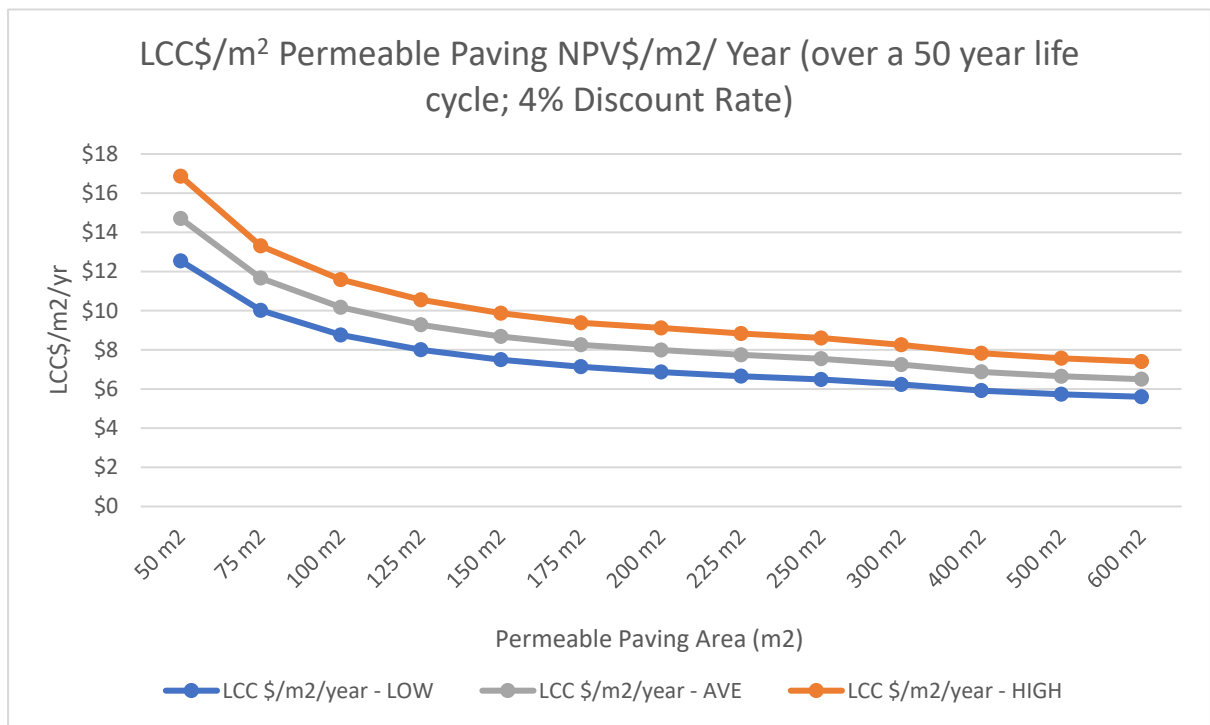


Figure 6.6 Low, average and high LCCs for urban permeable paving \$LCC/m² /year over a life cycle of 50 years and 4% discount rate

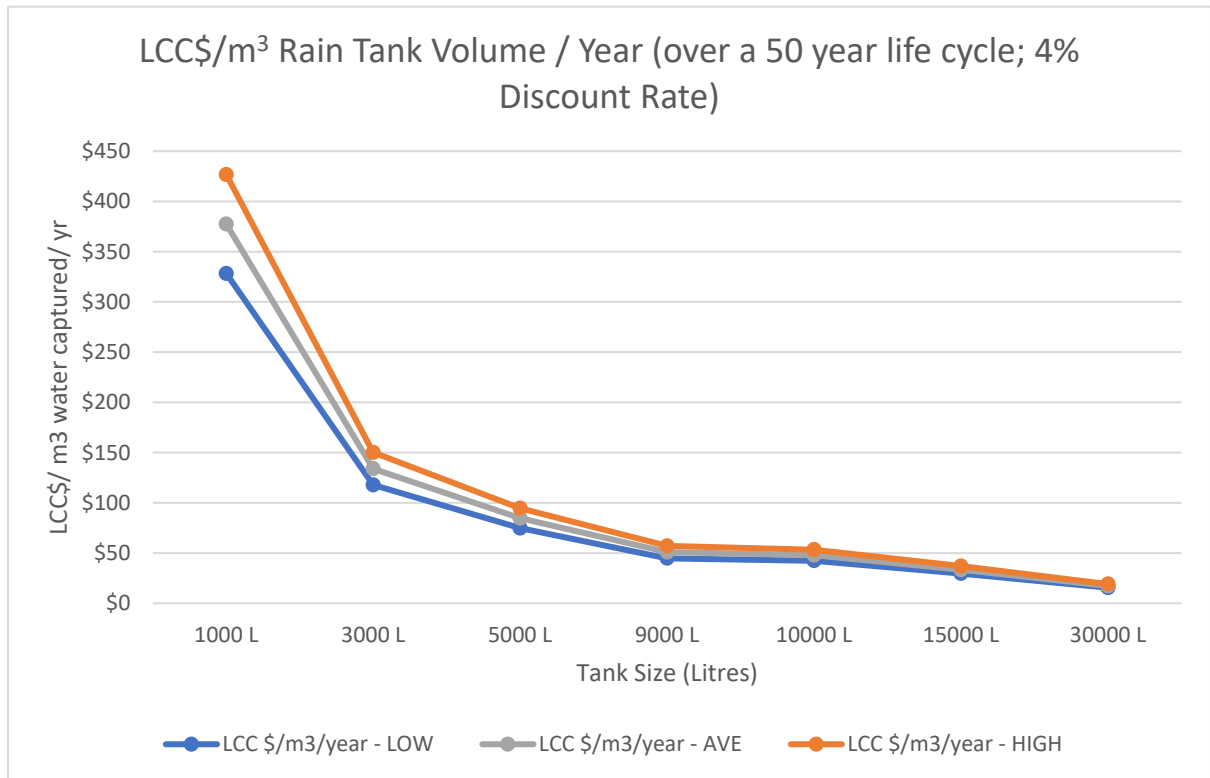


Figure 6.7 Low, average and high LCC models for urban rain tanks: \$LCC/m³ /year over a life cycle of 50 years and 4% discount rate.

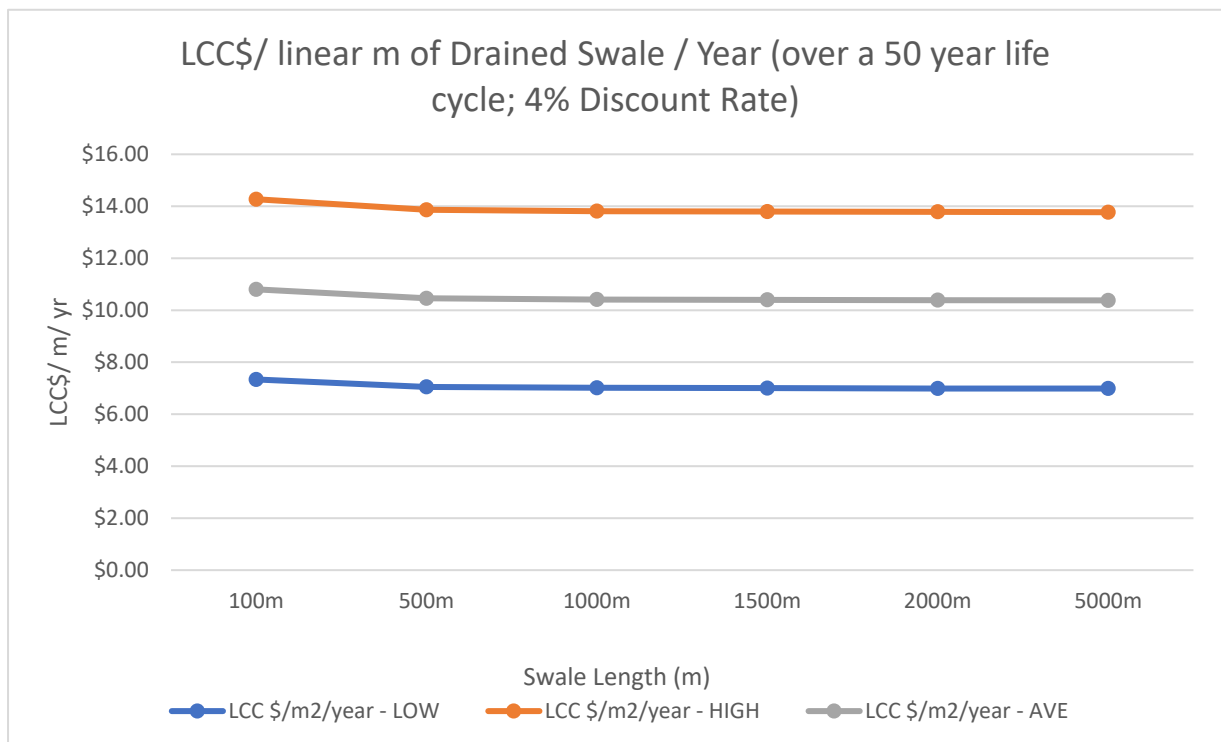


Figure 6.8 Low, average and high LCCs for urban drained swales: \$LCC/linear m/year over a life cycle of 50 years and 4% discount rate.

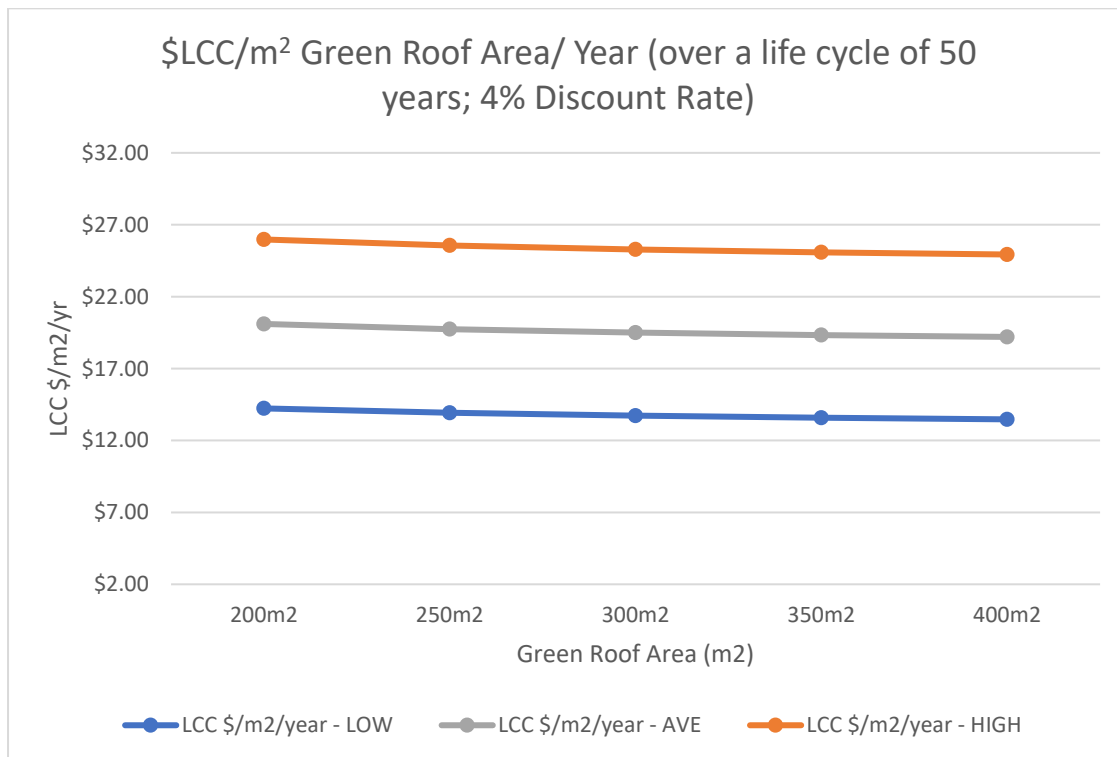


Figure 6.9 Low, average and high LCCs for urban green roofs: \$LCC/m² /year over a life cycle of 50 years and 4% discount rate.

The effect of the discount rate on the LCCs is also clearly evident, as shown in **Figures 6.10** and **6.11**. As expected, the higher discount rate (6%) places less emphasis on the long term maintenance costs and leads to a reduction in the LCC, more so for devices with a greater proportionate maintenance cost component of the LCC. Conversely, the 2% discount rate costs are a more conservative assessment of long term costs.

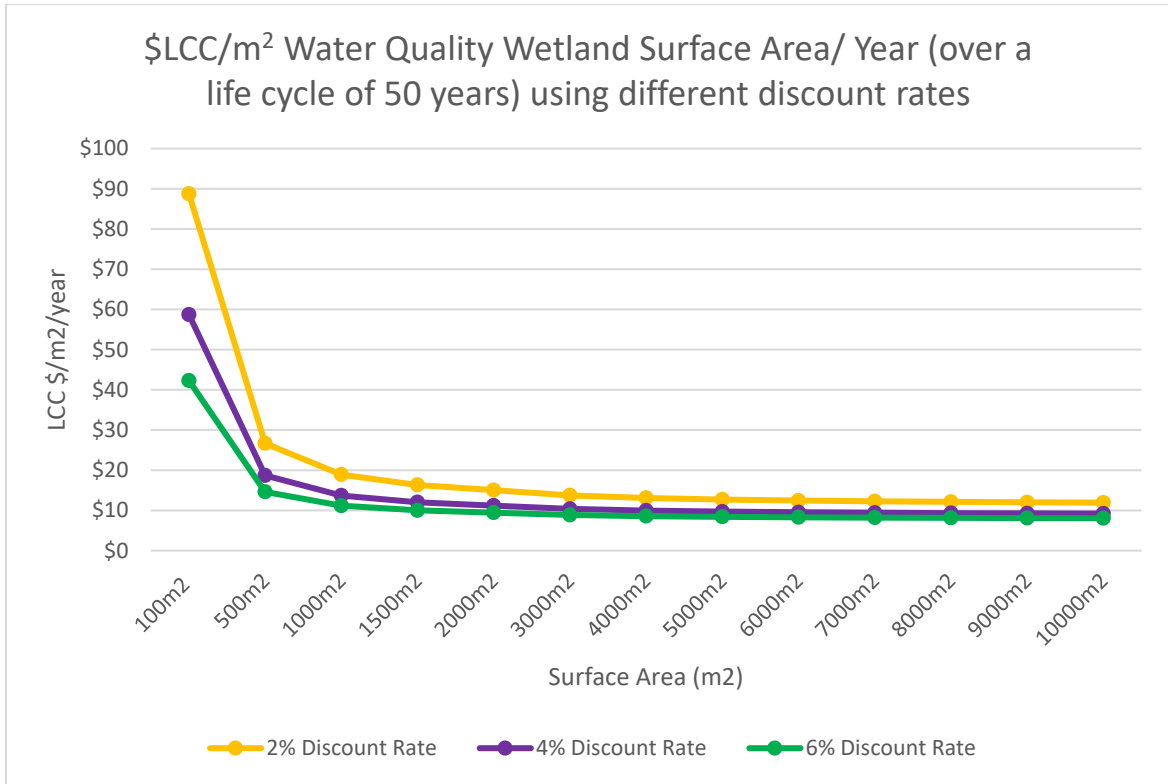


Figure 6.10 Average LCCs for urban water quality wetlands (\$LCC/m² /year) over a life cycle of 50 years and using a 2%, 4% and 6% discount rate.

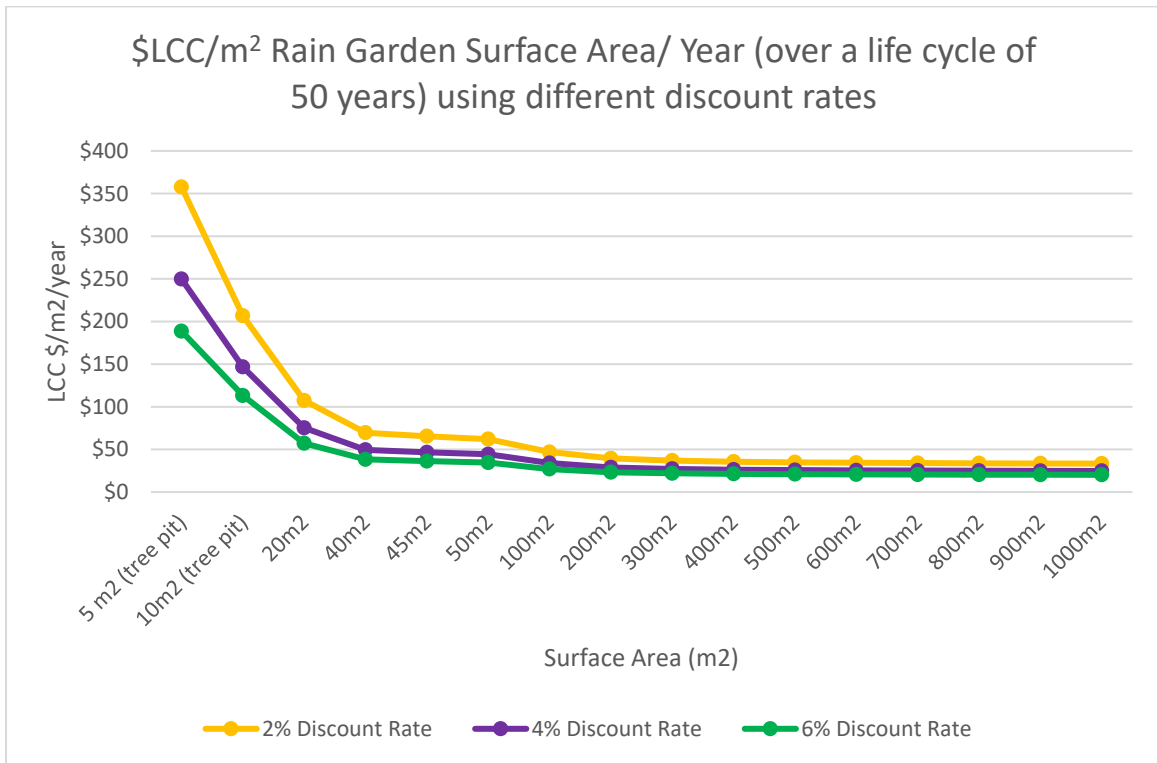


Figure 6.11 Average LCCs for urban rain gardens and tree pits (\$LCC/m² /year) over a life cycle of 50 years and using a 2%, 4% and 6% discount rate.

As part of the LCC analysis, the portion of the LCC which relates to the design, consenting, management and construction of a device (i.e. the TAC) was also calculated. It is important to understand the TAC portion of the LCC for two main reasons:

1. Knowing the TAC portion helps decision-makers to understand where different elements of the LCC fall within the urban development chain. For instance, the entity which bears the upfront design, consenting and construction costs might differ from the entity who will become responsible for the maintenance of the stormwater asset.
2. In order to correctly calculate the total LCC for a particular stormwater device, the development cost factor must only be applied to the TAC.

TAC portions for each device and discount rate are included in **Appendix B** and maintenance cost curves are provided in **Appendix E**.

6.3 Rain gardens or wetlands?

FWMT LCC modelling work has highlighted that device size can have a marked effect on costs, mainly due to maintenance cost efficiencies realised by larger devices (i.e. that larger devices have equivalent absolute but lesser relative maintenance costs). **Figures 6.1** and **6.3** illustrate that small urban wetlands and urban rain gardens are not cost-efficient solutions, either for a private individual or for councils. For instance, urban wetlands are three-fold more expensive over their lifecycle if <400 m² whilst urban rain gardens are nearly one and a half-fold greater if <500m².

From a purely LCC perspective, economies of scale can be realised for urban rain gardens of around 50m² - 100m² (**Figures 6.12**). That is for surfaces areas of less than 400m² urban rain gardens would be a cheaper stormwater solution (from a treatment perspective) than urban wetlands (**Figure 6.12**).

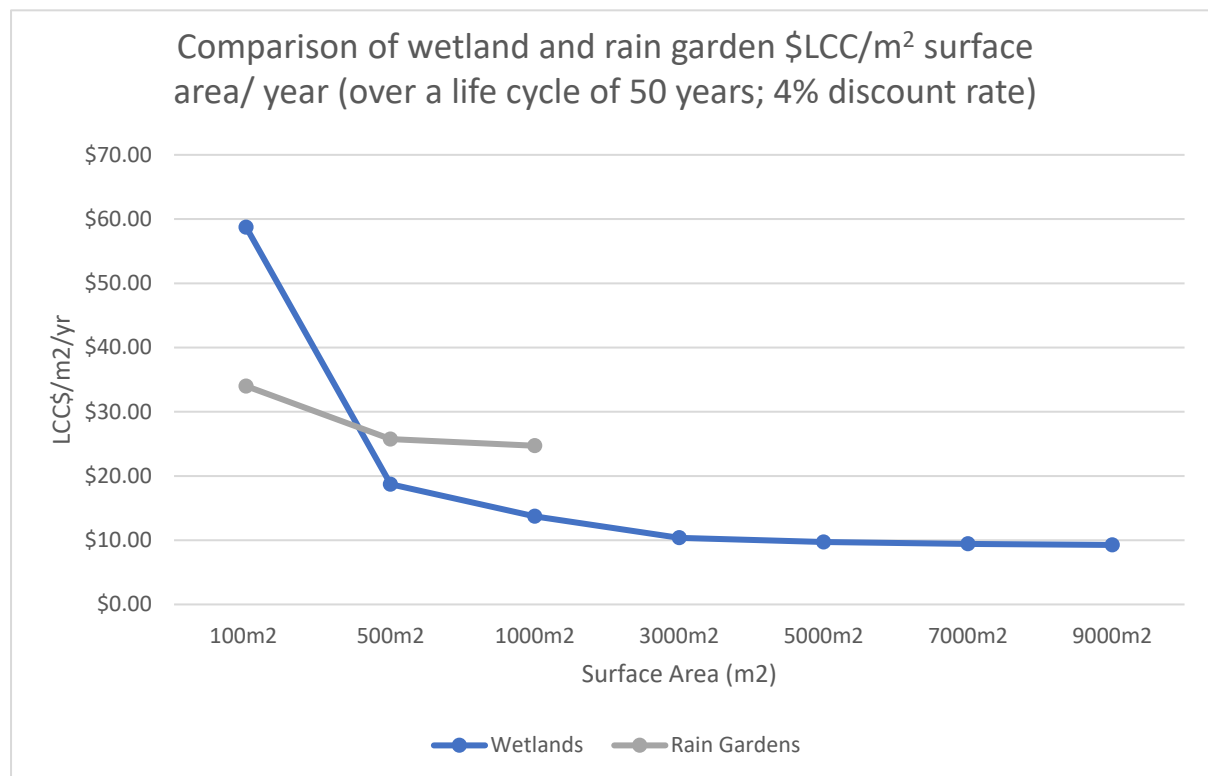


Figure 6.12 A comparison of wetland and rain garden \$/LCC/m²/yr for a range of surface areas, over a life cycle of 50 years and using a 4% discount rate.

6.4 Understanding where costs fall in the urban development value chain: “Who Pays”?

The FWMT is able to not simply cost and further, optimise cost for water quality outcomes, but also inform decisions of which party is required to pay for achieving water quality outcomes (i.e., whom carries the LCC for urban devices). Traditional cost models do not consider or provide information around implications for where the cost will fall within the urban development process. In other words, whether they are developer-related, public utility, private business or house-hold costs.

Table 6.1 describes where different costs may lie within this urban development value chain and relates these costs to a range of stormwater device types. In reality, all costs are borne in differing proportions by private individuals via “on-charging” from developers, network utility fees or rates (targeted and other wise), businesses increase the price of their goods or services, or everyday household costs.

Table 6.1 The public/ private split of costs for different types of stormwater management devices

Land-Use	Device type	Total Acquisition Costs	Maintenance Costs
On-site devices (greenfield and brownfield areas): - residential	Rain tanks Rain gardens Permeable paving On-site infiltration Green roofs	PRIVATE (homeowner)	PRIVATE (homeowner)
- commercial and industrial	Rain tanks Rain gardens Filter systems	PRIVATE (business)	PRIVATE (business)
Catchment devices (greenfield):	Wetlands Ponds	PRIVATE (developer)	PUBLIC (network operator)
Catchment devices (brownfields):	Wetlands Ponds Filter systems	Cost Share (developer + network operator)	PUBLIC (network operator)
Roading (greenfield)	Swales Rain gardens Filter systems	PRIVATE (developer)	PUBLIC (network operator)
Roading (brownfield/ retrofit)	Swales Rain gardens Filter systems	PUBLIC (network operator)	PUBLIC (network operator)

7 LCC model review and incorporation into the FWMT

7.1 LCC model review and statistical analysis

Review of the LCC model results highlighted that uses of average device LCCs across a range of device sizes could generate spurious findings. Notably, that the average standardised TAC (by area or length of device) may not reflect marked differences between large and small devices. Further, through the effect of area or length independent maintenance costs, LCC data is heavily right-skewed (e.g., increases in surface area or length result in corresponding decreases in LCC).

This effect may be explained by similar specified maintenance activities being required independently of the scale of the device, with the cost per unit then biased by the device scale. These effects are likely to merge where treatment trains feature combinations involving smaller scale devices. This is likely in brownfields interventions where any cost assessment understatement would be compounded by the relatively higher cost of the interventions in those circumstances. Since the FWMT requires an individual “average” cost per urban intervention, further investigation was needed.

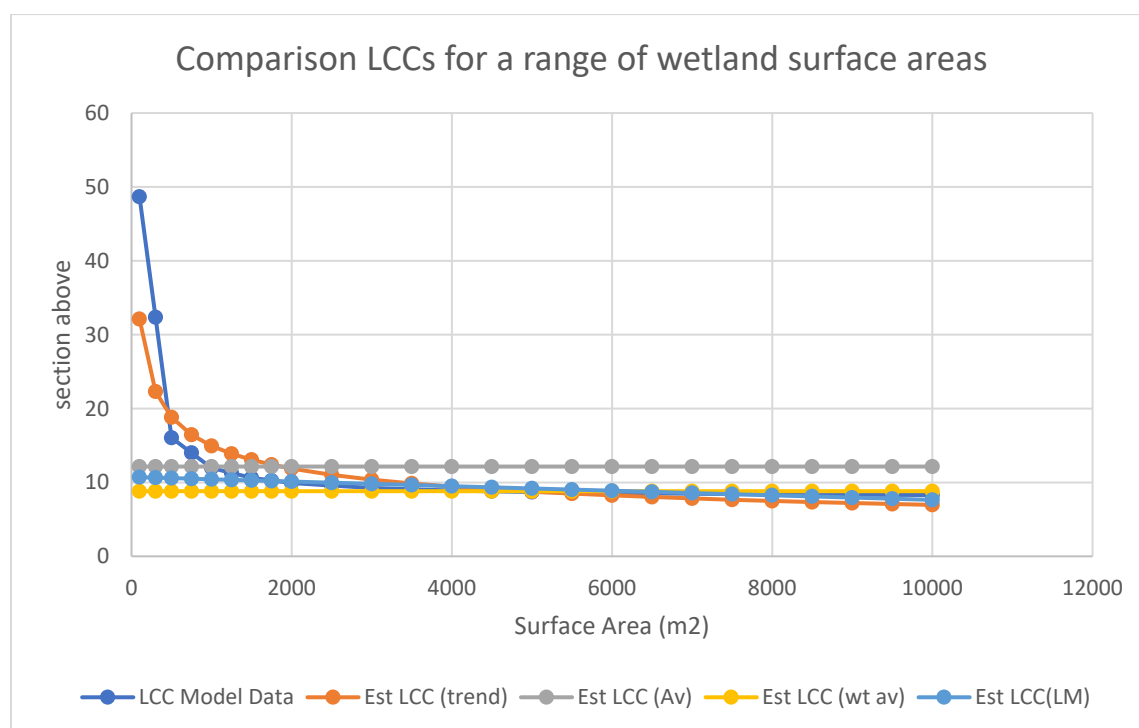


Figure 7.1 Comparison of LCC assessment models for a range of urban wetland surface areas against actual LCC modelled data results (Figure 6.1), where device scale is influential. The dark blue line (LCC Model Data) is the average LCC cost as modelled and presented in Figure 6.1).

After further analysis, the remedy for this issue was to develop nonlinear relationships for LCC with increasing device scale. **Figure 7.1** illustrates this effect for urban wetlands. It contrasts the individual model LCC results (reported in Section 6, **Figure 6.1** for wetlands) with that derived from four models for LCC as a function of device scale, i.e.: nonlinear trend - Estimated LCC(trend); Estimated LCC(Average); Estimated LCC calculated as a weighted average - Estimated LCC (wt av); Estimated LCC a linear model - Estimated LCC (LM). **Figure 7.1** demonstrates that using an estimated average, weighted average and a linear model underperform and do not accurately represent the

right-skewed LCC modelled results generated for various wetland surface area sizes (as shown for wetlands in **Figure 6.1**) in contrast to the nonlinear relationship. Use of these less efficient data portrayals could lead to underestimating the cost of small devices and potentially overestimate the cost of larger scale devices.

Nonlinear models utilised log-log transformations of the underlying data. The nonlinear relationship is expressed as:

$$\$LCC \text{ (per unit per year)} = e^{Constant + \ln(Area) * BetaArea}$$

Regression analysis was undertaken to estimate the terms Constant and BetaArea in the equation above. The scope of the analysis was limited to one explanatory variable, area. Closer fits and accordingly stronger replicate performance could be obtained from models with additional explanatory variables. This aspect is reflected the recommendations section below. The model estimation was performed in Stata (version 16); the results are included in **Appendix D**. The functions provide a good fit within the low and high cost envelope generated from the LCC models for all devices, but do tend to slightly underestimate the cost of very small devices. The analysis in Stata shows the models are highly statistically significant; they explain between 81% and 95% of the variability within the LCC model results; the coefficients obtained (constant and BetaArea) are statistically significant at the 1% level. An example of this fit is shown in **Figure 7.2** for rain gardens.

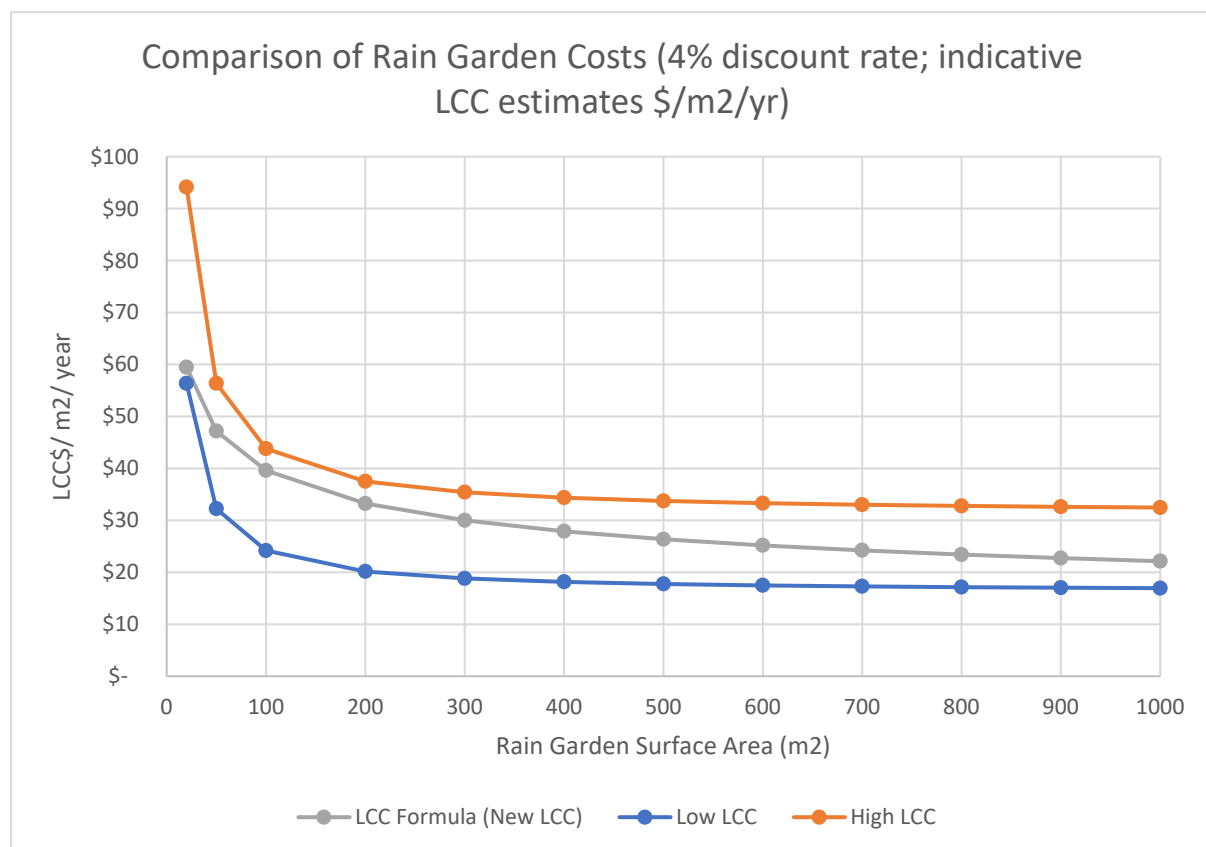


Figure 7.2 Comparison between the modelled low and high LCC results (Figure 6.3), and the LCC nonlinear relationship for rain gardens

The nonlinear relationship has been developed in order to assist Healthy Waters in using LCC estimates in their catchment planning process. The use of the relationship will assist Healthy Waters in relatively easily and quickly identifying LCCs for a range of urban stormwater devices and a range

of surface area sizes, without the need to run numerous individual LCC models (as has been done here). In this regard, an Aggregated Cost Model (ACM), using this relationship, is in development in Excel as part of “phase 2” of this project. The purpose of the model will be to facilitate the modelling of LCCs of stormwater devices in series (i.e. as part of a treatment train), based on this nonlinear relationship. The model will include the relevant constants and BetaArea values for a range of devices and discount rates. It will also incorporate calculations to include land costs, the TAC portion and the land development factor.

7.2 Incorporation of the LCC results into the FWMT

The FWMT includes a Stormwater Management Model (SUSTAIN) that simulates the potential performance of varying structural devices and source control interventions (type and sizing) for improving integrated stream hydrology and water quality (e.g., in both urban and rural areas). SUSTAIN will represent key attributes of the preferred structural devices to simulate their performance in terms of flow, concentration and load reduction. This then provides the capability to simulate potential cumulative effects of catchment-scale networks of stormwater interventions and practices on hydrology and instream water quality, in both a rural and urban setting. SUSTAIN can also be used to analyse the costs and potentially benefits of NPS-FM implementation scenarios at a later stage.

A subset of the LCC results presented in Section 6.2 will inform the cost analysis within the pilot run of SUSTAIN (**Appendix C** and the updated rain garden LCCs in **Appendix F**). In order to use these average LCCs, the following formula has been coded for device specific data input into SUSTAIN:

*TOTAL LCC over 50 years per device = (((AVE LCC\$/UNIT/yr*50)+(land cost \$/m²)+(((AVE LCC\$/UNIT/yr*50)*TAC Portion)*Dev Factor))) * device footprint OR catchment area treated OR water volume captured*

Where:

AVE LCC\$/unit/yr: the average LCC for a particular device size and discount rate (as described in Section 6.2 and included in **Appendix C**, or the nonlinear relationships presented in Section 7.1 and included in **Appendix D**)

Land cost: as taken from the HW rates database (as described in Section 3)

TAC Portion: the average TAC portion for a particular device size and discount rate (as described in Section 6.2 and included in **Appendix C**)

Dev Factor: the development factor which relates to the pre-development landuse/ geographical location of the device (i.e. greenfields development, brownfields development, retrofits) (as described in Section 6.2).

For the reasons outlined in Section 7.1, this approach should only be used for the subset of known device sizes included within **Appendix C** (and the updated rain garden LCCs in **Appendix F**).

8. Conclusions and recommendations

8.1 Conclusions

This report has documented the process followed to collect cost information and use existing cost data to inform TACs and MCs used within a LCC model. New 'purpose-built' LCC models have been developed for a range of urban stormwater management devices for optimisation modelling by the FWMT, namely: ponds and wetlands, rain gardens and treepits, swales, infiltration basins, filter systems, permeable paving, rain tanks and green roofs.

More than 120 individual LCC models were run and used to develop urban device LCCs, based on a 4% discount rate and 50 year LCAP. The LCCs have been summarised according to either the surface area of the device, volume of water captured or the catchment area treated. The LCC models span a range of unit cost inputs (i.e., low and high unit TAC and MCs). Low and high LCCs were generated and the effect of the discount rate on long term maintenance costs analysed, with additional models run using a 2% and 6% discount rate. The relationship between and effect of long term maintenance costs on device size has also been investigated. The LCC results have re-enforced prior research undertaken (Ira *et al.*, 2008; 2012 and 2015; Ira and Simcock, 2019) that emphasised two components of LCC are most important for urban devices:

1. the area which the device treats;
2. the frequency and type of maintenance undertaken.

The previous research referenced above found that the 3rd most important component which influences costs is the level of treatment provided (this cost driver has not been further explored through this project since devices have been designed according to GD01 standards).

Notably, device design, construction methodology, topography, geographical location, soils and availability of materials will also affect LCC. The limited spread of existing cost datasets prevents these secondary cost drivers from being identified currently. Further work is needed to collect cost information in clearly defined templates to better understand how these secondary cost drivers affect overall LCCs. Equally increased documentation of urban device costs is recommended, to improve resolution and understanding of how TACs and MCs (regular and corrective) vary by size, locale and party (e.g., developer, private resident, Auckland Council).

The results of the LCC runs are suitable for use in future catchment planning processes and for incorporation into the FWMT, representing best available evidence and novel outputs for New Zealand stormwater management as a whole.

It should be recognized that the LCCs only relate to the direct costs associated with a particular stormwater device. Additionally, the LCCs provided are non-financial indicative cost estimates, and the assessment does not make any assumptions about the feasibility, timing, uptake or optimisation of interventions in specific location(s), or about financing, governance or distributions of costs for particular catchments or activities. In order to obtain a full understanding of the economic implications of an intervention used within the FWMT, a total economic valuation (TEV) approach should be undertaken, which balances direct costs with indirect costs, avoided costs, cost efficiency and other ancillary benefits.

8.2 Recommendations

The project has highlighted a number of areas where further research is needed to refine the underlying cost information which is used in the LCC models. Key areas for further work include:

- Using the cost data collection templates developed in this project to collect Auckland-specific total acquisition and maintenance costs in order to refine the LCC estimates and to further investigate the effect of the secondary cost drivers mentioned in Section 6.
 - It is recommended that Council initiate a project to record and collect construction cost information for vested assets. **Appendix A** includes an example copy of the total acquisition cost data collection protocol used for this study, and this could be expanded and amended to ensure cost information is documented and related to specific design criteria (such as contributing catchment area and surface area).
 - It is recommended that Council initiate a project to record and collect maintenance cost information for stormwater assets on their maintenance register. **Appendix A** includes an example copy of the maintenance cost data collection protocol used for this study. As part of maintenance inspections or works undertaken, maintenance contractors could be asked to complete the data collection protocol so that maintenance frequencies, activities and costs can be collected in an individualised and device-specific way (rather than as part of an overall maintenance contract).
- Building on the above data collection process, further work is needed to better understand the relationship between secondary cost drivers, such as device design, topography, geographical location, soils and availability of materials.
- Understanding LCCs is only one part of the decision-making process and other factors, such as resilience, ease of adaptation and institutional frameworks (i.e. ownership models) would also need to be considered. For example resilience theory indicates that distributed systems of smaller devices are considered more resilient in the long term than catchment scale devices (Moore and Semadeni-Davies, 2015). Further research is needed to investigate the relationship between cost and different device considerations (e.g. device shape (which leads to edge effects, or economies of scale that could be realised by having devices in series, such as in green streets applications).
- Very little cost information is available for infiltration basins. If this stormwater device is a priority for Council, then further cost information needs to be collected in order to refine the LCC estimates.
- Further modelling could be undertaken to increase the relevant surface or catchment area size range limitations for the LCCs provided.
- Further work could be undertaken to estimate the indirect costs, avoided costs and cost efficiency of particular stormwater devices in order to present a more balanced economic assessment of the long term cost of a particular solution.

Finally, two outcomes of this analysis have relevance for the further development of SUSTAIN beyond early testing.

- Firstly it is recommended that SUSTAIN does not use LCCs which have been averaged across a range of surface area sizes. The cost module in SUSTAIN could be developed to undertake a more sophisticated statistical analysis for the reasons explained in Section 7.1.
- Secondly, models limited to one explanatory variable have, in turn, limited replication capacity. Models with 2-3 explanatory variables provide superior performance. Where input data for SUSTAIN to enable this precision is limited, Monte Carlo simulation provides an avenue to create lookup tables for provision with the enhanced equations that enables finer precision in replication of LCC estimates in SUSTAIN catchment modelling. This has particular relevance for depictions of interventions in smaller brownfields catchments where space may constrain device size selection in treatment trains.

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Appendix A – Cost data collection templates

APPENDIX A - CONSTRUCTION COST DATA COLLECTION PROTOCOL (JUNE 2018)

Please complete both tables and copy/ paste them below for each treatment device that you're able to provide data on.

TREATMENT DEVICE GENERAL INFORMATION (device types: ponds, wetlands, rain gardens, infiltration, proprietary, swales, rain tanks, green roofs, etc.)

PARAMETER	INFORMATION
Treatment device type	
Treatment device (subdivision) "name" and address (if possible)*	
Estimate the total catchment area treated by the stormwater mitigation device (ha)	
If known, estimate the total impervious area treated (ha or m2 - please specify unit)	
Catchment landuse (e.g. Residential, commercial, industrial, mixed (pls specify), roading, etc)	
Was the treatment part of a greenfields development or retrofit/ infill device (i.e. description of project/ landuse)?	
Estimate the area of the treatment device itself (m2):	
- rain gardens: filtration area (m2)	
- infiltration: infiltration area (m2)	
- wetlands + ponds: treatment zone (pond area incl surrounding grass/ vegetated/ landscaped areas)	
- swales + filter strips: length and width (linear m)	
- rain tanks: tank size (litres)+ whether it is used for re-use	
- proprietary: type + no. of filters, cartridges, etc.	

*Note: no individual cost or design information will be divulged as part of this project - information will only be used to generate average costs. Written permission will first be obtained if we would like to use the cost/ design information as part of a case study

COST INFORMATION

Please provide an estimate of the requested cost information (if known)

PARAMETER	COST INFORMATION	Data Quality/ Source*	Year of Cost Data
Estimate percentage of design and construction cost related to consenting, feasibility, etc costs			
Total design and construction costs for the device			
Estimate the percentage of design and construction costs relating to project management			
Estimate the land cost for the area of the treatment device (if known)			
Out of the total earthworking and stormwater civil works costs, estimate the portion (%) of cost that relates to the construction of this stormwater treatment device			

Other information (please specify):			

*Please choose the category from the drop down menu which is the most reflective of the cost data estimate

THANK YOU FOR YOUR TIME AND ASSISTANCE!

If you have any queries, please contact Sue Ira on sue.ira@koruenvironmental.co.nz (ph: 021 922 408)

APPENDIX A - EXAMPLE MAINTENANCE PROTOCOL FOR WETLANDS/ PONDS

WETLANDS/ PONDS

Routine Maintenance	Frequency (Per Year)	Unit	COST		Year of Cost Data
			Low	High	
Routine General Maintenance (tree trimming/lifting, mowing*, maintaining healthy vegetation cover, removing litter)					
Removing debris (eg litter, dead vegetation) from outlet and inlet /forebay structures					
Inspections (Weeds, ducks, QA, inspection of embankments, spillways, outfalls, overall functioning of facility, integrity of fences if present)					
Scheduled Routine Mechanical Maintenance (pumps, outlets, removing mosquito breeding areas)					
Make good from vandalism					
Weed Management					
Aquatic weed management					
Initial Aftercare of Plants (for first 5 years)					
<i>OTHER ACTIVITIES NOT INCLUDED HERE (pls list below):</i>					

*mowing relates to access tracks only - other mowing is associated with non-functional components of wetland.

Corrective Maintenance	Frequency (Number of Years)	Unit	COST		Year of Cost Data
			Low	High	
Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments/baffles, erosion)					
Replacement of parts (grates, trash screens)					
Replanting the wetland zone					
Desilting and disposal of sediment from forebay					
Desilting and disposal of sediment from main pond					
<i>OTHER ACTIVITIES NOT INCLUDED HERE (pls list below):</i>					

THANK YOU FOR YOUR TIME AND ASSISTANCE!

If you have any queries, please contact Sue Ira on sue.ira@koruenvironmental.co.nz (ph: 021 922 408)

Appendix B – Life cycle cost results

APPENDIX B - Water Quality Wetlands 2% Discount Rate

Base date of costs: 2018

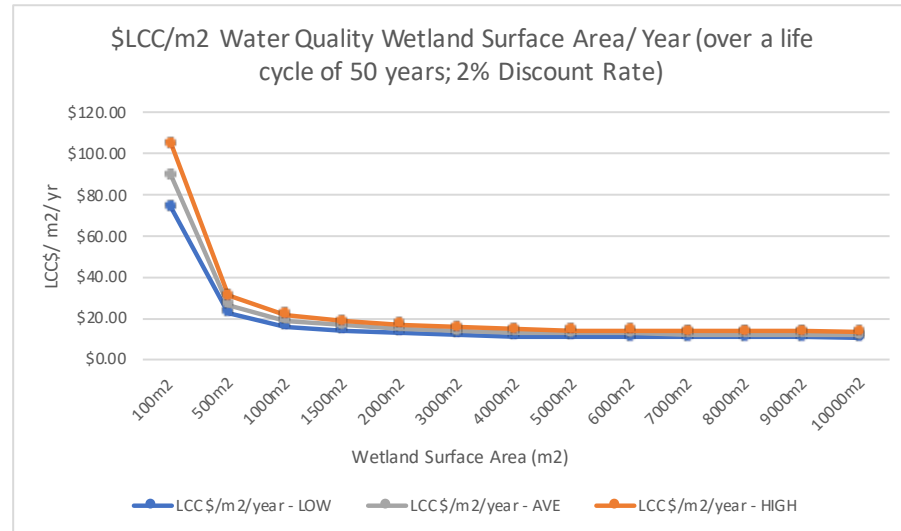
Analysis period: 50 years

Constructed Water Quality Wetland Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m2	\$73.35	9%	\$104.17	7%	\$88.76	8%
500m2	\$22.56	28%	\$30.80	23%	\$26.68	26%
1000m2	\$16.21	39%	\$21.63	33%	\$18.92	36%
1500m2	\$14.10	45%	\$18.57	39%	\$16.34	42%
2000m2	\$13.04	49%	\$17.05	42%	\$15.04	46%
3000m2	\$11.98	53%	\$15.52	46%	\$13.75	50%
4000m2	\$11.45	56%	\$14.75	49%	\$13.10	52%
5000m2	\$11.13	57%	\$14.29	50%	\$12.71	54%
6000m2	\$10.92	59%	\$13.99	51%	\$12.46	55%
7000m2	\$10.77	59%	\$13.77	52%	\$12.27	56%
8000m2	\$10.66	60%	\$13.61	53%	\$12.13	56%
9000m2	\$10.57	61%	\$13.48	53%	\$12.02	57%
10000m2	\$10.50	61%	\$13.38	54%	\$11.94	57%

Disclaimer:

The cost information used to generate the above values has been collated from various councils, contractors and consultants around New Zealand and the cost models are based on the best available information at the time of writing this report.

However, cost information is notoriously variable, and information surrounding maintenance activities, frequencies and costs is scant. Whilst every effort has been made to ensure the consistency and integrity of the data collected and analysed, reliance should not be placed on actual dollar values. Decision-makers should rather use the costing information to understand the potential relative difference between the different green infrastructure solutions. Cost information is provided in good faith for the sole purpose of the comparison of intervention options within SUSTAIN.



APPENDIX B - Ponds 2% Discount Rate

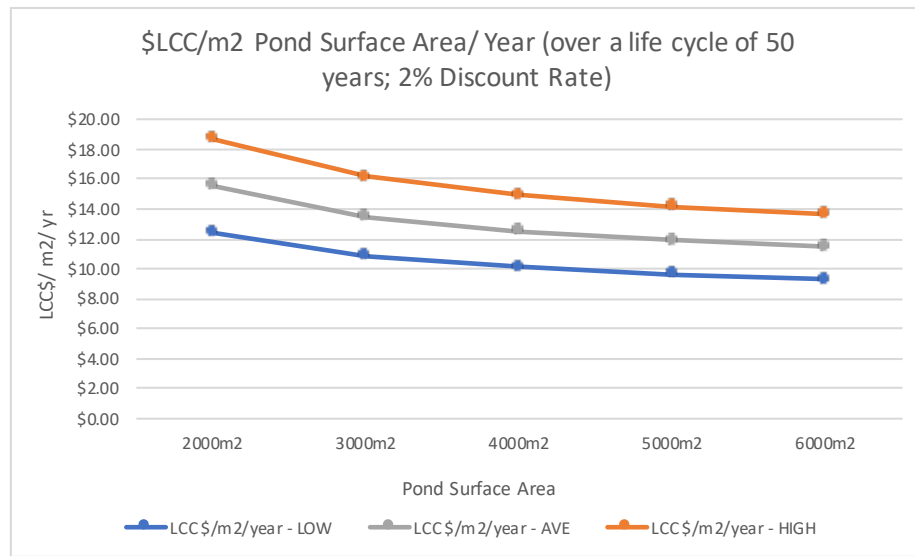
Base date of costs: 2018

Analysis period: 50 years

Pond Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
2000m2	\$12.41	40%	\$18.67	34%	\$15.54	37%
3000m2	\$10.87	46%	\$16.16	40%	\$13.52	43%
4000m2	\$10.10	50%	\$14.91	43%	\$12.50	46%
5000m2	\$9.63	52%	\$14.16	45%	\$11.90	49%
6000m2	\$9.32	54%	\$13.66	47%	\$11.49	50%

Disclaimer:

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APPENDIX B - Rain Gardens + Tree Pits - 2% Discount Rate

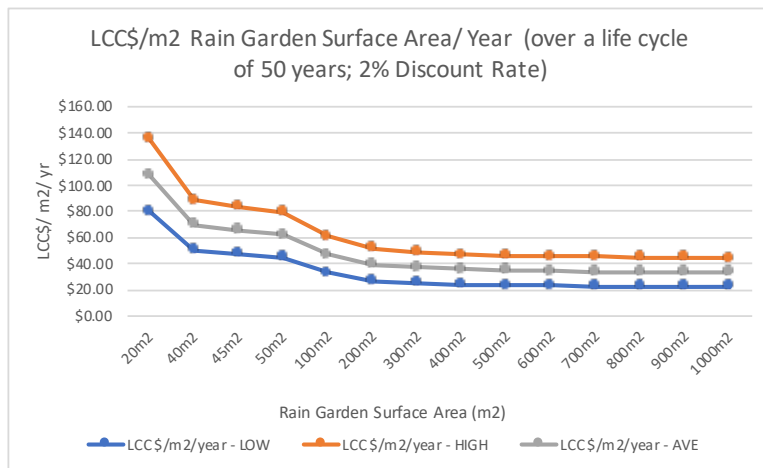
Base date of costs: 2018

Analysis period: 50 years

Rain Gardens Size (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
5 m2 (tree pit)	\$281.66	10%	\$433.82	6%	\$357.74	8%
10m2 (tree pit)	\$164.18	11%	\$249.34	11%	\$206.76	11%
20m2	\$79.88	11%	\$134.82	8%	\$107.35	9%
40m2	\$50.51	17%	\$88.70	12%	\$69.60	14%
45m2	\$47.24	18%	\$83.58	12%	\$65.41	15%
50m2	\$44.63	19%	\$79.48	13%	\$62.05	16%
100m2	\$32.88	26%	\$61.03	17%	\$46.96	21%
200m2	\$27.01	31%	\$51.80	20%	\$39.41	26%
300m2	\$25.05	34%	\$48.73	21%	\$36.89	27%
400m2	\$24.07	35%	\$47.19	22%	\$35.63	28%
500m2	\$23.49	36%	\$46.27	22%	\$34.88	29%
600m2	\$23.09	36%	\$45.65	23%	\$34.37	30%
700m2	\$22.81	37%	\$45.21	23%	\$34.01	30%
800m2	\$22.60	37%	\$44.89	23%	\$33.74	30%
900m2	\$22.44	37%	\$44.63	23%	\$33.54	30%
1000m2	\$22.31	38%	\$44.42	23%	\$33.37	31%

Disclaimer:

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APPENDIX B - Infiltration 2% Discount Rate

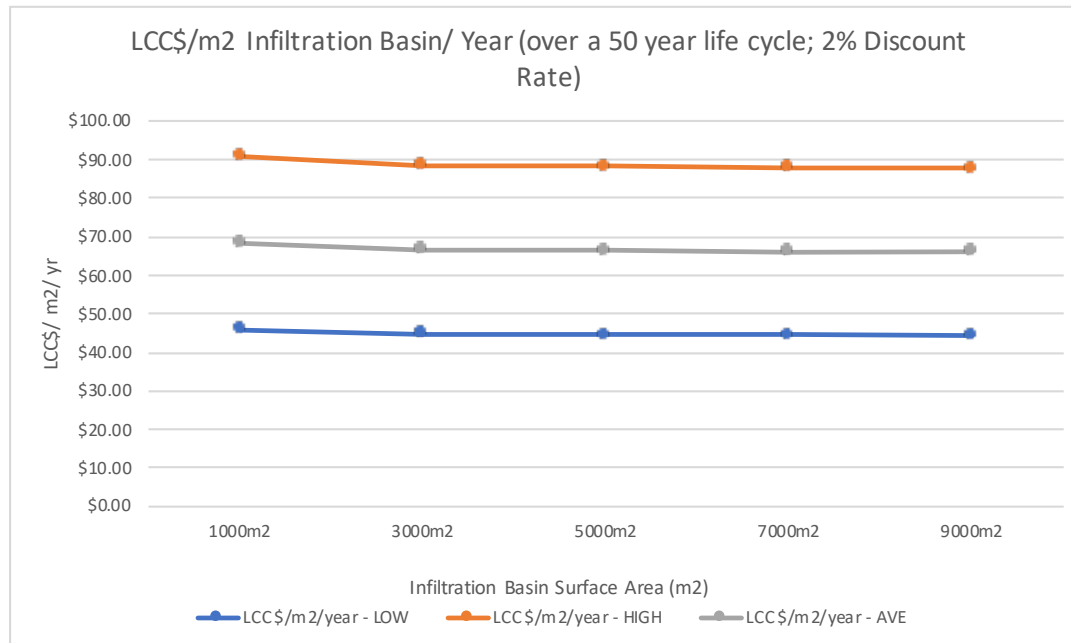
Base date of costs: 2018

Analysis period: 50 years

Infiltration Basin Size (m ²)	LCC \$/m ² /year - LOW	TAC Portion of LCC	LCC \$/m ² /year - HIGH	TAC Portion of LCC	LCC \$/m ² /year - AVE	TAC Portion of LCC
1000m ²	\$45.78	4%	\$90.79	4%	\$68.28	4%
3000m ²	\$44.71	4%	\$88.55	4%	\$66.63	4%
5000m ²	\$44.50	4%	\$88.10	4%	\$66.30	4%
7000m ²	\$44.41	4%	\$87.91	4%	\$66.16	4%
9000m ²	\$44.35	4%	\$87.80	4%	\$66.08	4%

Disclaimer:

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APPENDIX B - Filter Systems 2% Discount Rate

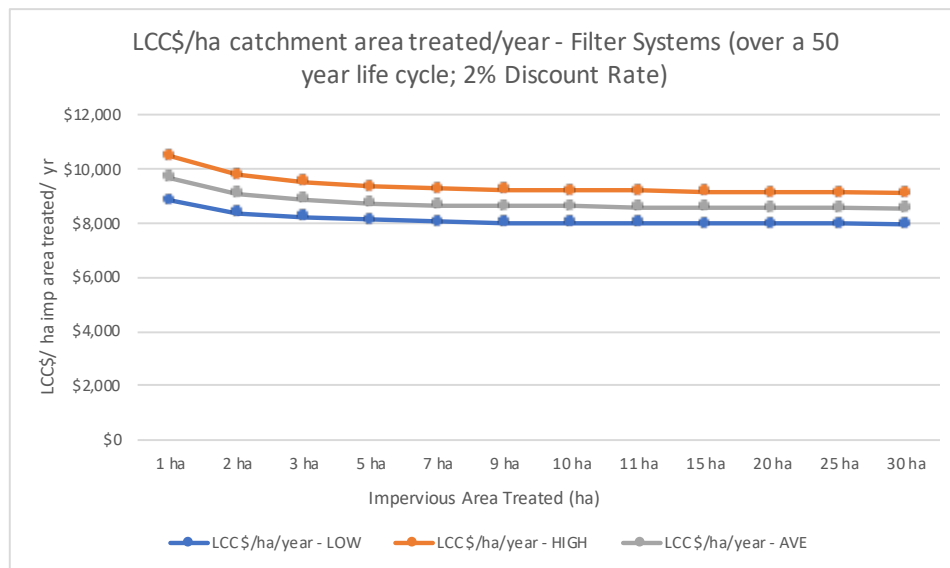
Base date of costs: 2018

Analysis period: 50 years

Filter Systems: Ha/ area treated	LCC \$/ha/year - LOW	TAC Portion of LCC	LCC \$/ha/year - HIGH	TAC Portion of LCC	LCC \$/ha/year - AVE	TAC Portion of LCC
1 ha	\$8,833	18%	\$10,463	18%	\$9,648	18%
2 ha	\$8,378	19%	\$9,764	19%	\$9,071	19%
3 ha	\$8,226	19%	\$9,531	20%	\$8,879	20%
5 ha	\$8,105	20%	\$9,345	20%	\$8,725	20%
7 ha	\$8,053	20%	\$9,265	21%	\$8,659	20%
9 ha	\$8,024	20%	\$9,220	21%	\$8,622	20%
10 ha	\$8,014	20%	\$9,205	21%	\$8,610	20%
11 ha	\$8,006	20%	\$9,192	21%	\$8,599	20%
15 ha	\$7,984	20%	\$9,158	21%	\$8,571	20%
20 ha	\$7,969	20%	\$9,135	21%	\$8,552	20%
25 ha	\$7,960	20%	\$9,121	21%	\$8,540	20%
30 ha	\$7,953	20%	\$9,112	21%	\$8,533	20%

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APPENDIX B - Permeable Paving 2% Discount Rate

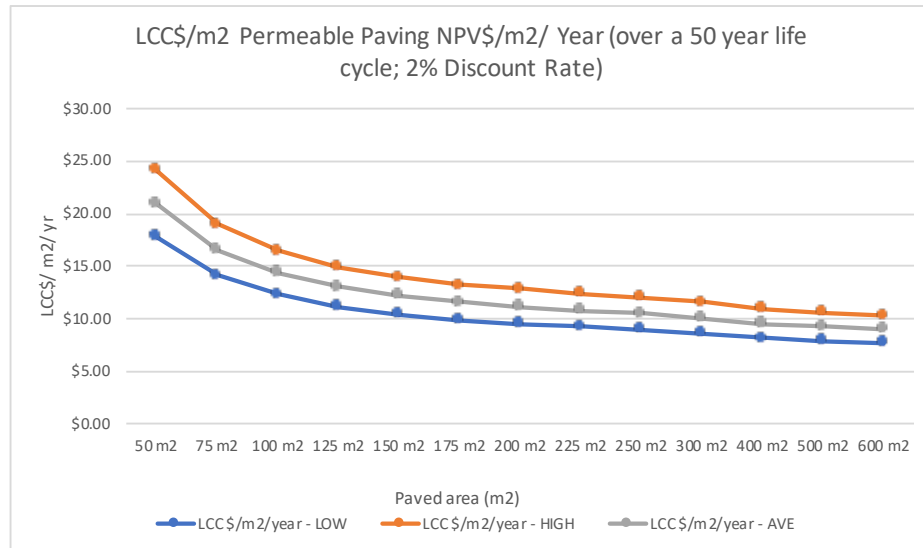
Base date of costs: 2018

Analysis period: 50 years

Permeable Paving (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
50 m2	\$17.76	12%	\$24.10	9%	\$20.93	11%
75 m2	\$14.09	15%	\$18.94	11%	\$16.51	13%
100 m2	\$12.25	17%	\$16.43	13%	\$14.34	15%
125 m2	\$11.15	19%	\$14.93	14%	\$13.04	16%
150 m2	\$10.41	20%	\$13.93	15%	\$12.17	17%
175 m2	\$9.89	21%	\$13.21	16%	\$11.55	18%
200 m2	\$9.49	22%	\$12.80	17%	\$11.15	19%
225 m2	\$9.19	23%	\$12.39	18%	\$10.79	20%
250 m2	\$8.94	23%	\$12.05	18%	\$10.50	21%
300 m2	\$8.57	24%	\$11.55	19%	\$10.06	22%
400 m2	\$8.11	26%	\$10.92	20%	\$9.52	23%
500 m2	\$7.84	26%	\$10.55	21%	\$9.19	24%
600 m2	\$7.65	27%	\$10.29	21%	\$8.97	24%

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APPENDIX B - Rain Tanks 2% Discount Rate

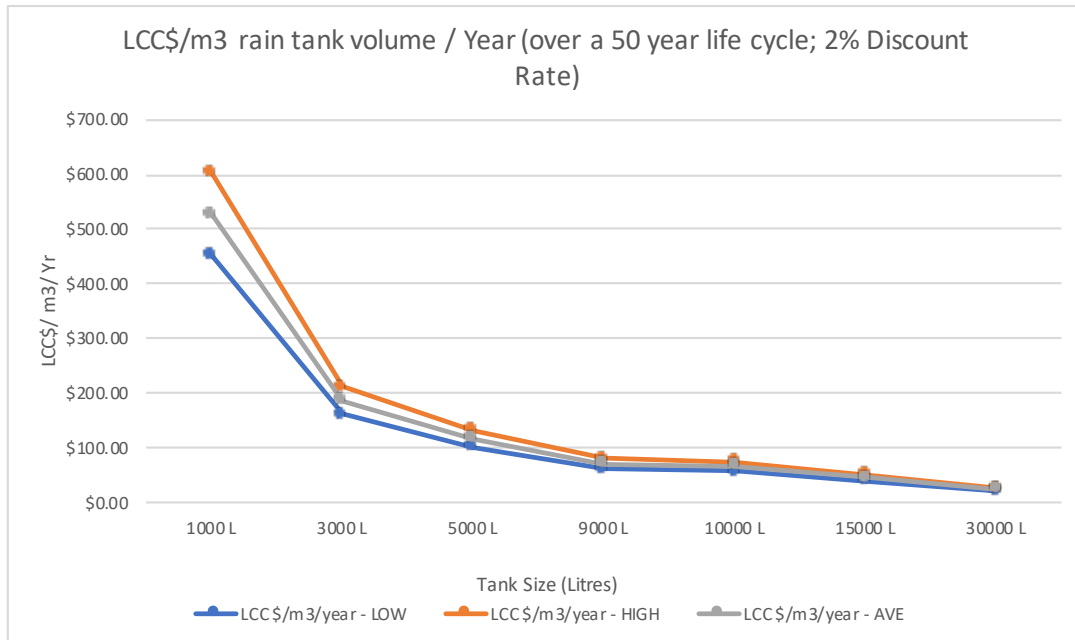
Base date of costs: 2018

Analysis period: 50 years

Rain Tank Size (Litre)	LCC \$/m3/year - LOW	TAC Portion of LCC	LCC \$/m3/year - HIGH	TAC Portion of LCC	LCC \$/m3/year - AVE	TAC Portion of LCC
1000 L	\$452.86	28%	\$603.94	21%	\$528.40	24%
3000 L	\$161.84	29%	\$211.59	23%	\$186.72	26%
5000 L	\$102.44	30%	\$132.84	24%	\$117.64	27%
9000 L	\$61.06	32%	\$79.68	26%	\$70.37	29%
10000 L	\$57.66	33%	\$74.29	27%	\$65.98	30%
15000 L	\$40.27	33%	\$51.42	27%	\$45.84	30%
30000 L	\$21.04	34%	\$26.46	28%	\$23.75	31%

Disclaimer:

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APPENDIX B - Drained Swales 2% Discount Rate

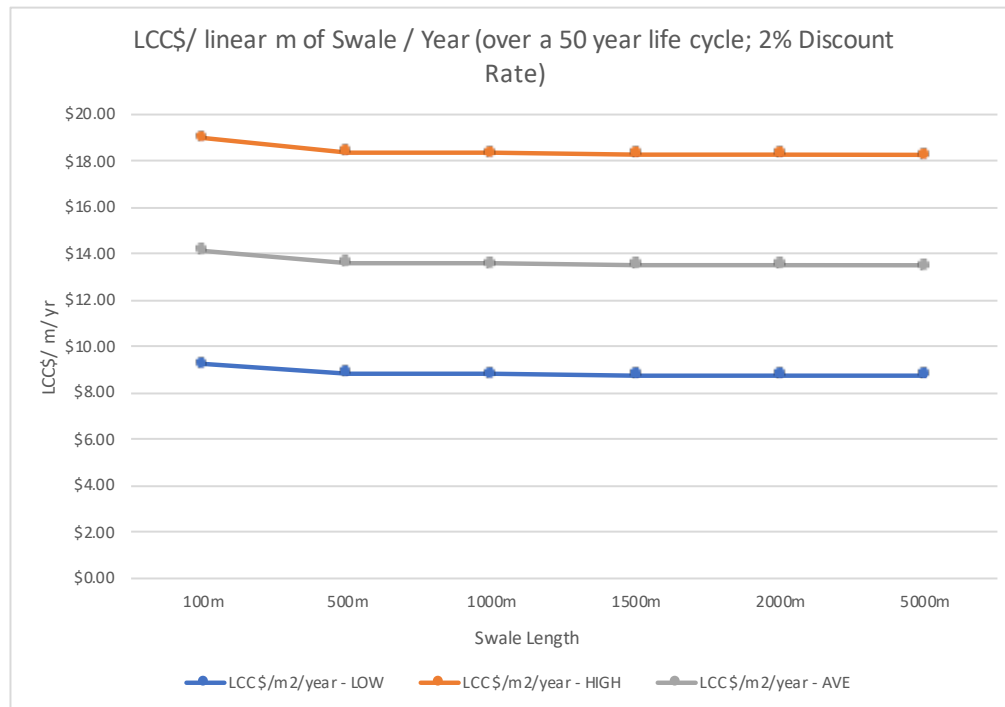
Base date of costs: 2018

Analysis period: 50 years

Swale Surface length	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m	\$9.25	54%	\$18.99	33%	\$14.12	44%
500m	\$8.84	57%	\$18.40	34%	\$13.62	45%
1000m	\$8.78	57%	\$18.32	34%	\$13.55	46%
1500m	\$8.77	57%	\$18.30	34%	\$13.53	46%
2000m	\$8.74	57%	\$18.28	34%	\$13.51	46%
5000m	\$8.74	57%	\$18.26	34%	\$13.50	46%

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APPENDIX B - Green Roofs 2% Discount Rate

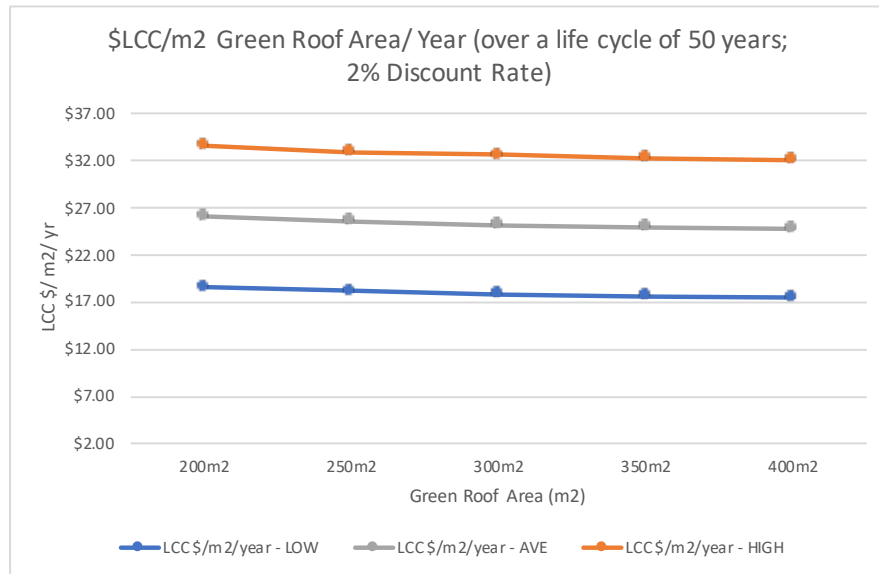
Base date of costs: 2018

Analysis period: 50 years

Green Roofs	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
200m2	\$18.58	32%	\$33.57	26%	\$26.07	29%
250m2	\$18.13	33%	\$32.95	27%	\$25.54	30%
300m2	\$17.84	34%	\$32.54	27%	\$25.19	30%
350m2	\$17.63	34%	\$32.25	27%	\$24.94	31%
400m2	\$17.47	34%	\$32.03	27%	\$24.75	31%

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APPENDIX B - Water Quality Wetlands (4% DR)

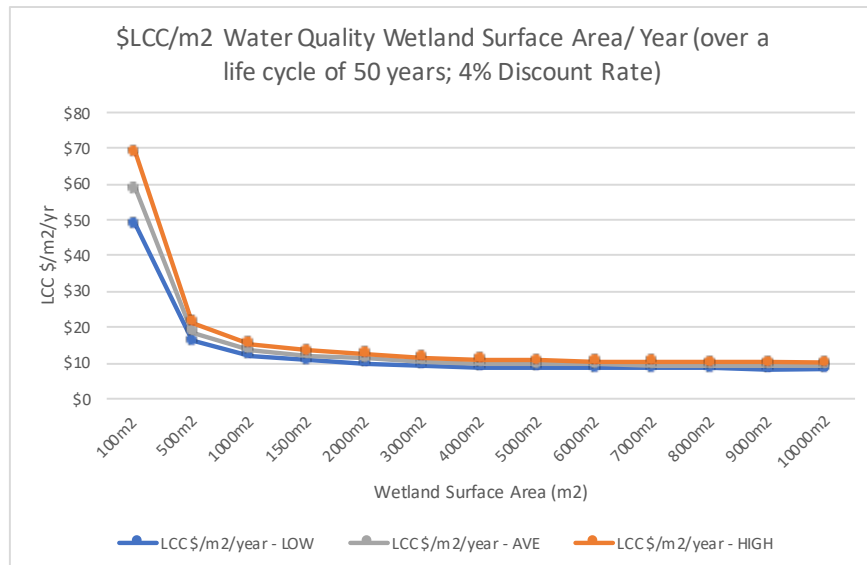
Base date of costs: 2018

Analysis period: 50 years

Constructed Water Quality Wetland Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m2	\$48.67	13%	\$68.76	10%	\$58.72	12%
500m2	\$16.05	40%	\$21.38	34%	\$18.71	37%
1000m2	\$11.97	53%	\$15.45	47%	\$13.71	50%
1500m2	\$10.61	60%	\$13.48	53%	\$12.04	57%
2000m2	\$9.93	64%	\$12.49	58%	\$11.21	61%
3000m2	\$9.25	69%	\$11.50	63%	\$10.38	66%
4000m2	\$8.91	72%	\$11.01	65%	\$9.96	69%
5000m2	\$8.70	74%	\$10.71	67%	\$9.71	70%
6000m2	\$8.57	75%	\$10.52	68%	\$9.54	72%
7000m2	\$8.47	76%	\$10.38	69%	\$9.42	72%
8000m2	\$8.40	76%	\$10.27	70%	\$9.33	73%
9000m2	\$8.34	77%	\$10.19	71%	\$9.27	74%
10000m2	\$8.30	77%	\$10.12	71%	\$9.21	74%

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APPENDIX B - Ponds (4% DR)

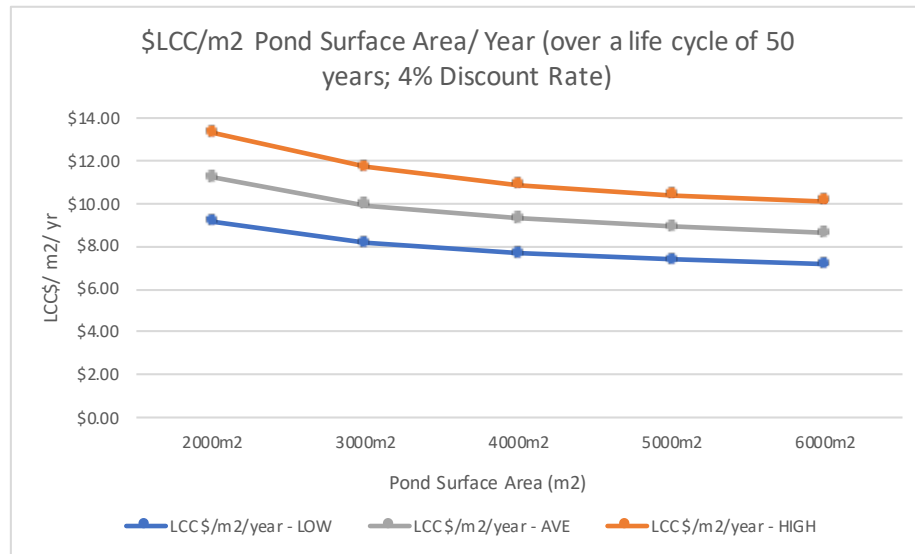
Base date of costs: 2018

Analysis period: 50 years

Pond Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
2000m2	\$9.15	55%	\$13.31	48%	\$11.23	51%
3000m2	\$8.16	61%	\$11.70	55%	\$9.93	58%
4000m2	\$7.67	65%	\$10.90	59%	\$9.28	62%
5000m2	\$7.37	68%	\$10.41	61%	\$8.89	65%
6000m2	\$7.17	70%	\$10.09	63%	\$8.63	67%

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APPENDIX B - Rain Gardens + Tree Pits (4% DR)

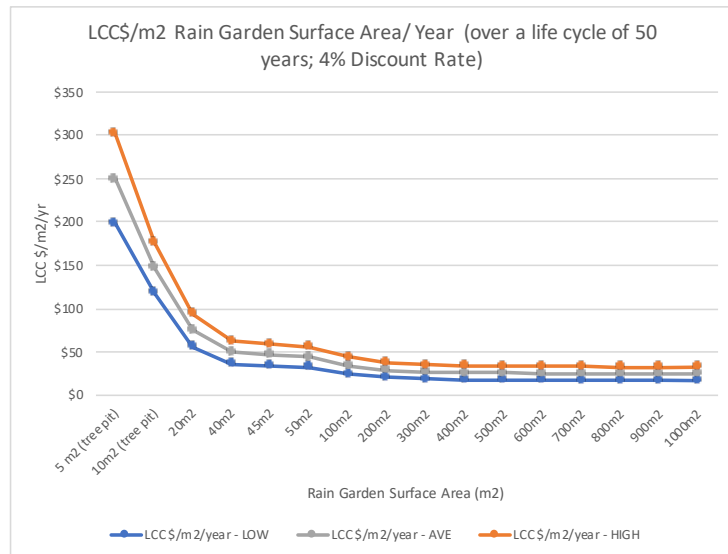
Base date of costs: 2018

Analysis period: 50 years

Tree Pits (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
5 m2 (tree pit)	\$198.28	14%	\$301.32	9%	\$249.80	11%
10m2 (tree pit)	\$117.83	23%	\$175.48	15%	\$146.66	19%
20m2	\$56.37	15%	\$94.13	11%	\$75.25	13%
40m2	\$36.26	23%	\$62.67	17%	\$49.46	20%
45m2	\$34.02	25%	\$59.17	18%	\$46.60	21%
50m2	\$32.24	26%	\$56.38	18%	\$44.31	22%
100m2	\$24.19	35%	\$43.79	24%	\$33.99	29%
200m2	\$20.17	42%	\$37.50	28%	\$28.83	35%
300m2	\$18.83	45%	\$35.40	29%	\$27.12	37%
400m2	\$18.16	46%	\$34.36	30%	\$26.26	38%
500m2	\$17.75	47%	\$33.73	31%	\$25.74	39%
600m2	\$17.49	48%	\$33.31	31%	\$25.40	40%
700m2	\$17.29	49%	\$33.01	32%	\$25.15	40%
800m2	\$17.15	49%	\$32.78	32%	\$24.97	40%
900m2	\$17.04	49%	\$32.61	32%	\$24.82	41%
1000m2	\$16.95	50%	\$32.47	32%	\$24.71	41%

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APPENDIX B - Infiltration Basin (4% DR)

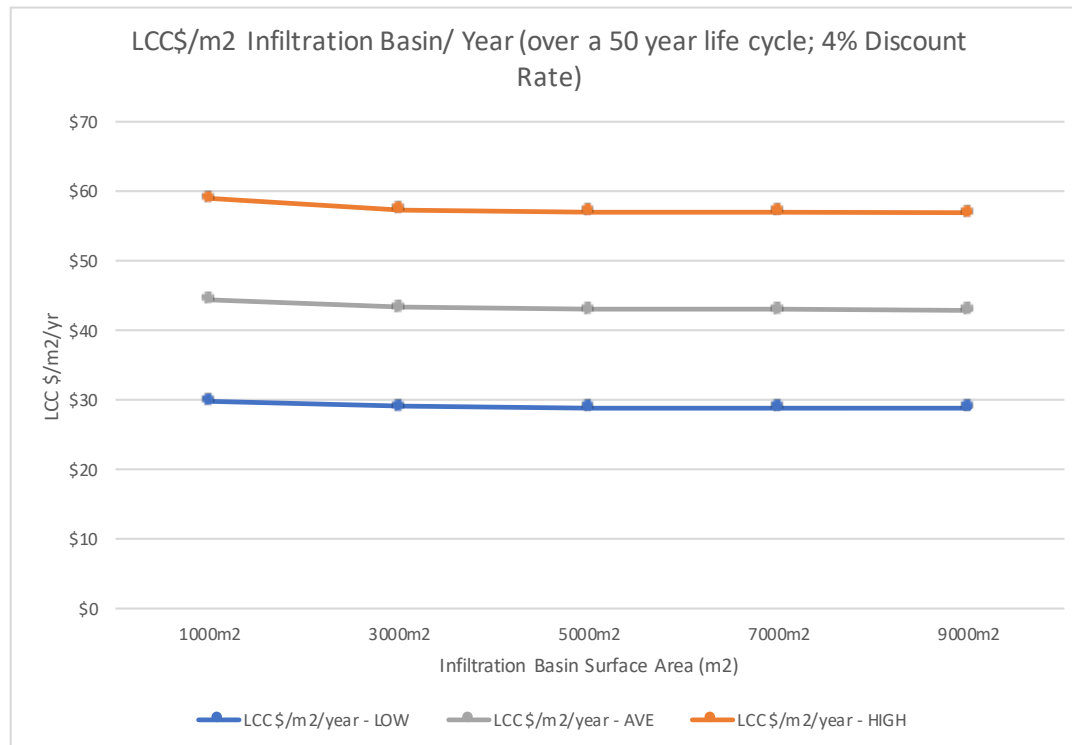
Base date of costs: 2018

Analysis period: 50 years

Infiltration Basin Size (m ²)	LCC \$/m ² /year - LOW	TAC Portion of LCC	LCC \$/m ² /year - HIGH	TAC Portion of LCC	LCC \$/m ² /year - AVE	TAC Portion of LCC
1000m ²	\$29.79	6%	\$58.97	6%	\$44.38	6%
3000m ²	\$29.05	7%	\$57.43	6%	\$43.24	6%
5000m ²	\$28.91	7%	\$57.13	6%	\$43.02	6%
7000m ²	\$28.84	7%	\$56.99	6%	\$42.92	6%
9000m ²	\$28.81	7%	\$56.92	6%	\$42.86	6%

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APPENDIX B - Filter Systems (4% DR)

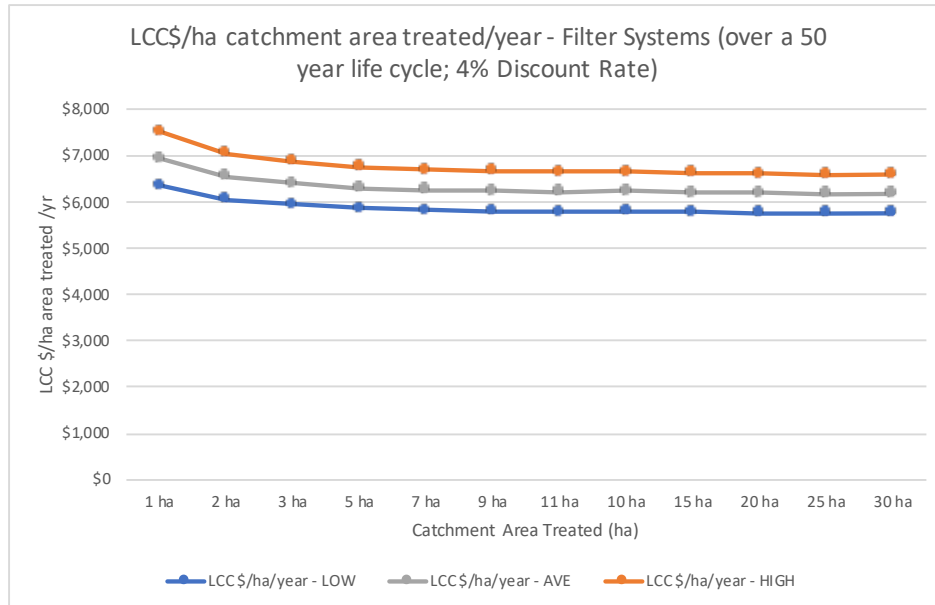
Base date of costs: 2018

Analysis period: 50 years

Filter Systems: Ha/ area treated	LCC \$/ha/year - LOW	TAC Portion of LCC	LCC \$/ha/year - HIGH	TAC Portion of LCC	LCC \$/ha/year - AVE	TAC Portion of LCC
1 ha	\$6,356	25%	\$7,518	25%	\$6,937	25%
2 ha	\$6,044	26%	\$7,038	27%	\$6,541	27%
3 ha	\$5,939	27%	\$6,878	28%	\$6,409	27%
5 ha	\$5,856	27%	\$6,750	28%	\$6,303	28%
7 ha	\$5,820	27%	\$6,695	28%	\$6,258	28%
9 ha	\$5,794	27%	\$6,665	29%	\$6,229	28%
11 ha	\$5,788	27%	\$6,645	29%	\$6,217	28%
10 ha	\$5,794	27%	\$6,654	29%	\$6,224	28%
15 ha	\$5,773	27%	\$6,622	29%	\$6,197	28%
20 ha	\$5,762	28%	\$6,606	29%	\$6,184	28%
25 ha	\$5,756	28%	\$6,596	29%	\$6,176	28%
30 ha	\$5,752	28%	\$6,590	29%	\$6,171	28%

Disclaimer:

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APPENDIX B - Permeable Paving (4% DR)

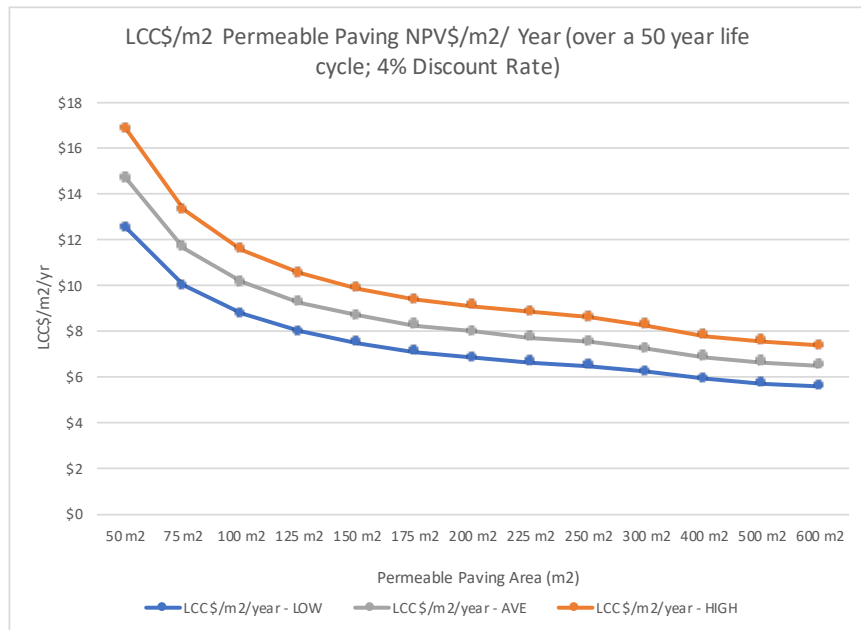
Base date of costs: 2018

Analysis period: 50 years

Permeable Paving (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
50 m2	\$12.54	17%	\$16.86	13%	\$14.70	15%
75 m2	\$10.02	21%	\$13.30	16%	\$11.66	18%
100 m2	\$8.76	24%	\$11.59	18%	\$10.17	21%
125 m2	\$8.00	26%	\$10.56	20%	\$9.28	23%
150 m2	\$7.49	28%	\$9.87	21%	\$8.68	24%
175 m2	\$7.13	29%	\$9.38	22%	\$8.26	26%
200 m2	\$6.86	30%	\$9.12	24%	\$7.99	27%
225 m2	\$6.65	31%	\$8.83	25%	\$7.74	28%
250 m2	\$6.49	32%	\$8.60	25%	\$7.54	29%
300 m2	\$6.23	33%	\$8.26	26%	\$7.24	30%
400 m2	\$5.92	35%	\$7.83	28%	\$6.87	31%
500 m2	\$5.73	36%	\$7.57	29%	\$6.65	32%
600 m2	\$5.60	37%	\$7.40	29%	\$6.50	33%

Disclaimer:

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APPENDIX B - Rain Tanks (4% DR)

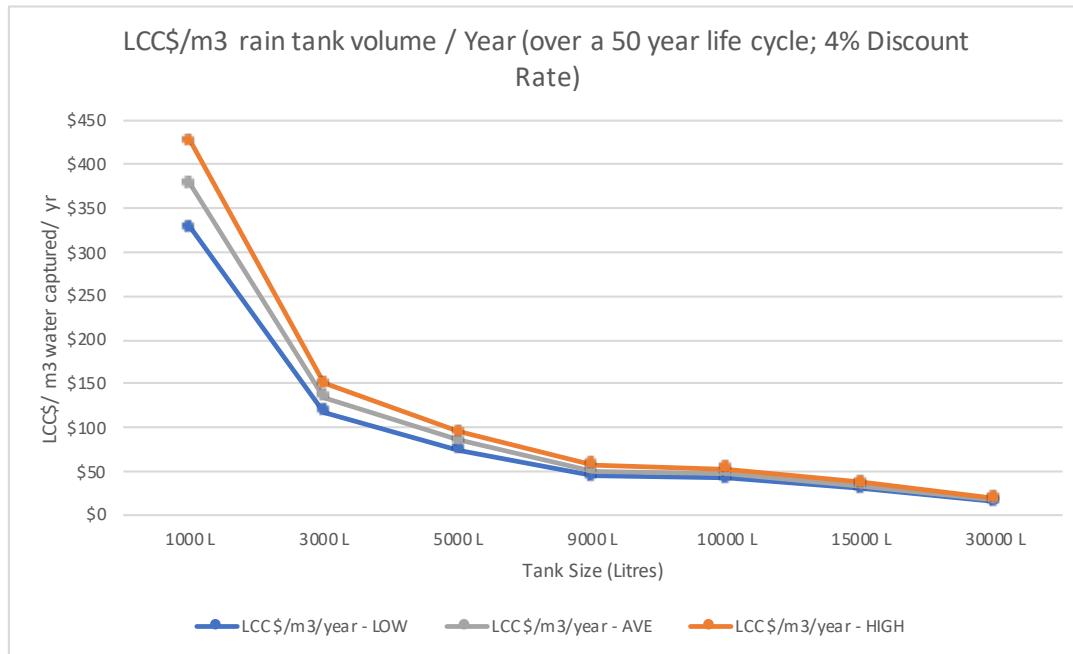
Base date of costs: 2018

Analysis period: 50 years

Rain Tank Size (Litre)	LCC \$/m3/year - LOW	TAC Portion of LCC	LCC \$/m3/year - HIGH	TAC Portion of LCC	LCC \$/m3/year - AVE	TAC Portion of LCC
1000 L	\$328.24	38%	\$426.65	30%	\$377.44	34%
3000 L	\$117.78	40%	\$150.11	32%	\$133.94	36%
5000 L	\$74.77	42%	\$94.59	33%	\$84.68	37%
9000 L	\$44.72	43%	\$57.06	36%	\$50.89	40%
10000 L	\$42.33	44%	\$53.34	37%	\$47.83	41%
15000 L	\$29.62	45%	\$37.01	38%	\$33.31	42%
30000 L	\$15.51	46%	\$19.08	39%	\$17.29	43%

Disclaimer:

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APPENDIX B - Drained Swales (4% DR)

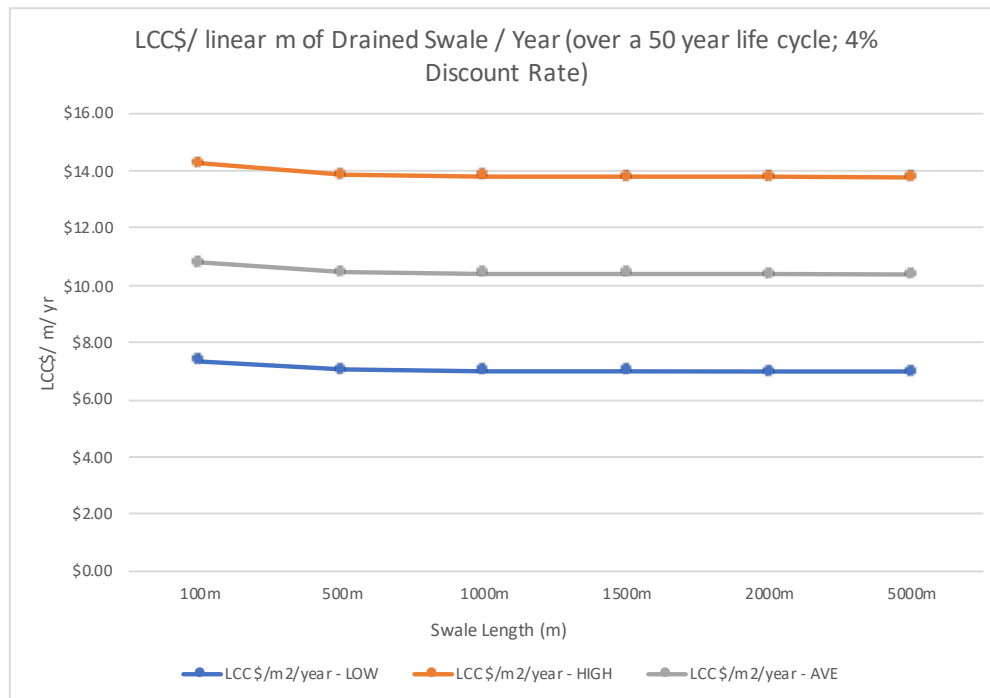
Base date of costs: 2018

Analysis period: 50 years

Swale Surface length	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m	\$7.34	68%	\$14.27	44%	\$10.80	56%
500m	\$7.05	71%	\$13.86	45%	\$10.46	58%
1000m	\$7.02	71%	\$13.81	46%	\$10.41	58%
1500m	\$7.00	71%	\$13.79	46%	\$10.40	59%
2000m	\$6.99	72%	\$13.79	46%	\$10.39	59%
5000m	\$6.99	72%	\$13.77	46%	\$10.38	59%

Disclaimer:

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APPENDIX B - Green Roofs (4% DR)

Base date of costs: 2018

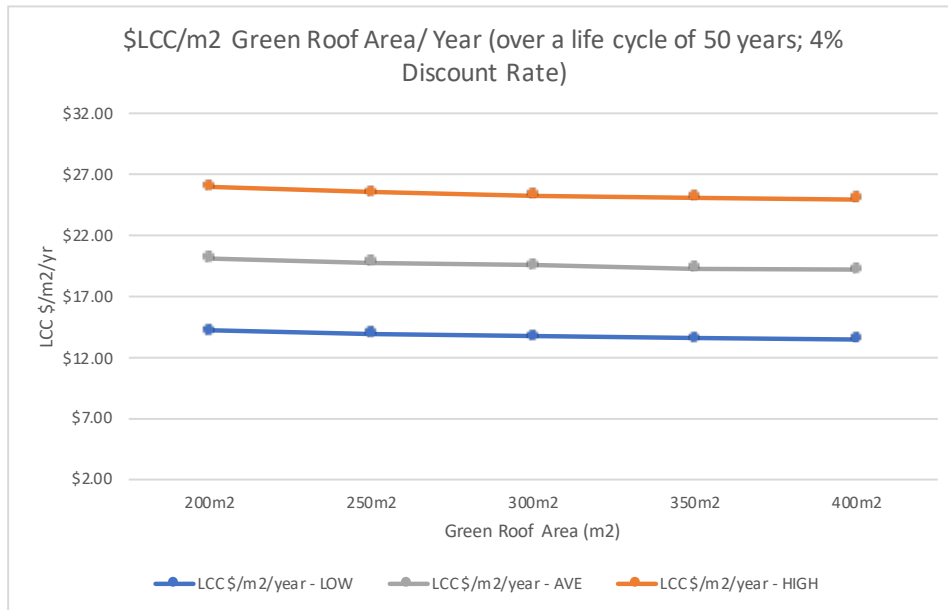
Analysis period: 50 years

Green Roofs	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
200m2	\$14.23	42%	\$25.98	34%	\$20.10	38%
250m2	\$13.93	43%	\$25.56	34%	\$19.74	39%
300m2	\$13.72	44%	\$25.28	35%	\$19.50	39%
350m2	\$13.58	44%	\$25.08	35%	\$19.33	40%
400m2	\$13.47	45%	\$24.93	35%	\$19.20	40%

Disclaimer:

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However, cost information is notoriously variable, and information surrounding maintenance activities, frequencies and costs is scant. Whilst every effort has been made to ensure the consistency and integrity of the data collected and analysed, reliance should not be placed on actual dollar values. Decision-makers should rather use the costing information to understand the potential relative difference between the different green infrastructure solutions. Cost information is provided in good faith for the sole purpose of the comparison of intervention options within SUSTAIN.



APPENDIX B - Water Quality Wetlands 6% Discount Rate

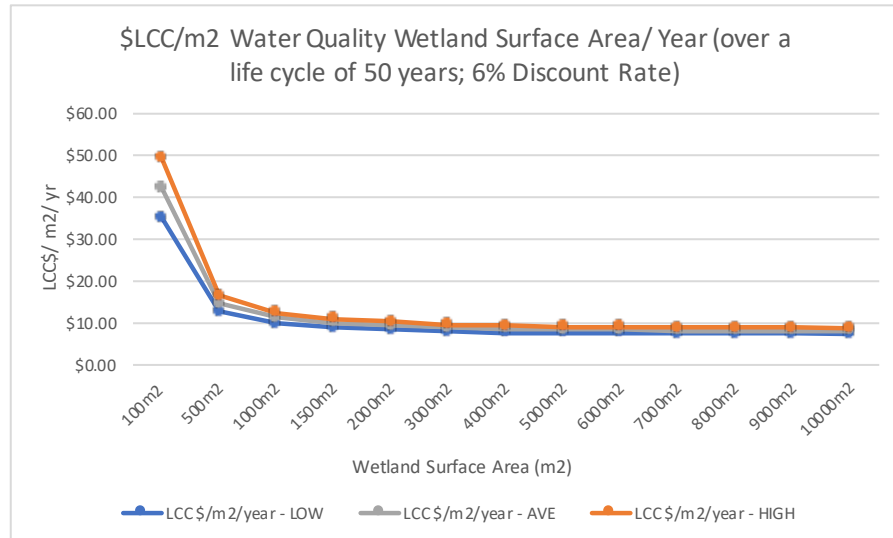
Base date of costs: 2018

Analysis period: 50 years

Constructed Water Quality Wetland Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m2	\$35.21	18%	\$49.38	15%	\$42.29	16%
500m2	\$12.72	50%	\$16.54	44%	\$14.63	47%
1000m2	\$9.91	65%	\$12.44	58%	\$11.17	61%
1500m2	\$8.97	71%	\$11.07	65%	\$10.02	68%
2000m2	\$8.51	75%	\$10.39	69%	\$9.45	72%
3000m2	\$8.04	80%	\$9.70	74%	\$8.87	77%
4000m2	\$7.80	82%	\$9.36	77%	\$8.58	79%
5000m2	\$7.66	84%	\$9.15	79%	\$8.41	81%
6000m2	\$7.57	85%	\$9.02	80%	\$8.29	82%
7000m2	\$7.50	85%	\$8.92	81%	\$8.21	83%
8000m2	\$7.45	86%	\$8.85	81%	\$8.15	84%
9000m2	\$7.41	86%	\$8.79	82%	\$8.10	84%
10000m2	\$7.38	87%	\$8.74	82%	\$8.06	85%

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Model Summary Spreadsheet - Ponds (6% DR)

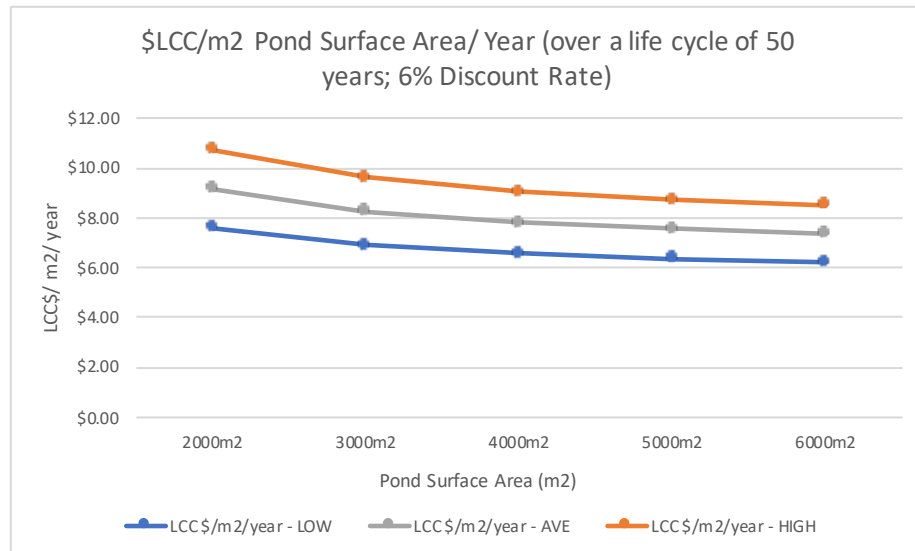
Base date of costs: 2018

Analysis period: 50 years

Pond Size	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
2000m2	\$7.58	66%	\$10.71	60%	\$9.15	63%
3000m2	\$6.90	72%	\$9.60	67%	\$8.25	70%
4000m2	\$6.56	76%	\$9.05	71%	\$7.81	73%
5000m2	\$6.36	79%	\$8.72	73%	\$7.54	76%
6000m2	\$6.22	80%	\$8.50	75%	\$7.36	78%

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APPENDIX B - Rain Gardens + Tree Pits - 6% Discount Rate

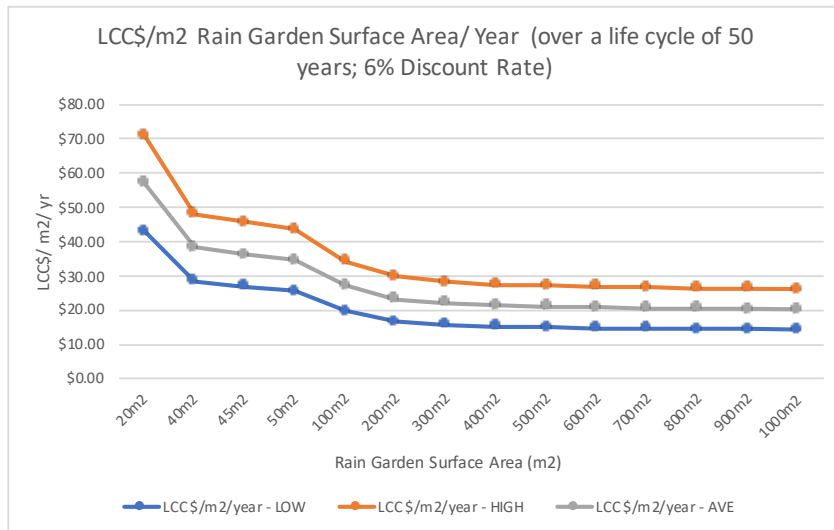
Base date of costs: 2018

Analysis period: 50 years

Rain Gardens Size (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
5 m2 (tree pit)	\$151.26	18%	\$226.00	12%	\$188.63	15%
10m2 (tree pit)	\$92.27	29%	\$134.10	20%	\$113.18	25%
20m2	\$43.18	19%	\$71.17	15%	\$57.17	17%
40m2	\$28.43	30%	\$48.19	22%	\$38.31	26%
45m2	\$26.79	31%	\$45.64	23%	\$36.22	27%
50m2	\$25.48	33%	\$43.60	24%	\$34.54	28%
100m2	\$19.58	43%	\$34.41	30%	\$26.99	37%
200m2	\$16.63	51%	\$29.81	35%	\$23.22	43%
300m2	\$15.65	54%	\$28.28	37%	\$21.96	45%
400m2	\$15.16	55%	\$27.51	38%	\$21.34	47%
500m2	\$14.86	57%	\$27.05	38%	\$20.96	47%
600m2	\$14.67	57%	\$26.75	39%	\$20.71	48%
700m2	\$14.53	58%	\$26.53	39%	\$20.53	49%
800m2	\$14.42	58%	\$26.36	39%	\$20.39	49%
900m2	\$14.34	59%	\$26.24	40%	\$20.29	49%
1000m2	\$14.27	59%	\$26.14	40%	\$20.20	49%

Disclaimer:

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APPENDIX B - Infiltration Basins 6% Discount Rate

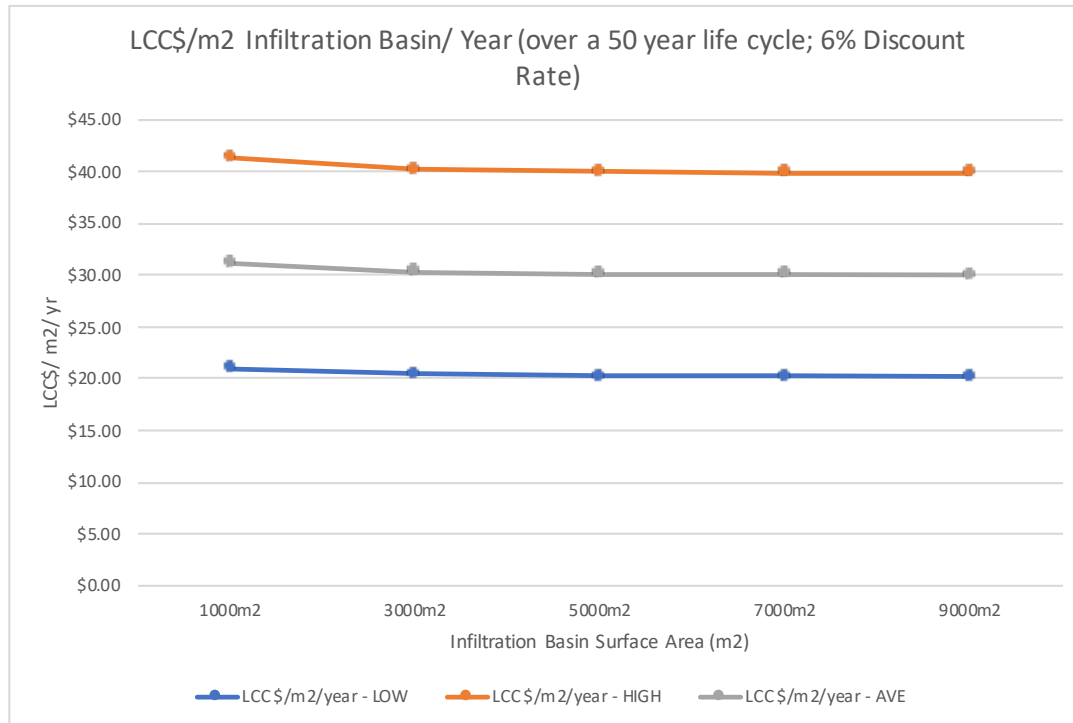
Base date of costs: 2018

Analysis period: 50 years

Infiltration Basin Size (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
1000m2	\$20.95	9%	\$41.35	8%	\$31.15	9%
3000m2	\$20.41	9%	\$40.22	8%	\$30.31	9%
5000m2	\$20.30	9%	\$40.00	8%	\$30.15	9%
7000m2	\$20.25	9%	\$39.90	8%	\$30.08	9%
9000m2	\$20.22	9%	\$39.85	8%	\$30.04	9%

Disclaimer:

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APPENDIX B - Filter Systems 6% Discount Rate

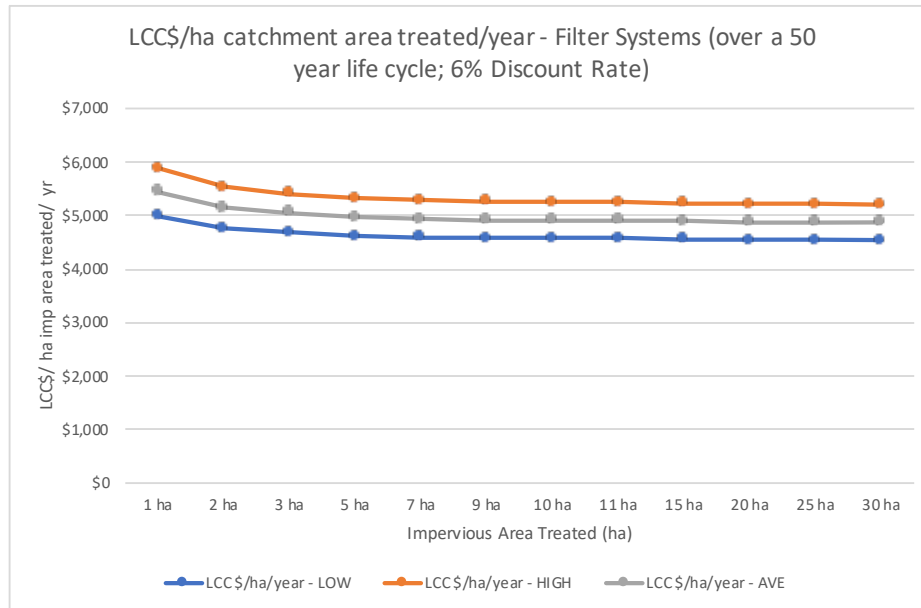
Base date of costs: 2018

Analysis period: 50 years

Filter Systems: Ha/ area treated	LCC \$/ha/year - LOW	TAC Portion of LCC	LCC \$/ha/year - HIGH	TAC Portion of LCC	LCC \$/ha/year - AVE	TAC Portion of LCC
1 ha	\$4,985	32%	\$5,886	32%	\$5,436	32%
2 ha	\$4,755	33%	\$5,532	34%	\$5,144	34%
3 ha	\$4,679	34%	\$5,415	35%	\$5,047	35%
5 ha	\$4,617	34%	\$5,320	36%	\$4,969	35%
7 ha	\$4,591	35%	\$5,280	36%	\$4,935	35%
9 ha	\$4,577	35%	\$5,257	36%	\$4,917	35%
10 ha	\$4,571	35%	\$5,250	36%	\$4,910	35%
11 ha	\$4,567	35%	\$5,243	36%	\$4,905	35%
15 ha	\$4,556	35%	\$5,226	36%	\$4,891	36%
20 ha	\$4,548	35%	\$5,214	36%	\$4,881	36%
25 ha	\$4,544	35%	\$5,207	36%	\$4,875	36%
30 ha	\$4,541	35%	\$5,202	37%	\$4,872	36%

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APPENDIX B - Permeable Paving (6% DR)

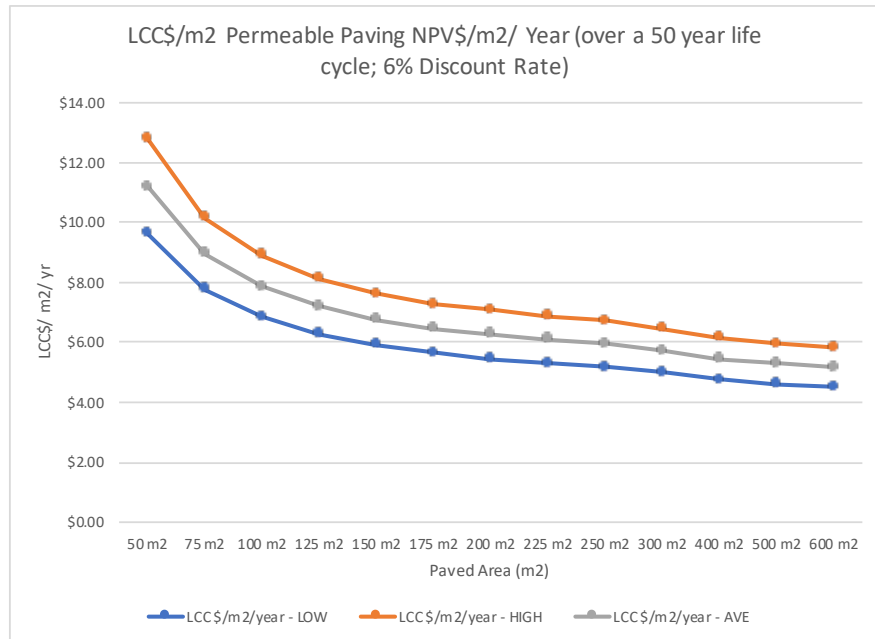
Base date of costs: 2018

Analysis period: 50 years

Permeable Paving (m2)	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
50 m2	\$9.63	22%	\$12.79	17%	\$11.21	20%
75 m2	\$7.77	27%	\$10.15	21%	\$8.96	24%
100 m2	\$6.84	31%	\$8.89	23%	\$7.87	27%
125 m2	\$6.28	33%	\$8.14	26%	\$7.21	29%
150 m2	\$5.91	35%	\$7.63	27%	\$6.77	31%
175 m2	\$5.65	37%	\$7.27	29%	\$6.46	33%
200 m2	\$5.45	38%	\$7.10	31%	\$6.27	34%
225 m2	\$5.29	39%	\$6.89	32%	\$6.09	35%
250 m2	\$5.17	40%	\$6.72	32%	\$5.94	36%
300 m2	\$4.98	42%	\$6.47	34%	\$5.73	38%
400 m2	\$4.75	44%	\$6.15	35%	\$5.45	39%
500 m2	\$4.61	45%	\$5.96	36%	\$5.29	41%
600 m2	\$4.52	46%	\$5.83	37%	\$5.18	41%

Disclaimer:

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APPENDIX B - Rain Tanks 6% Discount Rate

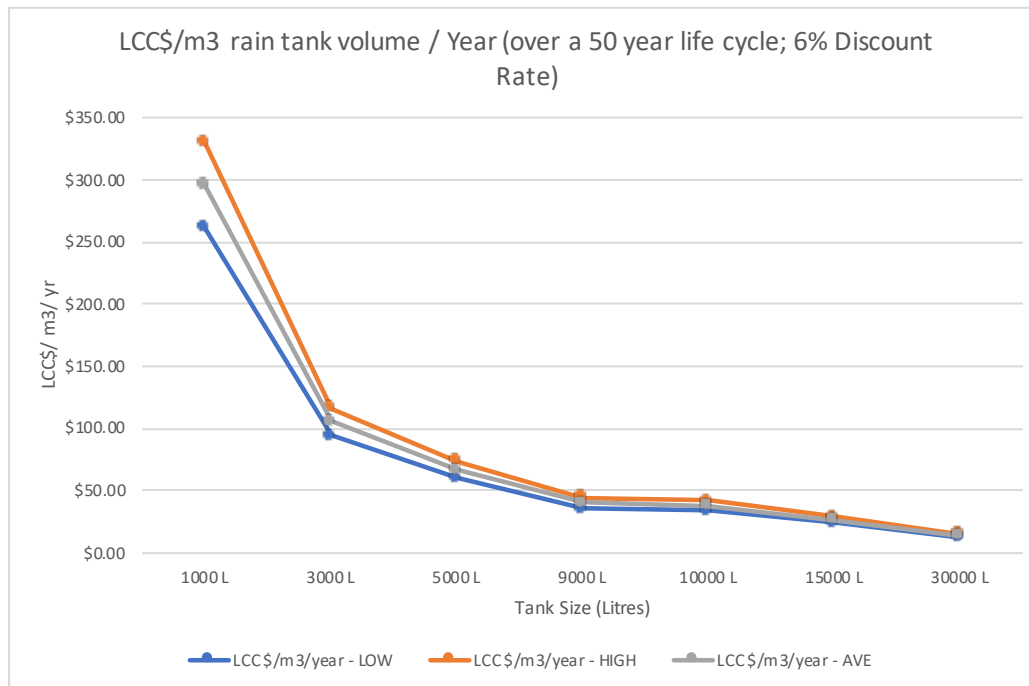
Base date of costs: 2018

Analysis period: 50 years

Rain Tank Size (Litre)	LCC \$/m3/year - LOW	TAC Portion of LCC	LCC \$/m3/year - HIGH	TAC Portion of LCC	LCC \$/m3/year - AVE	TAC Portion of LCC
1000 L	\$260.97	48%	\$329.48	39%	\$295.23	43%
3000 L	\$94.09	50%	\$116.53	41%	\$105.31	46%
5000 L	\$59.94	52%	\$73.76	43%	\$66.85	47%
9000 L	\$36.00	54%	\$44.81	46%	\$40.40	50%
10000 L	\$34.17	55%	\$42.01	47%	\$38.09	51%
15000 L	\$23.97	56%	\$29.24	48%	\$26.60	52%
30000 L	\$12.58	57%	\$15.11	49%	\$13.84	53%

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APPENDIX B - Drained Swales 6% Discount Rate

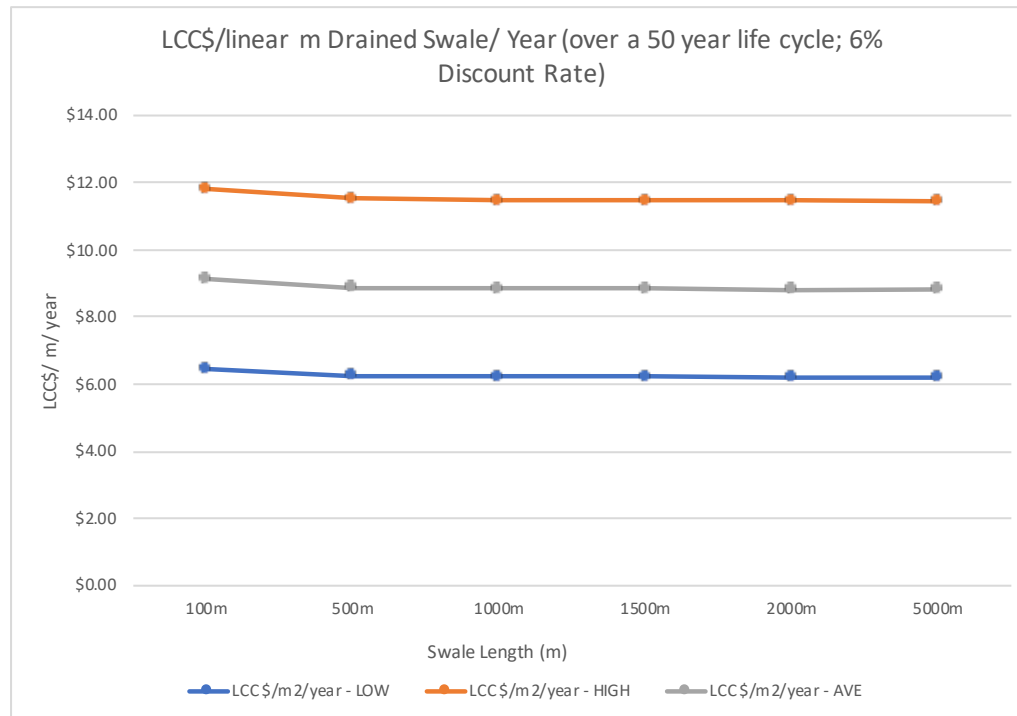
Base date of costs: 2018

Analysis period: 50 years

Swale Surface length	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
100m	\$6.45	77%	\$11.81	53%	\$9.13	65%
500m	\$6.24	80%	\$11.51	55%	\$8.88	67%
1000m	\$6.22	80%	\$11.48	55%	\$8.85	68%
1500m	\$6.21	81%	\$11.46	55%	\$8.84	68%
2000m	\$6.20	81%	\$11.46	55%	\$8.83	68%
5000m	\$6.20	81%	\$11.45	55%	\$8.82	68%

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APPENDIX B - Green Roofs 6% Discount Rate

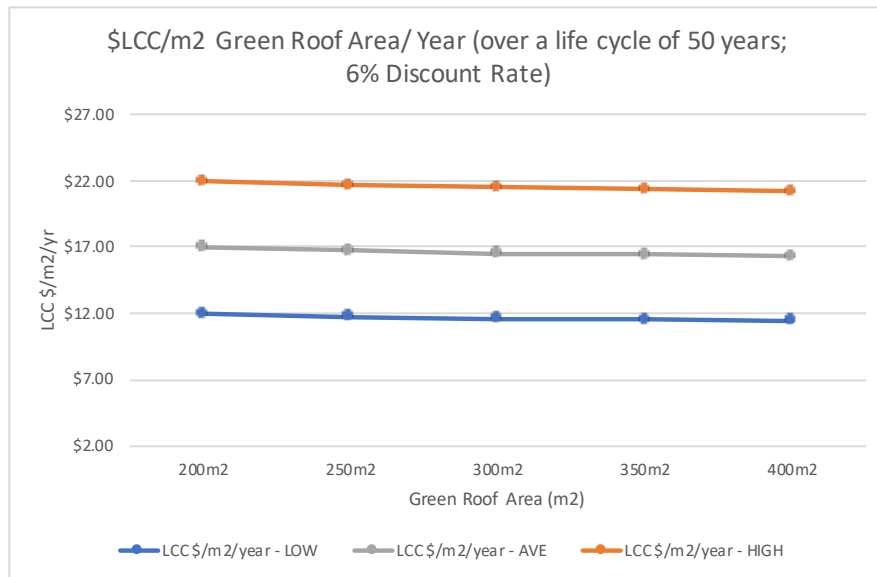
Base date of costs: 2018

Analysis period: 50 years

Green Roofs	LCC \$/m2/year - LOW	TAC Portion of LCC	LCC \$/m2/year - HIGH	TAC Portion of LCC	LCC \$/m2/year - AVE	TAC Portion of LCC
200m2	\$11.99	50%	\$21.97	40%	\$16.98	45%
250m2	\$11.76	51%	\$21.67	41%	\$16.71	46%
300m2	\$11.61	52%	\$21.46	41%	\$16.54	46%
350m2	\$11.51	52%	\$21.32	41%	\$16.41	47%
400m2	\$11.43	52%	\$21.21	41%	\$16.32	47%

Disclaimer:

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Appendix C – LCC results to be used in the pilot run of sustain

APPENDIX C - SUSTAIN PILOT RUN - GREATER TAMAKI CRE: NON-FINANCE INDICATIVE LCC ESTIMATES

Urban Structural Interventions

Base date of costs: 2018
 Analysis period: 50 years

LCC COST FORMULA FOR SUSTAIN

The total life cycle cost is a function of:

TOTAL LCC over 50 years per device = (((LCC\$/UNIT/yr*50)+(land cost \$/m2)+(((LCC\$/UNIT/yr*50)*TAC Portion)*Dev Factor))) * device footprint OR catchment area treated OR water volume captured

LCC AVERAGE \$ COST

RAIN GARDENS/ TREE PITS (LCC\$/m2/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate
Green Street (new dev) rain garden: 4 - 6m2	\$357.74	\$249.80	\$188.63
Green Street (retrofit) rain garden: 4 - 6m2	\$357.74	\$249.80	\$188.63
Lot rain garden: 10 m2	\$206.76	\$146.66	\$113.18
Lot rain garden: 11 - 20 m2	\$157.05	\$110.95	\$85.18
Subcatchment rain garden: 500 - 600m2	\$34.63	\$25.06	\$20.46
Subcatchment rain garden: 700 - 800m2	\$33.38	\$25.57	\$20.83

RAIN TANKS (LCC\$/m3/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate
Residential dual use (5,000 L tank)*	\$117.64	\$84.68	\$66.85
Residential dual use (10,000 L tank)*	\$65.98	\$47.83	\$38.09
Commercial dual use (10,000 L tank)*	\$65.98	\$47.83	\$38.09
Industrial dual use (10,000 L tank)*	\$65.98	\$47.83	\$38.09

* tank size based on email from Caleb Clarke on 23/1/2020

FILTER SYSTEMS (LCC\$/ha*/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate
Filter systems: 0 - 1 ha	\$9,648	\$6,937.00	\$5,436.00

*relates to ha impervious area treated

WETLANDS (LCC\$/m2/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate
Wetlands 2000 - 3000m2	\$14.40	\$10.79	\$9.16
Wetlands 3000 - 4000m2	\$13.43	\$10.17	\$8.73
Wetlands 4000 - 5000m2	\$12.91	\$9.83	\$8.50

SPLIT OF COSTS

RAIN GARDENS/ TREE PITS (LCC\$/m2/yr)	TOTAL ACQUISITION COST (TAC) PORTION			ROUTINE MAINTENANCE COST (RMC) PORTION			CORRECTIVE MAINTENANCE COST (CMC) PORTION		
	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate
Green Street (new dev) rain garden: 4 - 6m2	8%	11%	15%	81%	80%	78%	11%	9%	7%
Green Street (retrofit) rain garden: 4 - 6m2	8%	11%	15%	81%	80%	78%	11%	9%	7%
Lot rain garden: 10 m2	9%	13%	17%	80%	79%	76%	11%	8%	7%
Lot rain garden: 11 - 20 m2	11%	16%	21%	74%	72%	69%	15%	12%	10%
Subcatchment rain garden: 500 - 600m2	29%	39%	48%	55%	51%	47%	16%	10%	5%
Subcatchment rain garden: 700 - 800m2	30%	40%	49%	53%	50%	46%	17%	10%	5%

TOTAL ACQUISITION COST (TAC) PORTION

ROUTINE MAINTENANCE COST (RMC) PORTION

CORRECTIVE MAINTENANCE COST (CMC) PORTION

RAIN TANKS (LCC\$/m3/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate
Residential dual use (5,000 L tank)*	27%	37%	47%	26%	24%	23%	47%	39%	30%
Residential dual use (10,000 L tank)*	30%	41%	51%	23%	22%	19%	47%	37%	30%
Commercial dual use (10,000 L tank)*	30%	41%	51%	23%	22%	19%	47%	37%	30%
Industrial dual use (10,000 L tank)*	30%	41%	51%	23%	22%	19%	47%	37%	30%

* tank size based on email from Caleb Clarke on 23/1/2020

TOTAL ACQUISITION COST (TAC) PORTION

ROUTINE MAINTENANCE COST (RMC) PORTION

CORRECTIVE MAINTENANCE COST (CMC) PORTION

FILTER SYSTEMS (LCC\$/ha*/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate
Filter systems: 0 - 1 ha	18%	25%	32%	68%	65%	61%	14%	10%	7%

*relates to ha impervious area treated.

TOTAL ACQUISITION COST (TAC) PORTION

ROUTINE MAINTENANCE COST (RMC) PORTION

CORRECTIVE MAINTENANCE COST (CMC) PORTION

WETLANDS (LCC\$/m2/yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate	2% Discount Rate	4% Discount Rate	6% Discount Rate
Wetlands 2000 - 3000m2	48%	63%	75%	6%	5%	5%	46%	32%	20%
Wetlands 3000 - 4000m2	51%	67%	78%	5%	4%	5%	44%	29%	17%
Wetlands 4000 - 5000m2	53%	69%	80%	4%	4%	4%	43%	27%	16%

DEVELOPMENT FACTOR

BMP/ Intervention	Factor
New BMP in undeveloped (greenfields) area	0
New BMP in partially developed (brownfields area)	0.5
New BMP in developed area (retrofit)	1
New BMP – difficult installation in highly urban settings	2

LAND COSTS

Land costs per HRU to be provided separately by AC Healthy Waters.

Disclaimer:

The cost information used to generate the above values has been collated from various councils, contractors and consultants around New Zealand and the cost models are based on the best available information at the time of writing this report. However, cost information is notoriously variable, and information surrounding maintenance activities, frequencies and costs is scant. Whilst every effort has been made to ensure the consistency and integrity of the data collected and analysed, reliance should not be placed on actual dollar values. Decision-makers should rather use the costing information to understand the potential relative difference between the different green infrastructure solutions. Cost information is provided in good faith for the sole purpose of the comparison of intervention options within SUSTAIN.

Appendix D – LCC trend functions

APPENDIX D - AC FWMT: NON-FINANCE INDICATIVE LCC ESTIMATE TREND FUNCTIONS

Base date of costs: 2018
 Analysis period: 50 years

FORMULA FOR APPLICATION OF COSTS INTO A CATCHMENT PLANNING MODEL OR SUSTAIN:

The total life cycle cost is a function of:

TOTAL LCC over 50 years per device = $((LCCS/UNIT/yr*50)+(land\ cost\ \$/m^2)+(((LCCS/UNIT/yr*50)*TAC\ Portion)*Dev\ Factor)))$ * device footprint OR catchment area treated OR water volume captured

LCC FORMULA

Excel Formula:
 $LCCS/unit/year = EXP(Constant + \ln(Area)*BetaArea)$

	2% Discount Rate	4% Discount Rate	6% Discount Rate	Size Limitations	Unit
WETLANDS (LCC\$/m2/yr)					
Constant	5.86158	5.30268	4.80014	100 - 10,000 m2	Surface Area (m2)
BetaArea	-0.38858	-0.35497	-0.31325		
PONDS (LCC\$/m2/yr)					
Constant	4.82161	4.23026	3.70815	2,000 - 6,000 m2	Surface Area (m2)
BetaArea	-0.27523	-0.24002	-0.19809		
RAIN GARDENS (LCC\$/m2/yr)					
Constant	5.21192	4.82081	4.49966	20 - 1,000 m2	Surface Area (m2)
BetaArea	-0.26311	-0.2493	-0.23102		
SWALES (LCC\$/ m/yr)					
Constant	2.73801	2.4705	2.30085	100 - 5000 linear m	Swale Length (m)
BetaArea	-0.011079	-9.98E-03	-8.47E-03		
FILTER SYSTEMS (LCC\$/ha area treated/yr)					
Constant	9.14014	8.81184	8.56997	1 - 30 ha	Catchment Area Treated (ha)
BetaArea	-0.03119	-0.029715	-0.027784		
PERMEABLE PAVING (LCC\$/m2/yr)					
Constant	4.18403	3.78256	3.44255	50 - 600 m2	Surface Area (m2)
BetaArea	-0.32547	-0.31281	-0.29469		
GREEN ROOFS (LCC\$/m2/yr)					
Constant	3.65526	3.34861	3.13303	200 - 400 m2	Roof Area (m2)
BetaArea	-0.074844	-0.066002	-0.057133		
RAIN TANKS (LCC\$/m3 water captured/yr)					
Constant	12.488	12.1075	11.8091	1,000 - 30,000 L tanks	Volume Water captured (m3)
BetaArea	-0.90338	-0.89716	-0.8897		

LCC AVERAGE \$ COST

LCC\$/m2/yr - Tree Pits	2% Discount Rate	4% Discount Rate	6% Discount Rate
0 - 5 m2	\$357.74	\$249.80	\$188.63
6 - 10m2	\$206.76	\$146.66	\$113.18

LCC\$/m2/yr - Infiltration Basins	2% Discount Rate	4% Discount Rate	6% Discount Rate
1000m2 - 10000m2	\$66.69	\$43.28	\$30.34

TOTAL ACQUISITION COST (TAC) PORTION

LCC\$/m ² /yr (Water Quality Wetlands)	2% Discount Rate	4% Discount Rate	6% Discount Rate
<1500m ²	28%	39%	48%
>1500m ²	53%	69%	80%
LCC\$/m ² /yr (Stormwater Ponds)	2% Discount Rate	4% Discount Rate	6% Discount Rate
<2000m ²	37%	51%	63%
2000 - 4000m ²	45%	60%	72%
>4000m ²	50%	66%	77%
LCC\$/m ² /yr (Rain Gardens)	2% Discount Rate	4% Discount Rate	6% Discount Rate
11 - 49m ²	13%	18%	23%
50m ² - 99m ²	19%	26%	32%
100m ² - 299m ²	23%	32%	40%
300m ² - 1000m ²	29%	39%	48%
LCC\$/m ² /yr (Tree Pits)	2% Discount Rate	4% Discount Rate	6% Discount Rate
0 - 5 m ²	8%	11%	15%
6 - 10m ²	14%	19%	25%
LCC\$/m/yr (Swales)	2% Discount Rate	4% Discount Rate	6% Discount Rate
100 - 5000m	47%	60%	69%
LCC\$/m ² /yr (Infiltration Basins)	2% Discount Rate	4% Discount Rate	6% Discount Rate
1000m ² - 10000m ²	4%	6%	9%
LCC\$/ha/yr (Filter Systems)	2% Discount Rate	4% Discount Rate	6% Discount Rate
<3 ha	19%	26%	33%
>3 ha	20%	28%	35%
LCC\$/m ² /yr (Permeable Paving)	2% Discount Rate	4% Discount Rate	6% Discount Rate
50m ² - 100m ²	13%	18%	23%
101m ² - 600m ²	20%	28%	35%
LCC\$/m ³ /yr (Green Roofs)	2% Discount Rate	4% Discount Rate	6% Discount Rate
200 - 400m ²	30%	39%	46%
LCC\$/m ³ /yr (Rain Tanks)	2% Discount Rate	4% Discount Rate	6% Discount Rate
1000L - 3000L tanks	25%	35%	45%
5000L - 9000L tanks	28%	38%	48%
10000L - 300000L tanks	30%	42%	52%

DEVELOPMENT FACTOR

BMP/ Intervention	Factor
New BMP in undeveloped (greenfields) area	0
New BMP in partially developed (brownfields area)	0.5
New BMP in developed area (retrofit)	1
New BMP – difficult installation in highly urban settings	2

LAND COSTS

Land costs per HRU to be provided separately by AC Healthy Waters.

Disclaimer:

The cost information used to generate the above values has been collated from various councils, contractors and consultants around New Zealand and the cost models are based on the best available information at the time of writing this report. However, cost information is notoriously variable, and information surrounding maintenance activities, frequencies and costs is scant. Whilst every effort has been made to ensure the consistency and integrity of the data collected and analysed, reliance should not be placed on actual dollar values. Decision-makers should rather use the costing information to understand the potential relative difference between the different green infrastructure solutions. Cost information is provided in good faith for the sole purpose of the comparison of intervention options within SUSTAIN.

Appendix E – Maintenance cost curves

Urban Stormwater Structural Interventions: Maintenance Cost Curves

Introduction

Appendix F provides further information on the maintenance portion of the LCCs presented in Section 6 of this report.

Wetlands

Maintenance costs for wetlands which have a surface area of 3000m² or larger comprise 20% - 30% of the annual low LCC estimate and 30% - 37% for the annual high LCC estimate. For wetlands less than 3000m², the maintenance portion significantly increases as the surface area decreases, with the maintenance portion of the annual LCC estimate varying from 60% to 66% for a 500m² wetland for both the low and high LCC estimates. This relationship can be seen in Figure 1.

A similar trend is visible for stormwater ponds (Figure 2)

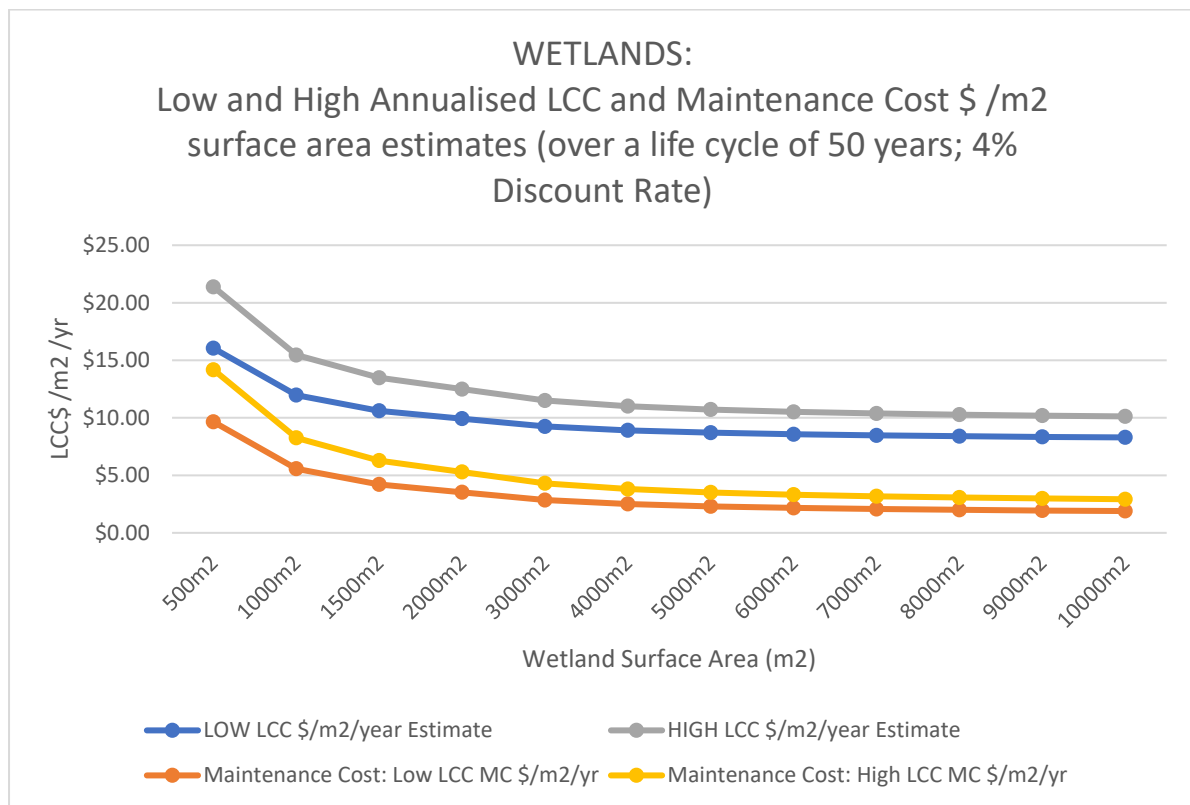


Figure 1 Wetland maintenance costs compared with the LCC estimate

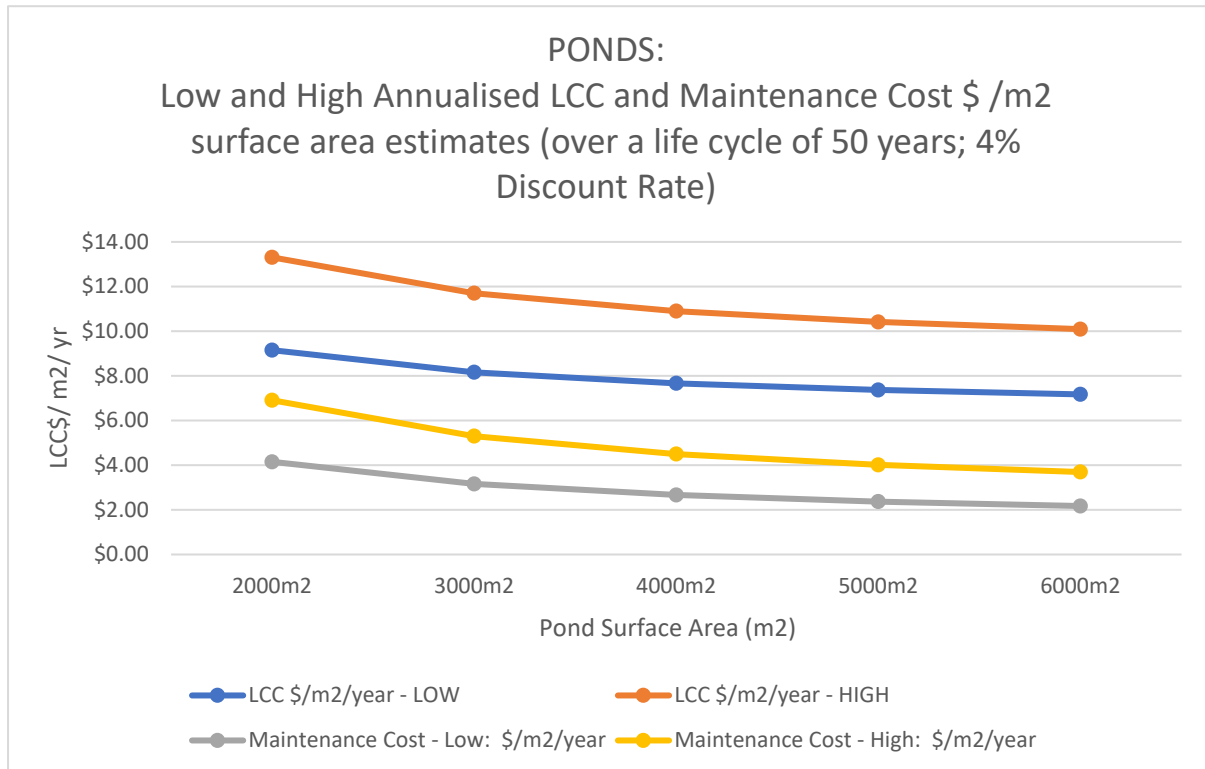


Figure 2 Pond maintenance costs compared with the LCC estimate

Tree Pits and Rain Gardens

Maintenance costs for rain gardens and tree pits significantly increase as the surface area of the device decreases (Figure 3). For rain gardens less than 50m², 70% - 85% of the low LCC estimate equates to the maintenance cost, whilst 80% - 90% equates to maintenance in the high LCC estimate. For rain gardens larger than 50m², the maintenance portion of the LCC varies between 50% and 70% of the LCC estimate.

As discussed in the main report, much of the specified maintenance (e.g. inspections, clearing inlets and outlets) is not related to the size of the device, thus contributing to the inverse relationship between cost and surface area. Additionally, small rain gardens experience edge effects (i.e. vegetation is more susceptible to damage/ die-off/ pests along edges). The high edge to area ratio of small rain gardens negatively affects cost.

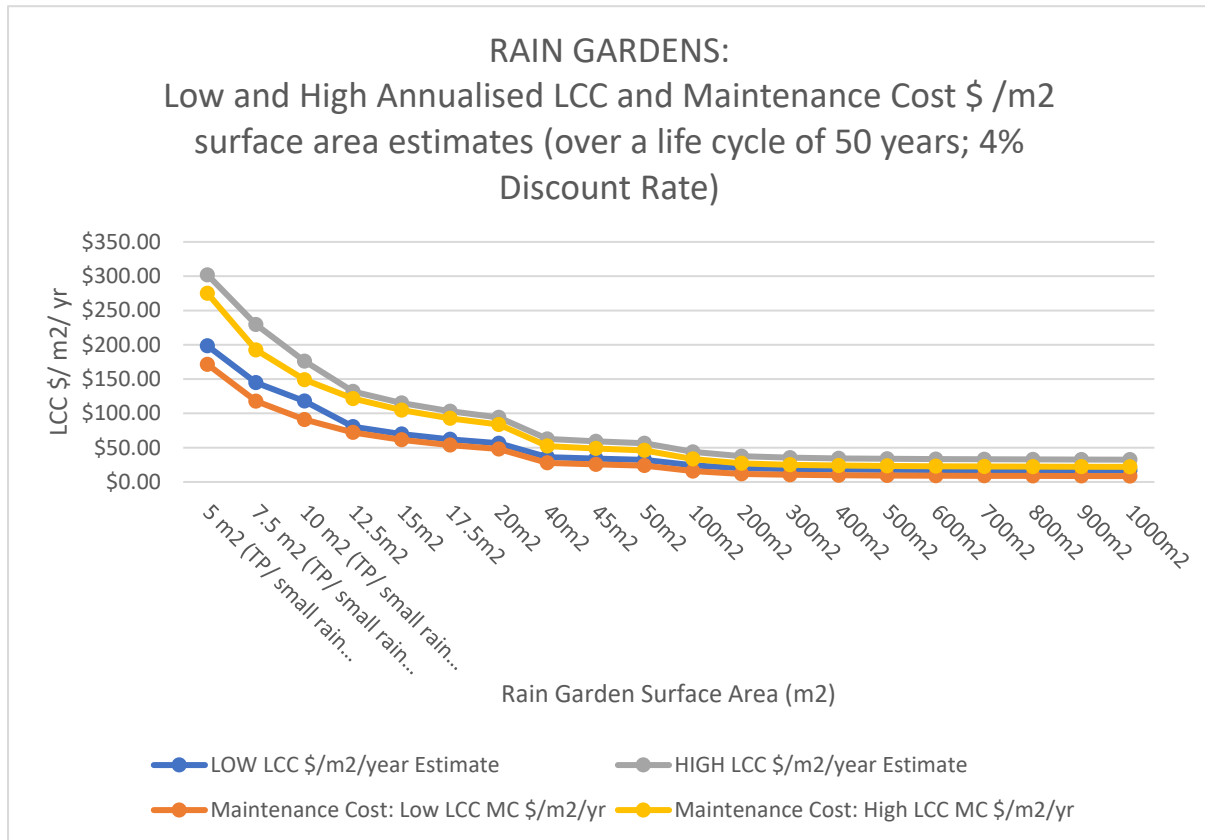


Figure 3 Tree pit/ rain garden maintenance costs compared with the LCC estimate

Infiltration Basins

There is not a large change in maintenance costs of infiltration basin with an increase in surface area (Figure 4). On average, 90% - 95% of the LCC estimate equates to maintenance costs. The high level of maintenance needed is likely reflective of the clogging potential of infiltration basins.

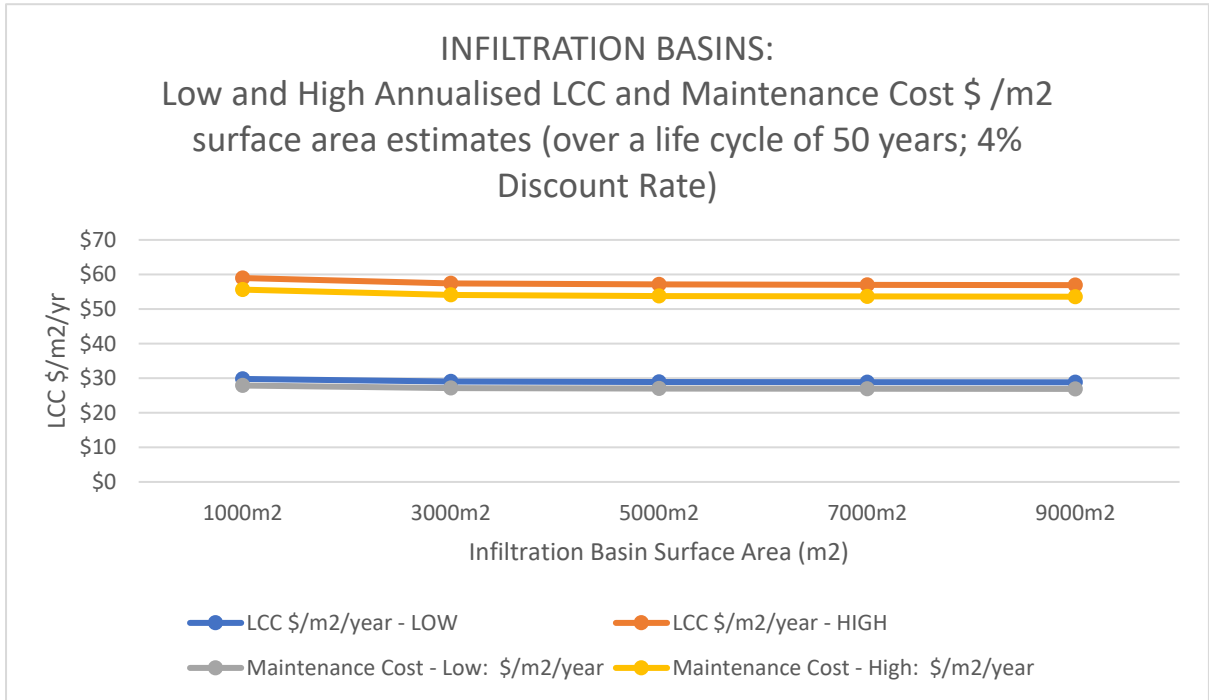


Figure 4 Infiltration basin maintenance costs compared with the LCC estimate

Filter systems

Seventy to 75% of the LCC of filter systems relates to ongoing maintenance costs. This is relatively similar to the level of maintenance incurred via rain gardens.

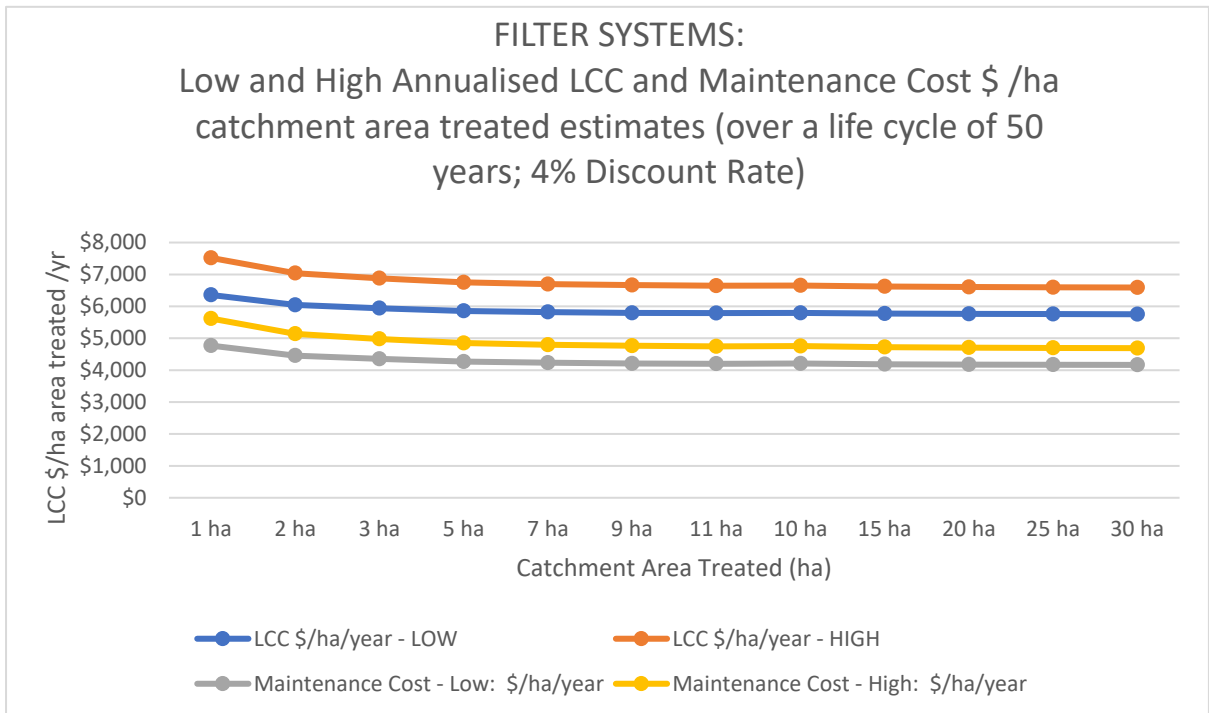


Figure 5 Filter system maintenance costs compared with the LCC estimate

Mown swales

Whilst an inverse relationship between swale length and cost is present (Figure 6), it is far less significant than for rain gardens or wetlands/ ponds. Based on the low LCC estimate, approximately 25% of the LCCs relate to maintenance activities, this increases to 45% for the high LCC estimate. This level of maintenance is likely to be lower if no mow or low mowing native grass swales are used.

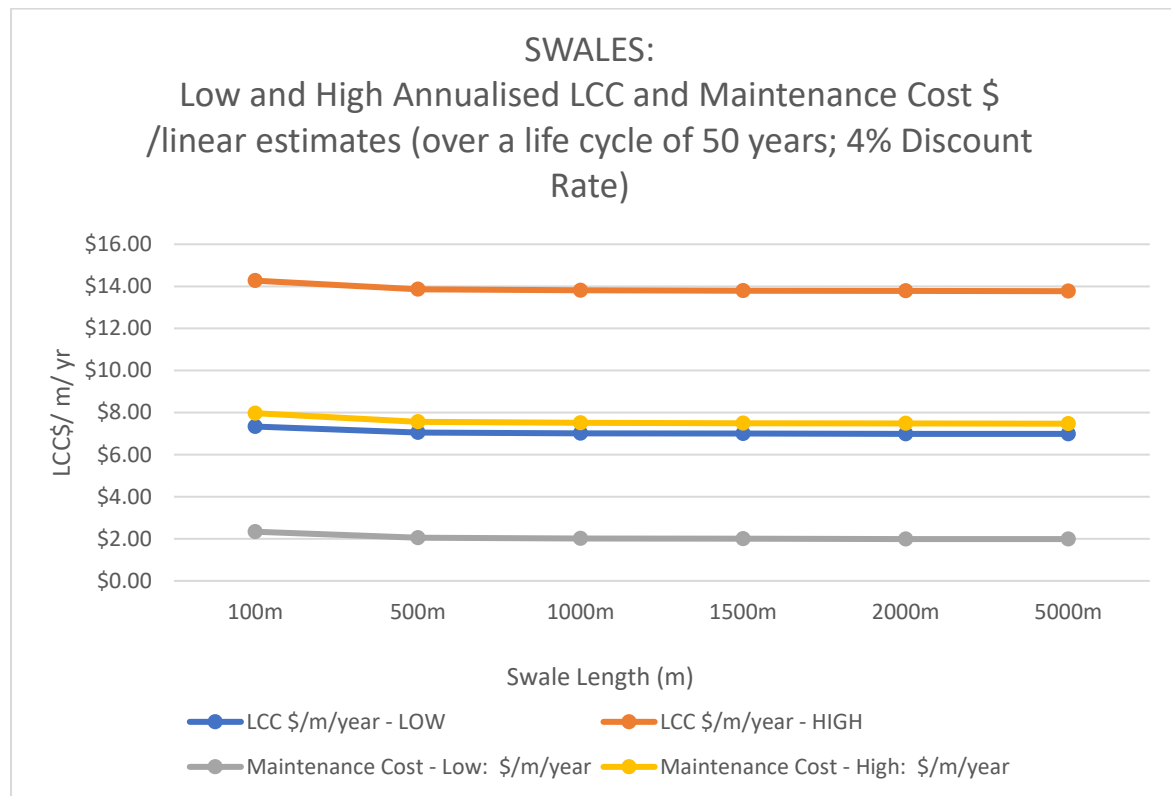


Figure 6 Swale maintenance costs compared with the LCC estimate

Green roofs

Just over half of the LCC of green roofs equates to maintenance, i.e. approximately 55% - 60% for the low LCC estimate and, on average, 65% for the high LCC estimate relates to maintenance activities on green roofs.

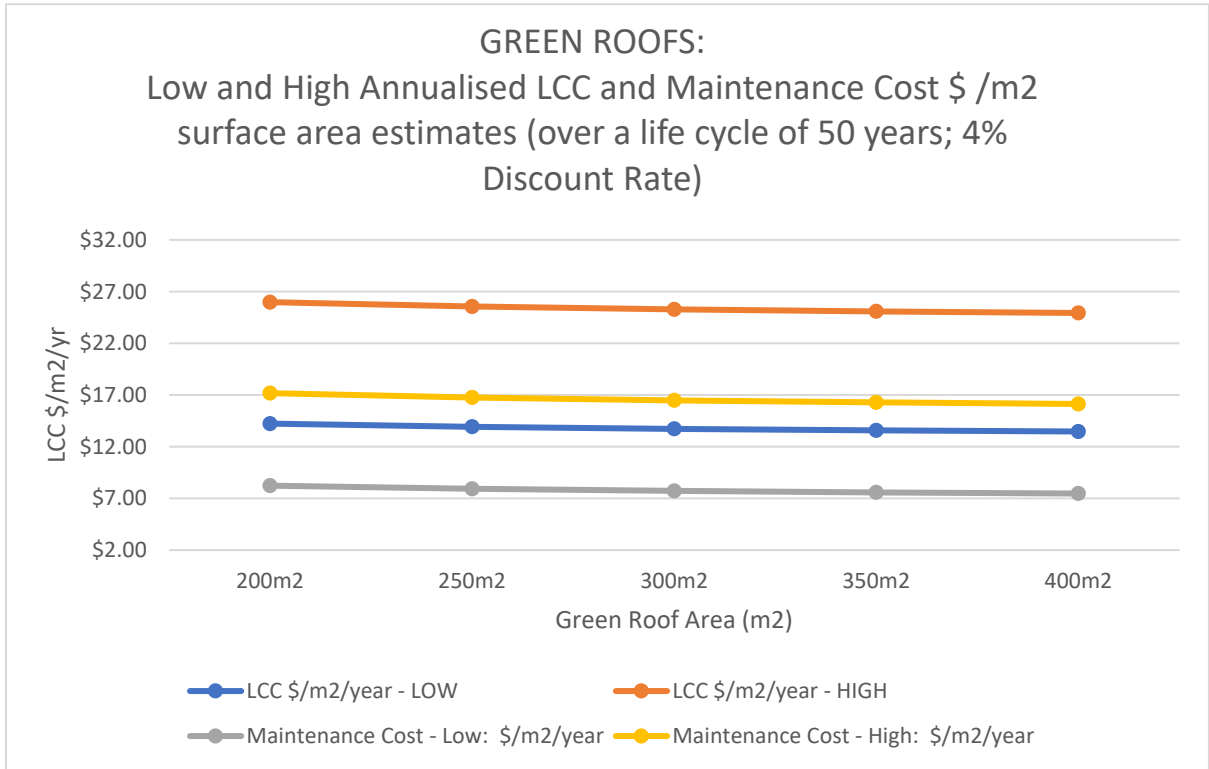


Figure 7 Green roof maintenance costs compared with the LCC estimate

Appendix F – Memo on updated rain garden LCC model assumptions and results for use in sustain



Memo

- Catchment Management
- Environmental Planning
- Training
- Resource Consents

To: Tom Stephens
Cc:
From: Sue Ira
Date: 19 August 2021
Re: FWMT Rain Garden Life Cycle Costs - Revision

Dear Tom,

I trust you are keeping well.

As you are aware, I continually strive to update my stormwater cost and maintenance information and integrate any new data/ information I receive into my LCC models. Much of our research into costs of stormwater treatment, especially around maintenance, is unprecedented in New Zealand, and we are learning more about green infrastructure maintenance requirements on a regular basis.

Over the last few months Robyn Simcock and I have been involved in various projects on rain gardens, and have also witnessed the effects of maintenance and maintenance activities on rain gardens. It has since become apparent to us that some of our routine maintenance frequencies that we recommended via the Activating WSUD in NZ research programme should be reduced and our recommendations amended. As you are aware, we used the Activating WSUD in NZ recommended maintenance frequencies for the AC FWMT LCC models. Given the focus of SUSTAIN in terms of optimizing based on cost, I feel that it is important that the AC FWMT LCCs are based on the best available and most recent information. I have therefore updated the Rain Garden LCC model template and re-run the rain garden LCC models for those rain garden sizes needed in SUSTAIN.

The purpose of this memo is to document the changes I have made to the rain garden model assumptions, rationale behind the changes, how the changes effect our original cost estimates and recommended new LCC indicative estimates.

RAIN GARDEN LCC MODEL CHANGES

The changes to the rain garden LCC model affect the maintenance costs. The total acquisition costs (TAC) remain unchanged. The new model recommends a high level of maintenance during the first 3 years of the rain garden's life, following construction, otherwise known as "establishment maintenance". Thereafter, routine maintenance visits can be reduced. Our original model, on the other hand, had a set number of maintenance visits throughout the life of the rain garden (see the comparisons in the Table 1 and 2).

Table 1 Original rain garden maintenance frequency and cost assumptions (Table 4-14 of the “Part 1 Urban Devices” cost report).

Routine Maintenance	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Routine Landscape Maintenance:				
Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.	9	m ²	\$0.50	\$1.30
It includes up to 5% replanting or re-mulching (especially at inlets and edges).				
It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity.				
Functional Drainage Maintenance:	12	per RG	\$120	\$175
Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.				
Flush out drainage.				
Traffic Control Costs:	9	m ²	\$1.00	\$3.20
TMPs and traffic lane closure (static or mobile works)				
Minor repairs:	1	per RG	\$120	\$175
Repairs to grills on outlets/ inlets; additional soil/ mulch needed; erosion				
Make good following vandalism:	2	per RG	\$120	\$175
Relates to primarily vegetation and graffiti removal				

Additional RMC	Frequency (Per Yr)	Unit	2018 Costs	
			Low	High
Initial aftercare of plants (first 3 years)	4	m ²	\$1.20	\$3.48
Initial aftercare of tree pits (first 3 years)				
Checking stakes/supports and then their removal where required	3	m ²	\$0.75	\$1.00
May need fertilisation in sandy and large rain gardens in clean catchments (note: if high-fertility-requiring trees less than 4 m tall are planted, then double to twice per year, using slow-release fertilisers/ organic mulch amended with compost)	1	m ²	\$0.75	\$1.00
24 monthly pruning for first 6 years to develop healthy structural form and lift canopy to required sight lines	1	m ²	\$1.00	\$1.40

Corrective Maintenance	Frequency (No. of Yrs)	Unit	2018 Costs	
			Low	High
Additional mitigative actions: - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Additional trimming of vegetation around signs or lights (services and signage should not be placed in raingardens). - Removing dead vegetation due to ponding because of incorrect rain garden mix or poor outlet design.	5	m ²	\$2.60	\$6.00
Fixing erosion of outlets due to poor slope control or undersized rain gardens.	5	m ²	\$0.50	\$0.75
TMPs and traffic lane closure (static or mobile works)	5	m ²	\$1.00	\$3.20
Infiltration Testing (if needed)	4	per test	\$100	\$520
Removal & disposal of sediments (including replacement with new media) + cartage	50	m ³	\$55	\$147
Complete replanting	50	m ²	\$1.50	\$7.20
Major maintenance of drainage system, e.g. replacement of parts	15	per RG	\$1,200	\$3,900

Table 2 New rain garden maintenance cost and frequency assumptions (recommended for future use – changes in red)

Establishment Maintenance	Frequency (Per Yr)	Unit
Initial aftercare of plants (first 3 years)	4	m ²
Initial aftercare of tree pits (first 3 years) Checking stakes/supports and then their removal where required	3	m ²
May need fertilisation in sandy and large rain gardens in clean catchments (note: if high-fertility-requiring trees less than 4 m tall are planted, then double to twice per year, using slow-release fertilisers/ organic mulch amended with compost)	1	m ²
24 monthly pruning for first 6 years to develop healthy structural form and lift canopy to required sight lines	1	m ²
Routine Landscape Maintenance:		

Establishment Maintenance	Frequency (Per Yr)	Unit
<p>Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.</p> <p>It includes up to 5% replanting or remulching (especially at inlets and edges).</p> <p>It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity.</p>	4	m ²
<p>Functional Drainage Maintenance:</p> <p>Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.</p> <p>Flush out drainage.</p>	4	per RG
<p>Traffic Control Costs:</p> <p>TMPs and traffic lane closure (static or mobile works)</p>	8	m ²
<p>Unstabilised Sites:</p> <p>Removal & disposal of sediments (including replacement with new media) + cartage - top 10mm of rain garden media</p>	1	m ³

Ongoing Annual Routine Maintenance	Frequency (Per Yr)	Unit
<p>Routine Landscape Maintenance:</p> <p>Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.</p> <p>It includes up to 5% replanting or remulching (especially at inlets and edges).</p> <p>It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity.</p>	3	m ²
<p>Functional Drainage Maintenance:</p> <p>Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.</p> <p>Flush out drainage.</p>	3	per RG
<p>Traffic Control Costs:</p> <p>TMPs and traffic lane closure (static or mobile works)</p>	3	m ²
<p>Minor repairs:</p> <p>Repairs to grills on outlets/ inlets; additional soil/ mulch needed; erosion</p>	1	per RG
<p>Make good following vandalism:</p>	2	per RG

Ongoing Annual Routine Maintenance	Frequency (Per Yr)	Unit
Relates to primarily vegetation and graffiti removal		
Other activities (please specify):	1	
Other activities (please specify):	1	

Long Term Corrective Maintenance	Frequency (No. of Yrs)	Unit
Additional mitigative actions: - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. - Additional trimming of vegetation around signs or lights (services and signage should not be placed in raingardens). - Removing dead vegetation due to ponding because of incorrect rain garden mix or poor outlet design.	5	m ²
Fixing erosion of outlets due to poor slope control or undersized rain gardens.	5	m ²
Removal & disposal of sediments (including replacement with new media) + cartage - top 10mm of rain garden media	5	m ³
TMPs and traffic lane closure (static or mobile works)	5	m ²
Infiltration Testing (if needed)	4	per test
Removal & disposal of sediments (including replacement with new media) + cartage	50	m ³
Complete replanting	50	m ²
Major maintenance of drainage system, e.g. replacement of parts	15	per RG
Other activities (please specify):	1	
Other activities (please specify):	1	

In summary, a new “establishment maintenance” table has been created in order to replace the “additional maintenance” needed for the first 3 years. The establishment maintenance activities and frequencies are needed to ensure that plants are able to successfully establish during the first 2-3 growing seasons, and that any excess sediment is removed.

After 3 years, it is expected that the number of maintenance visits can be reduced to 3 per year (ideally 2 of those would be routine maintenance inspections/ weeding/ plant care, and 1 additional inspection allowed for post storm maintenance). Our original model allowed for 9 maintenance visits throughout the life of the device. We now consider this to be excessive, assuming that the correct establishment maintenance has been undertaken.

Finally, we have allowed for a clean out of the top 10mm of sediments within the rain gardens every 5 years under corrective maintenance.

No changes were made to the unit costs themselves, only the frequencies and activities have been amended.

RATIONALE FOR THE CHANGES

Recent site visits to rain gardens, discussions with practitioners and viewing of maintenance activities have led us to review the frequency of routine maintenance inspections as recommended via the Activating WSUD in NZ research. The rationale behind changing the recommended maintenance frequencies are fourfold:

1. Previously we had recommended a standard number of maintenance visits throughout the life of the device (9 – 12 visits). Assuming the rain garden has been designed and constructed correctly, and significant effort placed in establishing the rain garden and protecting it from on-site sediment within the first 2-3 growing seasons, then the number of ongoing maintenance visits could be reduced to 3 times per year. This approach is more sustainable in the long term and could lead to less disturbance of the rain garden vegetation (which could then compromise its function) – see point 3 below.
2. Following on from point 1, the focus of rain garden maintenance should be during the establishment phase. Ensuring the plants are well cared for (watering/ pruning), and weeds and other undesirable plants minimised, the rain garden plants would be allowed to establish and flourish. Many of the bespoke rain gardens contain very little or completely inappropriate mulch, and thus the success of the rain garden relies on establishing a dense plant cover (without blocking the inlets and outlets). Once the plants have established, reduced care is needed.
3. Reducing the maintenance visits is more realistic and fits better within Council budgetary constraints. Additionally, it reduces stress (and therefore die-off) of plants as a result of poor or incorrect maintenance which is undertaken on a frequent basis. We have seen a number of rain gardens within the Auckland Region where the plants have died as a result of maintenance being done – this needs to be minimised as the cost to Council for replanting these devices is going to be significant and it leads to a very poor public perception of green infrastructure.
4. The establishment maintenance needs to account for an initial clean out of sediment from unstabilised sites. Many rain gardens are constructed and commissioned while the wider catchment area is still unstabilised and building sites open. Costs of an initial clean out needs to be included in the model.

IMPLICATIONS OF THE CHANGES – NEW COST RESULTS

Changing the routine maintenance frequencies significantly reduces the life cycle cost of small rain gardens and slightly increases the LCC of larger rain gardens. This is not unexpected since approximately 65% - 75% of the total LCC relates to maintenance. The increase in cost of the larger rain gardens (by, on average \$3 - \$5 LCC\$/m²/yr) is likely due to the new maintenance activity relating to cleaning out the top 10mm of sediment during the establishment phase.

The overall trend and inverse relationship between device size and LCC remains the same. The new average LCC \$/m² rain garden surface area/ year, for the 4% discount rate, in comparison with the original costs, are shown in Figure 1. Table 3 summarises the new cost outputs which can be used in SUSTAIN.

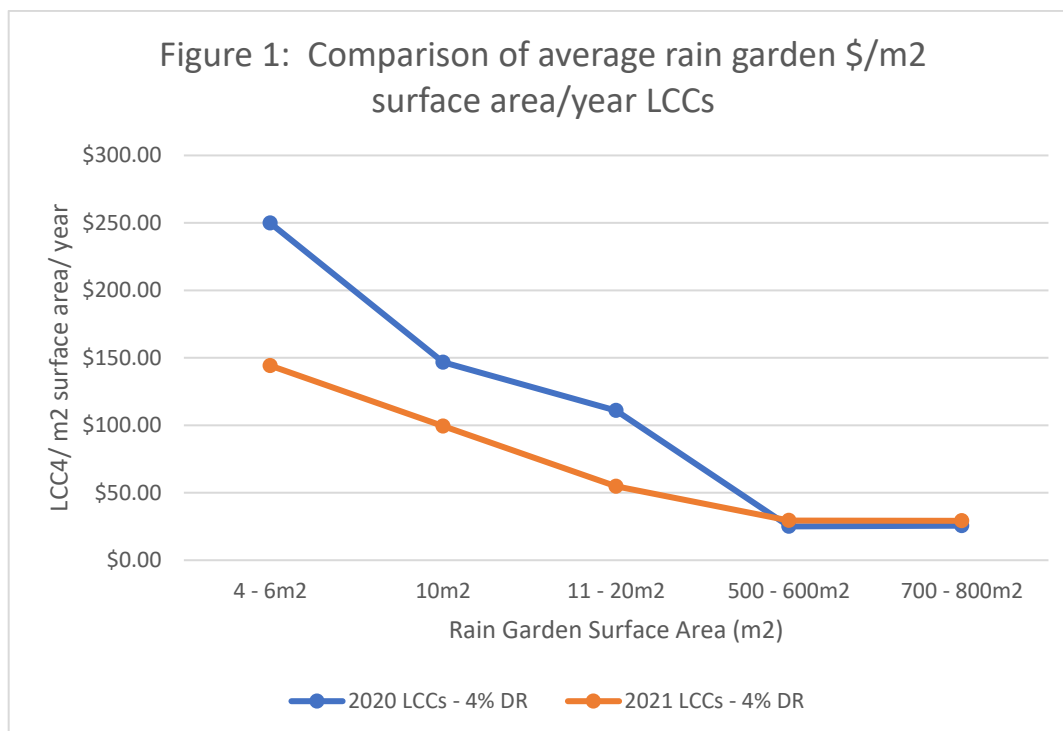


Table 3 Updated Rain Garden LCC \$/m²/year – recommended for use in SUSTAIN

RAIN GARDENS/ TREE PITS (LCC\$/m ² /yr)	2% Discount Rate	4% Discount Rate	6% Discount Rate
Green Street (new dev) rain garden: 4 - 6m ²	\$201.15	\$144.20	\$112.66
Green Street (retrofit) rain garden: 4 - 6m ²	\$201.15	\$144.20	\$112.66
Lot rain garden: 10 m ²	\$134.31	\$99.36	\$80.50
Lot rain garden: 11 - 20 m ²	\$75.30	\$54.77	\$43.19
Sub-catchment rain garden: 500 - 600m ²	\$37.54	\$29.43	\$25.02
Sub-catchment rain garden: 700 - 800m ²	\$37.21	\$29.21	\$24.86

I trust that this memo has clearly outlined the changes which I have made to the rain garden and tree pit LCC model, and has explained our rationale for doing so along with the updated recommended costs. I have also sent you an updated version of the Rain Garden LCC model template for AC Healthy Waters to use.

Please do not hesitate to contact me if you'd like to discuss any of these changes in further detail, or would like further information.

With best wishes,

Sue Ira

Find out more: fwmt@aucklandcouncil.govt.nz

