Understanding Costs and Maintenance of WSUD in New Zealand

Activating WSUD for Healthy Resilient Communities

Activating WSUD Aotearoa NZ

Manaaki Whenua Landcare Research

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National Science Challenges

BUILDING BETTER HOMES, TOWNS AND CITIES

Ko Ngā wā Kainga hei whakamāhorahora

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Activating WSUD for Healthy Resilient Communities

Funded by the Building Better Homes, Towns and Cities National Science Challenge

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July 2019

Cover: Green infrastructure (from top left): Christchurch raingarden, Auckland no-mow swales planted in native rushes, and Stoke mown swale with large trees

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Disclaimer:

The cost information used in this report has been collated from various councils, contractors and consultants around New Zealand and the cost models are based on the best available cost information at the time of writing this report. However, cost information is notoriously variable, and while every effort has been made to ensure the consistency and integrity of the data collected, reliance should not be placed on the actual costing figures. Decision-makers should rather use the costing information to understand the potential relative difference between the different green infrastructure solutions.

Executive Summary

WSUD has been offered as a solution to addressing the effects of stormwater discharges. However, a key impediment to implementation has been the perception that WSUD costs more to implement both in the short term (i.e. construction and development costs), and long term (i.e. high expenditure on operation and maintenance).

While WSUD has been used in New Zealand for at least 15 years, implementation of green infrastructure associated with WSUD is not yet mainstream in New Zealand. The drivers for wide-spread implementation of WSUD in New Zealand have been relatively weak until the recent development of the National Policy Statement for Freshwater Management (NPS-FM). As WSUD becomes the ‘new normal’ in New Zealand, so costs associated with green infrastructure will likely start to decrease as a result of increased demand and economies of scale of implementation.

One of the most frequently cited concerns about WSUD is the perception that it leads to an increased cost to councils and developers for stormwater management as, in general, the first examples of green infrastructure in an area typically have greatly inflated costs. However, these demonstration sites are important as they reduce the risk and allow experience to be developed through design/planning, construction and maintenance.

In this report we explore the key drivers and misconceptions around cost and maintenance as a barrier to implementing green infrastructure, and investigate the issue of who will bear this cost burden. The importance of understanding and quantifying avoided costs and cost efficiency as part of the overall decision-making process is introduced.

An international literature review was undertaken to obtain a better understanding of the cost differential between WSUD and traditional approaches to stormwater management, costs associated with WSUD, and issues surrounding maintenance of green infrastructure. The following individual WUSD approaches and green infrastructure devices are covered in the report:

- Minimising site disturbances
- Reducing impervious areas and associated piped infrastructure through streetscape design and clustering
- Creating or enhancing natural areas
- Water reuse/rain tanks
- Using green infrastructure, e.g. rain gardens, swales and filter strips, green roofs
- Using infiltration trenches to reduce runoff volumes

In addition to the literature review, a request was made to local and regional authorities, consultants, developers, and contractors for construction and maintenance cost information. The new cost information collected was then factored into existing cost databases. Based on the data received, total acquisition costs, maintenance costs, and life cycle costs were generated for a range of green infrastructure practices.

Summary tables of the likely maintenance activities, frequency of those activities and costs for the different green infrastructure practices are included in the report. The list of maintenance activities provided in the tables is not exhaustive, but rather is designed to cover key types of maintenance that is needed to ensure the functionality of the devices. A novel approach to understanding costs associated with the level of maintenance is introduced as three different maintenance models (amenity, functional, and bare minimum) are presented. This approach acknowledges that the two key drivers of maintenance costs are the frequency of the maintenance and the unit cost of the activity. The optimum level of maintenance (both from a maintenance cost and treatment

perspective) is the ‘functional’ model. This report also reviews advice on landscaping and vegetation practices that generate ‘Zero Additional Cost’, i.e. no increase in cost over and above costs of maintaining common, conventional streets and/or landscapes.

As part of the research, maintenance factsheets have been developed and are available on the project website at: https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design. These factsheets provide a summary of the key factors which influence maintenance costs along with tips for on-going maintenance. Checklists that can be used to undertake maintenance inspections have also been developed and are available on the same website.

Overall, this component of the Activating WSUD in NZ research funding has delivered a comprehensive investigation into the full life cycle costs of WSUD and has provided guidance on maintenance-led design and construction that impact maintenance costs. Additionally, the research funding has allowed for a series of costing and maintenance tools to be developed for use by stormwater professionals within New Zealand.

1. Introduction

1.1 Background

The Building Better Homes Towns and Cities (BBHTC) National Science Challenge is funding the 'Activating Water Sensitive Urban Design (WSUD) for healthy, resilient communities' research project. The project aims to deliver research and enhance capability to address critical current barriers to the uptake of WSUD in New Zealand.

WSUD is an alternative to conventional forms of urban development. It aims to integrate urban planning and water management in order to better manage, for example, water supply security, water quality in natural waterbodies, flood risk and amenity values of waterbodies.[1,2] While different jurisdictions place emphasis on different aspects of WSUD,[3] the following concepts are particularly evident in a New Zealand 'understanding' of what WSUD comprises:[4]

- minimising impervious areas: WSUD aims to limit stormwater runoff and contaminant generation at source by minimising the construction of impervious surfaces, such as roads and roofs through urban design techniques such as clustering and innovative streetscapes.
- minimising site disturbances: WSUD aims to limit earthwork volumes and extent through careful urban design which complements the existing landscape.
- creating or enhancing natural areas: WSUD aims to protect and enhance or recreate natural vegetated areas as well maintaining the functioning of natural drainage systems, rather than replacing stream networks with piped systems.
- use of green infrastructure: WSUD uses green technologies (wetlands, swales, rain gardens, green roofs, infiltration) to better manage stormwater in a way that complements its approach to land use planning and delivers benefits over and above stormwater.[5]

In New Zealand, WSUD clearly has a strong focus on management of stormwater and receiving water bodies. While consideration of its potential role in the water supply and wastewater sectors and in relation to wider (including non-water) contributions to urban liveability have received little attention, a future-focused approach recognises these other opportunities and areas of impact. For instance, a WSUD approach can mean providing an alternative water supply to enhance drought resilience. It can also mean contributing to urban amenity and community health through WSUD providing multi-functional green

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[1] Mouritz, M., M. Evangelisti, and T. McAlister. 2006. Water sensitive urban design. In: T. Wong, ed., Australian Runoff Quality. Engineers Australia, Sydney, Australia, pp. 5-1–5-22.

[2] Hoyer, J., W. Dickhaut, L. Kronawitter, and B. Weber. 2011 Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future. Jovis, Berlin, Germany. 144 p.

[3] Fletcher, T., W. Shuster, W. Hunt, R. Ashley, D. Butler, S. Arthur, S. Trowsdale, S. Barraud, A. Semadeni-Davies, J.-L. Bertrand-Krajewski, P. Mikkelsen, G. Rivard, M. Uhl, D. Dagenais, and V. Viklander. 2014. SUDS, LID, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage. Urban Water Journal 12(7): 525–542.

[4] For instance, in Auckland – see Lewis, M., J. James, E. Shaver, S. Blackbourn, A. Leahy, R. Seyb, R. Simcock, P. Wihongi, E. Sides, and C. Coste. 2015. Water Sensitive Design for Stormwater, Auckland Council Guideline Document GD2015/004. Auckland Council, Auckland, New Zealand.193 p.

[5] Moores, J. and Batstone, C. 2019. Assessing the Full Benefits of WSUD. Research report to the Building Better Homes, Towns and Cities National Science Challenge and 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

spaces to recreate and seek shade. While acknowledging the current stormwater focus of WSUD in New Zealand practice, this research considers it important to recognise that a truly WSUD approach can include some or all of these wider potential role(s).

1.2 Project overview

There are three phases to the project. Phase 1 is now complete and was the discovery phase, involving engagement with WSUD's community of practice to determine the project's subsequent research priorities.[6] Figure 1-1 highlights the areas of research as determined in Phase 1.

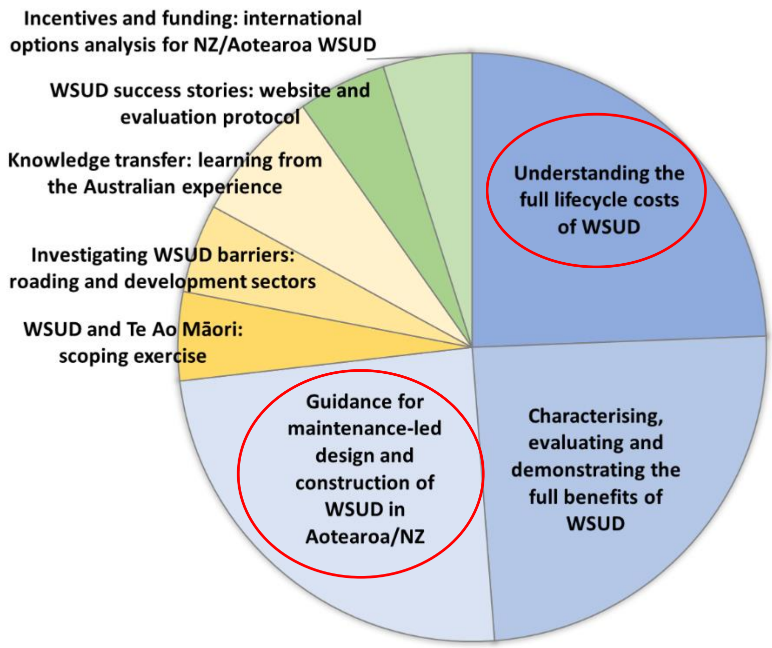

Figure 1-1 Activating WSUD in NZ Phase 1 research recommendations.[6]

The **purpose of this report** is to describe the research and findings undertaken to better understand the full life cycle costs of WSUD, along with potential future research needed to fill key gaps. Additionally, it includes guidance for operations-led design and construction that impact maintenance costs, focusing on actions that result in 'Zero Additional Cost' or no inflation of costs over and above costs of maintaining common conventional landscapes.

In Phase 3 of the project, the research team will disseminate research findings from the 'quick win' activities as well as delivering a co-designed and prioritised longer-term plan for the continued delivery and implementation of WSUD research, beyond the life of this project.

1.3 Understanding the costs and maintenance of WSUD – scope and risks

Based on priorities, barriers and issues raised during the discovery phase, the scope of the research into costs has been carefully defined as follows:

[6] Moores, J., Batstone, C., Simcock, R. and Ira, S. 2018. Activating WSUD for Healthy Resilient Communities – Discovery Phase: Results and Recommendations – Final Report.

- update and amend the COSTnz maintenance cost data protocols where possible based on new maintenance cost information collected through this project;
- update estimates around the total acquisition costs of green infrastructure as a result of new cost information collected through this project;
- define the avoided costs of land development as a result of a WSUD approach;
- update previous LCC modelling work and provide LCC estimates for green infrastructure where possible, taking account of all of the above;
- model costs of green infrastructure and avoided costs through a series of selected case studies; and
- integrate the cost research with the findings of the maintenance-led design project and complementary research into assessing the benefits of WSUD.

The cost data research has focussed on rain gardens, swales, wetlands, permeable paving, rain tanks, and green roofs. Understanding the costs of source control of metals generated from building materials and cars is outside the scope of the project.

A number of risks were identified in the initial scope which had the potential to affect the outcomes of the project. These include:

- scant new cost data (especially maintenance costs) are available in a usable and comparable form;
- the financial sensitivity of cost information could mean there is an unwillingness by people/companies to provide cost information;
- time delays due to a protracted data collection process; and
- budgetary constraints could limit the ability to create comparable traditional and WSUD case studies for costing purposes.

Despite these risks, new cost information was collected, along with information on maintenance activities and frequencies.

The scope of the maintenance-led design work has focussed on functional and maintenance cost-related aspects of green infrastructure design that lead to escalating maintenance costs over time. The research has also focussed on learnings from on-the-ground case studies, existing literature and maintenance guidelines.

1.4 Report content

Section 2 summarises the different type of cost quantification methods which have been used in the literature to better understand costs of WSUD. It also describes the key cost drivers in New Zealand and current cost misconceptions.

Section 3 of the report updates previous international literature reviews on costs and maintenance of WSUD and provides a summary of current cost considerations internationally.

Section 4 of the report sets out the results of the cost data collection process for total acquisition, maintenance and avoided costs, and provides updated COSTnz spreadsheets.

Section 5 describes principles and methods to achieve Zero Additional Maintenance costs and to avoid inflated maintenance costs.

Section 6 outlines the results from the case studies.

Section 7 concludes the report with a summary of key learnings and potential future research.

2. Understanding and determining cost

2.1 Introduction

Councils across New Zealand are currently facing significant stormwater problems related to the growth, development, and redevelopment of urban centres. These include issues such as:

- increased flooding, which causes problems for property owners as well as infrastructure, especially where 'downstream' capacity to manage increased impervious surfaces is limited, e.g. Stoke, Nelson, central Auckland, Dunedin South.
- 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.
- costs associated with long-term maintenance of constructed stormwater practices built to mitigate the abovementioned effects, especially as stormwater ponds reach the end of their lives.

WSUD has been offered up as a solution to address the effects of stormwater discharges. However, a key impediment to implementation has been the perception that WSUD costs more to implement both in the short term (i.e. construction and development costs), and long term (i.e. operating and maintenance costs). This section clarifies local (New Zealand) perceptions about cost.

Cost estimation plays a key role in all development activities. For developers, the bottom-line reality of cost usually outweighs marginally increasing environmental improvements gained from using alternative technologies. This is particularly true, if those alternative technologies result in slower consent processing or reduce perceived competitiveness of sales, through, for example, requiring covenants for device maintenance. For councils, the cost burden of long term maintenance of stormwater infrastructure is at the forefront of their minds throughout the regulatory process.[7] Maintenance adds to the bottom line of rates, and rate increases are usually politically sensitive.[8]

Despite the importance of cost as a tool in the decision-making process, until recently there has been scant research undertaken in New Zealand on quantifying long term costs of alternative forms of development such as WSUD. The following sections describe some of the challenges of quantifying WSUD costs before summarising approaches adopted in the international literature for assessing the economics of WSUD. These include:

- life cycle cost analysis
- cost comparisons
- cost-benefit analysis.[9]

[7] Moores, J., Batstone, C., Simcock, R. and Ira, S. 2018. Activating WSUD for Healthy Resilient Communities – Discovery Phase: Results and Recommendations. Research report to the Building Better Homes, Towns and Cities National Science Challenge.

[8] However, Aucklanders overwhelmingly voted to pay both additional 'stormwater/water quality rate' and biodiversity rates in 2018 to improve both environmental outcomes in both areas.

[9] North Carolina State University. Undated. Low Impact Development – an Economic Factsheet.

2.2 Challenges for quantifying the costs of WSUD

Understanding the costs of WSUD presents a challenge for researchers, practitioners and decision-makers alike. Some of these challenges include:

- WSUD incorporates a range of approaches for managing stormwater discharges which are dependent on the characteristics of the development and climate, thus it is exceptionally difficult to estimate cost on a generic basis.
- WSUD focusses on treating contaminants and reducing the volume of stormwater 'at source'. As a result, a large number of the 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.
- WSUD practices are relatively new, and thus cost data relating to long-term operation and maintenance are scanty.
- In well-designed developments, WSUD is integrated with landscaping as part of design, construction, and especially maintenance. This reduces the additional costs of WSUD but can also make it difficult to extract cost information, for example, a swale that is mown at the same time as adjacent landscape, or leaves swept from all trees including those in WSUD.
- WSUD in public spaces are likely to be maintained under large, 'bulk' contracts that depend on the type of work and its location. For example, a council's parks department contractor may remove litter, mow, and weed, while a separate arborist contractor manages trees. The council's stormwater or roads department may employ an engineering contractor to sweep streets/pavements and empty catchpits. Green infrastructure practices may therefore fall between council departments, leading to lack of specific maintenance and/or maintenance by contractors with little knowledge of vegetation health. Not only is it challenging to quantify the cost when so many players are involved, but costs can also be inflated (see Section 4.4).

2.3 Life cycle costing analysis

A life cycle costing (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).[10] The Australian/New Zealand Standard 4536:199911 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 2-1). 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.[11,12]

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[10] Vesely, E-T., Arnold, G., Ira, S. and Krausse, M. 2006. *Costing of Stormwater Devices in the Auckland Region.* NZWWA Stormwater Conference.

[11] Australian/New Zealand Standard. 1999. Life Cycle Costing: An Application Guide, AS/NZ 4536:1999. Standards Australia, Homebush, NSW, Australia and Standards New Zealand, Wellington, NZ..

[12] Australian National Audit Office. 2001. Life Cycle Costing: Better Practice Guide. Canberra, Commonwealth of Australia.

LCC has a number of benefits and supports a number of applications and analyses:[13]

- 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; and
- LCC assists decision-makers understand the relative cost difference between two or more management options without the full-blown costs of detailed engineering assessments.

Life cycle costing 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 (Fig. 2-1).

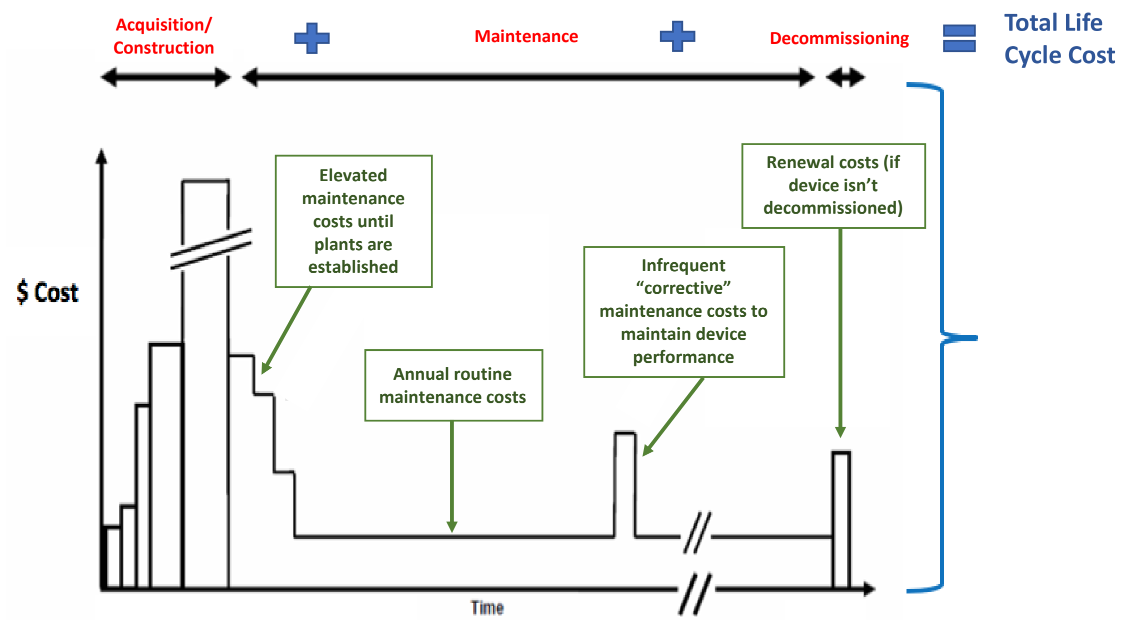

Figure 2-1 Phases in the life cycle of a stormwater practice and potentially associated costs.[14]

Decision-making on the use of low impact stormwater devices needs quality 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 operational costs which include design, construction, use, maintenance, and disposal. Life cycle costing can be used for structuring and analysing this financial information. However, while life cycle costing (LCC) is an important tool in understanding the costs associated with infrastructure development, it is only one parameter in the evaluation process,[14] and needs to be considered in the context of social, cultural, and environmental goals.

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[13] Lampe, L., Barrett, M., Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Hollon, M. 2005. Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems. WERF Report Number 01-CTS-21T.

[14] Adapted from Taylor, A. 2003. An Introduction to Life Cycle Costing Involving Structural Stormwater Quality Management Measures. Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria.

Life cycle costing can be done using either a statistical, or unit cost approach. A statistical approach is based on developing a statistically significant relationship between the size of a practice, and its acquisition and/or maintenance costs. Unit costing, however, involves identifying individual elements of the acquisition and maintenance phase, and costing them using average tender rates.[15]

A New Zealand example of life cycle costing is the development of the "COSTnz" a stormwater life cycle costing model developed under the Low Impact Urban Design and Development (LIUDD) project led by Landcare Research.[16] COSTnz is primarily based on unit costing but has been used to develop $/ha LCC graphs for different types of green infrastructure through the "Urban Planning that Sustains Waterbodies" (UPSW) project undertaken by NIWA and the Cawthron Institute.[17]

2.4 Cost comparisons

A different way of quantifying costs, which can be complementary to LCC, is to undertake cost comparisons of conventional developments, and compare these with costs associated with WSUD developments. There have been a number of these types of studies done both here in New Zealand as well as in the United States, and some of the results of these studies are presented in Section 3. A limitation of these studies is that the comparisons tend to focus solely on differences in construction and design related costs. The types of costs quantified during these analyses include:

- clearing and earthworks
- impervious area construction (e.g. concrete works, pavement and road construction, kerbing)
- stormwater drainage and reticulation
- sanitary sewers, and
- water reticulation

These costs are generally compared for the conventional and alternative site designs and assessed to determine whether or not there are 'avoided costs'.

2.5 Cost-benefit analyses

A cost-benefit analysis considers not only the full range of costs associated with undertaking life cycle costing, but also considers the economic benefits of a project. The analysis is more complex and time consuming than life cycle costing, but it does assist in highlighting that there are occasions where the economic benefits of undertaking WSUD projects can outweigh any additional expected costs.[9].

Environmental goods and services (e.g. clean air, good water quality, healthy fish, etc) are not easily measured in monetary terms as they are not 'tradable' commodities. As a result, it becomes increasingly more difficult to attempt to quantify their value to a community, or

[15] Ira, S. J. T., Vesely, E-T., Krausse, M. 2008. Life Cycle Costing of Stormwater Treatment: A Practical Approach for New Zealand. Proceedings of the 11th International Conference on Urban Drainage. Edinburgh, Scotland.

[16] Ira, S. J. T., Vesely, E-T., McDowell, C and Krausse, M. 2009. COSTnz – A Practical Life Cycle Costing Model for New Zealand. NZWWA Conference, Auckland.

[17] Ira, S.J.T., Batstone, C. and Moores, J. 2012. The incorporation of economic indicators within a spatial decision support system to evaluate the impacts of urban development on waterbodies in New Zealand. Seventh International Conference on Water Sensitive Urban Design Conference, Melbourne, Australia.

the loss of value resulting from degradation. The estimation of these values is called non-market valuation,[9] and is an important part of the cost-benefit analysis process. Ways of assessing the benefits of WSUD are the subject of a separate report within the Activating WSUD research project;[18] however, it is worth mentioning that negative economic impacts of conventional controls should also be quantified economically, otherwise management decisions will continue to be biased towards conventional controls.[19] The authors state:

> *Exclusive reliance on profitability and market value will favour the conventional approach to stormwater management by disregarding both the negative environmental externalities associated with this approach, and the positive environmental externalities associated with the low impact approach. Even when an attempt is made to include environmental benefits such as water savings, market distortions prevent the true manifestation of the associated impact. New Zealand costs and rates reflect the historically free treatment of water in this country….* (p. 12).

In many cities and towns within New Zealand, not only is potable water 'free' (i.e. included in general rates charges), but stormwater treatment is also 'free'. The widespread use of annual stormwater charges based on impervious surface areas in Europe and North America, with 'treebates' offsetting these in some cities (such as Portland, Oregon), is yet to be adopted in New Zealand. Their absence is a major disincentive to WSUD. The issue of alternative mechanisms for funding WSUD and incentives to encourage implementation in New Zealand has also been investigated and reported on by the research team.[20]

2.6. Cost drivers – the New Zealand context

While WSUD has been around for a number of years, implementation of green infrastructure associated with WSUD is not yet mainstream in New Zealand. In the USA and Europe, the huge cost of reducing overflows from combined stormwater and wastewater systems is a major driver for using green infrastructure to separate stormwater flows away from the wastewater network. In Australia, historic severe droughts have led to a nationally funded "Water Sensitive Cities" Cooperative Research Centre to research and integrate management of the 3 waters and transition Australia's cities into water sensitive cities. The drivers for wide-spread implementation of WSUD in New Zealand have been relatively weak until the recent introduction of the National Policy Statement for Freshwater Management (NPS-FM). The NPS-FM requires water quality targets to be set by regional and local councils to maintain or improve the water quality of New Zealand's freshwater, groundwater, and marine receiving environments. The requirements of the NPS-FM are unlikely to be met through the continued use of conventional piped business as usual (BAU) approaches. The costs of WSUD should therefore be compared with improved hard engineering approaches to meeting the newly set NPS-FM standards which means delivering to a standard that avoids, remedies or mitigates the effect of urban contaminants on our receiving water bodies and the effect of increased stormwater flows and volumes on public and private infrastructure.

[18] Moores, J and Batstone, C. 2019. Assessing the Full Benefits of WSUD.

[19] Vesely, E.-T., J. Heijs, C. Stumbles, and D. Kettle. 2005. The Economics of Low Impact Stormwater Management in Practice – Glencourt Place. NZWWA Conference. Auckland, New Zealand.

[20] Ira, S. and Batstone, C. 2019. An Investigation of Alternative Funding and Incentive Mechanisms to Support the Implementation of WSUD.

If WSUD becomes the preferred method for meeting NPS-FM standards in New Zealand, so costs associated with green infrastructure will likely start to decrease as a result of increased demand and economies of scale of implementation. Typical cost influences of WSUD include:[21]

- drainage area (specifically the level of imperviousness)
- site conditions (primarily around slope/site topography, soils, underlying geology, groundwater levels, accessibility)
- material availability and transport
- project size (larger project areas can have lower costs per metre squared due to construction efficiencies/economies of scale), and
- stormwater management requirements for treatment, attenuation and volume control.

Anecdotal evidence reported in the Activating WSUD Discovery Phase suggests further factors influencing cost in New Zealand include: restrictive or out-of-date codes of practice that set requirements for road widths, building materials, and infrastructure layout; planning rules and a restrictive consenting process; poor design of green infrastructure leading to increased rehabilitation and maintenance costs; the type of land use; and perceived market demand for a particular house or building type.[22] This anecdotal evidence links to one of the most frequently cited concerns about WSUD – the perception that it leads to an increased cost to councils and developers for stormwater management.[23] This misconception can arise when practitioners focus their attention solely on the new types of stormwater mitigation devices which would need to be constructed to provide stormwater treatment. The silo approach of council budgets and developer goals means that the greater cost savings of reduced earthworks, and reduced impervious surfaces and pipes are often not taken into consideration. In addition, the costs of undertaking stormwater treatment are not weighed against the benefits that they provide, nor against the cost of environmental and flood remediation costs. Evidence gathered during the Activating WSUD workshops and research period identified five specific factors that can inflate costs of the first examples of green infrastructure in a new area:

- Risk aversion. A lack of local precedence and local experience increases actual and perceived risk. A response can be inflated design costs (e.g. requiring more research due to an absence of guidance or local specifications), construction costs (e.g. because materials must be imported or manufactured in small quantities), and maintenance costs, as contractors expect worse-case outcomes and/or require new, specific training. A small number of devices means maintenance cannot take advantage of economies of scale, or specialisation. Risk may be pushed onto the suppliers, or the developer.[24] Some councils reduced risk by building the first examples of WSUD themselves, e.g. Waitakere Civic Centre living roof by Waitakere City Council, Paul Matthews raingarden by North Shore City Council). Other agencies provided grants for private developments, e.g. Auckland Regional Council's green

[21] US Army Corps of Engineers. 2014. *Cost-estimation tool for low impact development stormwater best management practices*. Public works Technical Bulletin 200-1-135.
[22] Moores, J., Batstone, C., Simcock, R. and Ira, S. 2018. Activating WSUD for Healthy Resilient Communities – Discovery Phase: Results and Recommendations. Research report to the Building Better Homes, Towns and Cities National Science Challenge.
[23] Ira, S.J.T. 2019. Incentives and Funding: an international literature review and recommendations for New Zealand. Research report to the Building Better Homes, Towns and Cities National Science Challenge.
[24] See Kirimoko Case study

infrastucture grants under which Manaaki Whenua Landcare Research's GI, Auckland Netball's GI, and Housing New Zealand's Talbot Park's GI were constructed
- Over-engineered designs. For roadside GI, this takes the form of over-engineered edges/load bearing walls with lots of concrete, excessive/redundant water proofing/ membranes, redundant drainage and/or large erosion-control structures. For living roofs this can mean excessive structural support for light-weight (extensive) roofs, or parapets where unjustified
- Designs are over-specified, using standards taken from other countries or regions that are difficult for local producers to comply with (e.g. raingarden media particle size distribution requirements)
- Design and planning approval take longer because councils are also learning, are risk averse, and may request more meetings, more modelling or external peer review, and additional features (such as specific maintenance manuals)
- There are no local suppliers of suitable materials, so materials are 'imported' from long distances.

The factors that influence the cost of maintaining the most common WSUD features in New Zealand (swales, rain gardens, and wetlands) when compared with other landscaping include the following (which are illustrated in each of the case studies in Section 6):
- How cohesive and integrated maintenance of plants is across WSUD and adjacent landscaping. This is achieved by using plants with similar maintenance practices and frequencies
- Site stormwater and pollution pressures – open earthwork/ building sites vs stabilised sites with low potential for erosion and generation of sediment
- Inlet design – the most common cause of high maintenance is poor inlet design or construction combined with an abundance of things that block inlets. Blocked inlets prevent devices working and can lead to overloading of individual inlets and erosion/scour
- Initial establishment success and weed competition – adequacy of initial care and 'hardening off' plant materials. Plants should reach a high cover that can be sustained
- The size and location of bare areas at handover – these are places where weeds are most likely to establish.
- Device shape, depth and volume in relation to watershed – these influence how much stress the plants are under – narrow devices are highly vulnerable
- Edge design, treatment and selection relative to plant growth rates
- People and vehicle pressure – unless designs physically exclude people and vehicles, then areas with high pedestrian counts are more vulnerable to damage and littering, and need more maintenance to maintain aesthetics
- High sediment loads require more intensive maintenance to sustain performance – although this can be mitigated to some extent by using forebays to capture sediment (and/or increasing road sweeping and applying source control); areas near roundabouts near landscaping yards could be expected to have more spills of soils/mulch and compost; Paul Matthews rain garden received extreme sediment loads as it was located immediately downhill of an unsealed yard with many truck movements

- Aesthetic requirements – high aesthetics are usually linked with higher maintenance costs, but not always, and are not as high as beds that have annual plantings (no stormwater devices should have annual plantings, especially green roofs, as they cannot be sustained)
- Region and site growing environment – areas that use de-icing salts
- Skill of the maintenance people and their equipment – crews that only use weed whackers and spray generally deliver poorer quality outcomes – superior outcomes and reduced overall cost are linked with maintenance people who proactively assess and manage maintenance
- How much maintenance has occurred, and how often. Infrequent maintenance usually takes longer; weeds have been allowed to set, and this increases ongoing maintenance and requires renewals (new media, new mulches, new plantings)
- Tree cover – trees usually lower maintenance of groundcover underneath them, unless the trees have large deciduous leaves.

2.7 Understanding the urban development value chain – "Who Pays"?

A key question asked during costing analyses is "*who will pay?*". Traditional cost models do not take into account or provide information around implications for where the cost will fall within the urban development value chain. In other words, whether they are developer-related, public utility, private business or house-hold costs. Figure 2-2 graphically illustrates where different costs may lie within this urban development value chain. Ultimately, all costs are borne 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.

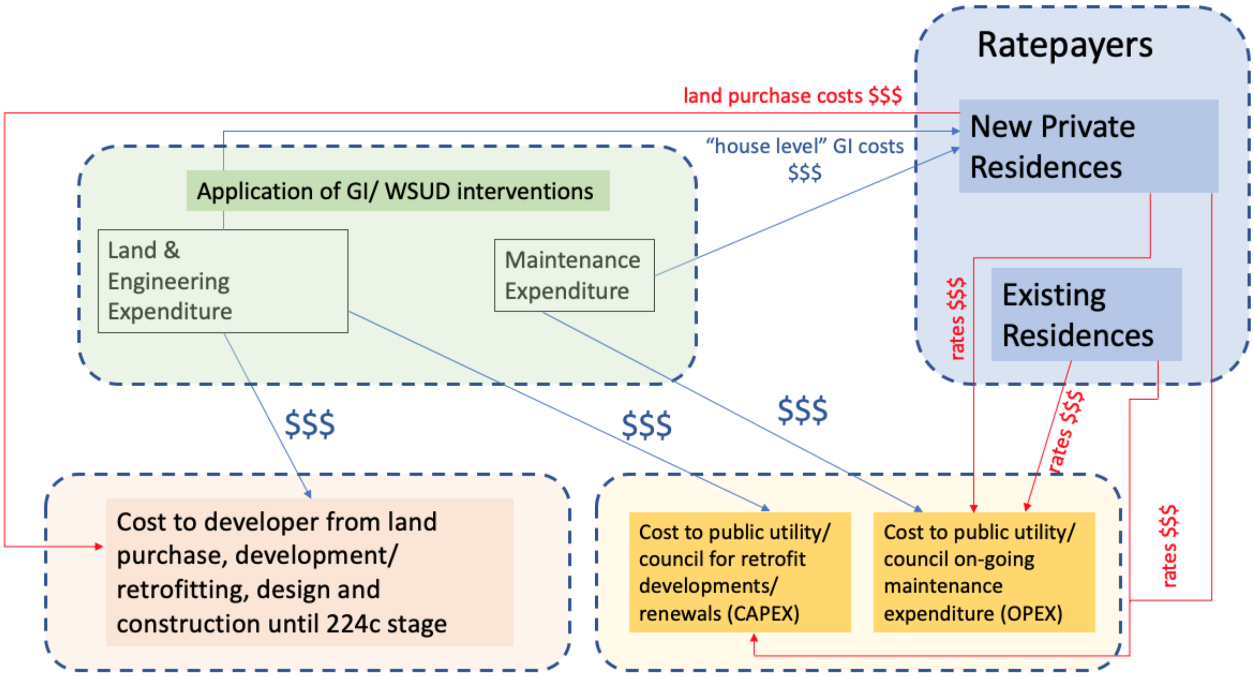

Figure 2-2 Understanding the urban development value chain and where costs fall along this continuum.

2.8 Synthesis – more fully considering costs

Much of the discussion around estimating costs in Section 2 has revolved around understanding construction and/ or maintenance costs. Decision-making financial models generally do not take into account the avoided costs of environmental remediation, flood remediation and property clean-up costs, and avoided project construction and landscaping costs. Nor do they assess projects or infrastructure delivery in terms of cost effectiveness indicators such as water quality, hydrological and habitat quality (aquatic and terrestrial) cost effectiveness, nor their effect on housing affordability or private development yield. In general, the short-term cost of delivering the project or infrastructure tends to be the singular most important decision-making criteria. The cost drivers highlighted in Section 2.6 need to be factored into financial models. Additionally, current models do not account for where costs fall within the urban development value chain (Section 2.7).

An alternative approach is needed to better understand economic efficiencies (avoided costs and cost efficiency) of WSUD solutions to challenge financial decision-making infrastructure models in New Zealand and overcome the focus on short-term cost. This alternative approach involves a broader consideration across a wide range of cost-related criteria discussed in the sections above. The scope of these criteria is presented in Figure 2-3. Figure 2-3 demonstrates that the WSUD cost drivers (e.g. soils, slopes, impervious area, planning rules) influence green infrastructure expenditure such as planning and consenting costs, construction costs, maintenance and land costs. Together, the drivers and expenditure lead to differing levels of environmental and project avoided costs, as well as influencing environmental and project cost effectiveness.

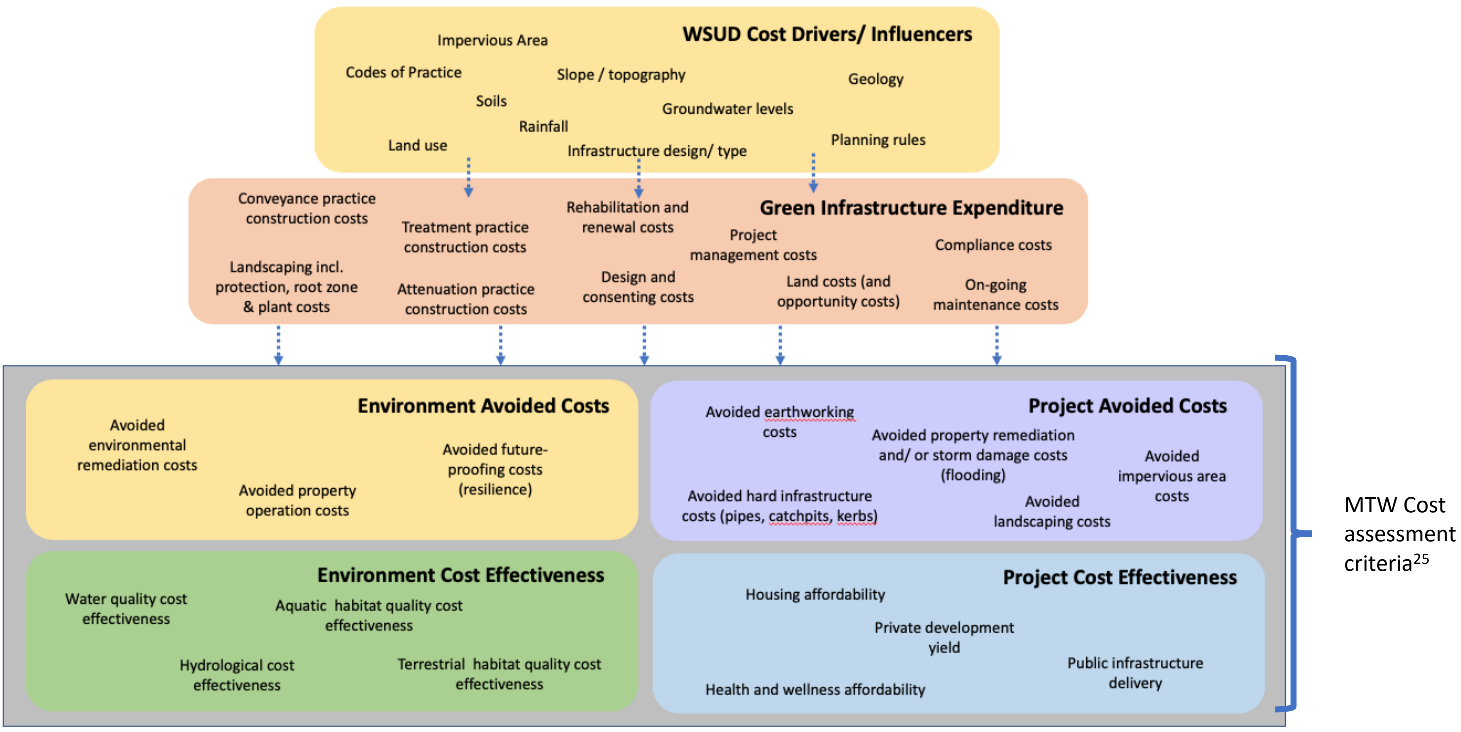

Figure 2-3 Synthesis of cost-related considerations for assessing WSUD projects, showing how drivers and expenditure influence cost efficiency and avoided costs.

In combination with the benefits workstream, the Activating WSUD team's research activities have demonstrated a need to provide a quick win' method by which practitioners can take account of the wider-ranging benefit and cost considerations that might otherwise be excluded from a business-case assessment of a WSUD project. The development of guidance for using MTW to assess costs also takes account the life cycle cost work described in Section 4 of this report. The Activating WSUD research team has addressed this need by developing the 'More Than Water' (MTW) assessment tool.[25] The name of the tool reflects the notion that WSUD and GI can deliver multiple co-benefits, many of which are unrelated to addressing the hydrological and water quality effects of urban development, which can lead to cost efficiencies and avoided costs both in the short and long term.

The tool provides for comparative assessments of WSUD and GI projects against conventional development approaches. It uses a qualitative assessment method that is easy to use and provides graphic demonstration of benefits and cost outcomes and how these might vary under different scenarios.

[25] Moores, J., Ira, S., Batstone, C. and Simcock, R. 2019. The "More Than Water" Assessment Tool. Available at: https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design

3. Costs and maintenance of WSUD approaches – an international literature review

3.1 Introduction

This section updates an earlier review on the cost differential between WSUD and traditional approaches to stormwater management.[26] It provides a summary of more recent literature and costs associated with WSUD, as well as expanding the review to include issues surrounding maintenance of green infrastructure.

The following individual WUSD approaches and green infrastructure devices are discussed:

- Minimising site disturbances
- Reducing impervious areas and associated piped infrastructure (through streetscape design and clustering)
- Creating or enhancing natural areas
- Water reuse/ rain tanks
- Using green infrastructure –
    - rain gardens
    - swales and filter strips
    - green roofs
- Using infiltration to reduce runoff volumes

3.2 Minimising site disturbances

By minimising site disturbances, developments are able to retain values of natural areas on the site (such as bush or wetland areas) that have important stormwater benefits in their own right. In addition, reducing the amount of earthworks needed on a site reduces potential sediment generation and delivery downstream. By reducing the amount of earthworks as well as clearing and grading, there will be reduced costs associated with the construction activity. Table 3-1 highlights that costs associated with excavating, carting and stock piling soils can be high, even more so if unsuitable materials need to be taken off site.

[26] Ira, S J T. 2014. Quantifying the cost differential between conventional and water sensitive design developments – a literature review. Report commissioned by the Cawthron Institute and NIWA for the Urban Planning that Sustains Waterbodies research project.

ACTIVITY	UNIT	LOW COST*	HIGH COST*
Earthworking - Clearing site	$/m² of total earthworks area	$0.30	$1.40
Earthworking - Strip topsoil	m²	$0.80	$5.20
Earthworking - Cut to fill	m³	$6.40	$12.50
Earthworking - Cut to waste	m³	$26.00	$94.00
Earthworking - Import fill to site	m³	$13.00	$65.00
Earthworking - Restablishment topsoil/grassing	m²	$1.00	$8.00
Earthworking - Sediment erosion control	$/m² of total earthworks area	$0.30	$1.40

*Base date of costs is 2016

Table 3-1 Average indicative cost estimates of earthworking activities (excluding labour costs) in New Zealand.[26]

There are also general day-works and labour costs involved in these operations that would further increase the cost. Therefore, if the amount of clearing and grading required is reduced, the cost of the construction process would be reduced. Further savings would be made as a result of the reduced need for sediment and erosion control on the site. The following savings for WSUD developments were reported in the literature:

- Based on 6 comparative case studies, a US study[27] reported cost savings relating to earthworking activities in the order of 10–60%.
- A NZ assessment[28] reported a 17–23% cost saving as a result of a WSUD during the construction/ development phase; 13% of the saving was attributed to reduced earthworking costs.
- A US study[29] found that WSUD saves 23–32% on site preparation (earthworking) costs.
- Auckland Council[30] compared 3 conventional and WSUD developments and reported savings in site preparation costs of 5–58%.

On average, WSUD can result in a significant cost saving on site preparation and earthworks costs of approximately 14–35%.

3.3 Reducing impervious area and associated piped infrastructure

Clustering of houses or businesses can significantly reduce the amount of impervious area and volume of earthworks on a site. The traditional type of site development seen in New

[27] USEPA. 2007. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. EPA 841-F-07-006

[28] Ira, S.J.T., Roa, A. and Carter, R. 2016. Understanding and determining the cost of long term maintenance and resilience of WSD. Paper for the 2016 NZ Water Conference

[29] Conservation Research Institute. 2005. Changing Cost Perceptions: An Analysis of Conservation Development. Report prepared for the Illinois Conservation Foundation and Chicago Wilderness.

[30] Shaver, E. 2009. Low Impact Design Versus Conventional Development: Literature Review of Developer-related Costs and Profit Margins. Prepared by Aqua Terra International for Auckland Regional Council. Auckland Regional Council Technical Report 2009/045.

Zealand to date encourages sprawl, while WSUD approaches encourage clustering of lots on a portion of the site in order to achieve the same overall density. Clustering allows for road lengths, house setbacks and impervious areas to be reduced, while open space areas are increased.

Impervious surfaces and associated infrastructure are expensive to construct. On average, a 600-mm diameter pipe costs about $250–450/m, with larger pipes, such as a 1200-mm diameter pipe, costing in the order of $950–1500/m.[31] If the length required for piping reduces, the cost of trenching and installing pipes, as well as the materials for the pipes themselves, will be less. The cost of road construction is also a significant part of the development budget. On average the cost of building a residential road is around $230–270/m^2.[31] These figures are based on a 150-mm thick sub-base, 100-mm base-course layer and 25mm of asphalt, with an additional $60/m for kerbing, if required. Concreting of light trafficked areas may cost between $65 and $120 /m^2.[31] It therefore follows that if the paved and road areas are reduced, the construction costs of a development will also be reduced. The following savings for WSUD developments were reported in the literature:

- A study in the United States found that by clustering (and therefore reducing road and service lengths), large-lot residential developments are able to save around 25% and smaller lots (e.g. 2000 m^2) achieve smaller savings of around 10%.[29] The same study found that piping costs can be reduced up to 47–69% [*note – this percentage infers that infiltration is possible but this is not always realistic for clay soils*].
- In other US studies,[32] pipeline and channel costs were reported to be 23–24% less for WSUD.[32]
- One study[33] found an approximately a 17% savings on impervious area costs. Auckland Council[34] documented studies from the USEPA that showed significant savings can be made through the reduction of impervious areas: Chapel Run: 66.9% (site imperviousness was reduced by 14%); Buckingham Green: 55.9% (site imperviousness was reduced by 2%); and Tharpe Knoll: 62.2% savings (site imperviousness was reduced by 5.2%).
- Auckland Council[34] also compared 3 conventional and WSUD developments and reported savings in paving costs of 17–23%, and infrastructure cost savings of 11% and 21% in 2 of the case studies. The third case study 3 indicated a 1% increase in stormwater infrastructure costs.
- At Kirimoko Park in Wanaka, the developer realised savings of 6% by using narrower roads in parts of the development and saved 50% on the overall construction costs by using swales to convey stormwater instead of pipes (this case study is discussed further in Section 6).
- A US study[35] further investigated the differential cost impact of implementing WSUD in greenfields versus brownfields developments. The authors state that if the impervious cover is <65% then the cost of WSUD and conventional development are

[31] COSTnz Life Cycle Costing model for New Zealand: http://www.costnz.co.nz

[32] Rozis, N. and Rahman, A. 2002. A Simple Method for Life Cycle Cost Assessment of Water Sensitive Urban Design. Global Solutions for Urban Drainage: pp. 1–11. doi: 10.1061/40644(2002)148 American Society of Civil Engineers.

[33] Clar, M. Undated. Pembroke Woods: Lessons Learned in the Design and Construction of an LID Subdivision.

[34] Shaver, E. 2009. Low Impact Design versus Conventional Development: Discussion of Developer Related Costs and Profit Margins. Report for the Auckland Regional Council. TR2009/045.

[35] ECONorthwest. 2011. Managing Stormwater in Redevelopment and Greenfield Development Projects using Green Infrastructure – economic factors that influence developers' decisions.

similar, but that if the impervious cover is >65%, then WSUD is up to 4 times more expensive.

3.4 Creating or enhancing natural areas – landscaping

By creating and re-establishing native forest/bush areas on a site (such as general revegetation or riparian cover to protect steep slopes), significant stormwater benefits, from a water quantity and quality perspective, can be achieved. However ecologically, it is much more important to retain existing (remnant) natural areas because when plants are removed and soils are stripped, the biological potential is greatly reduced.[36] Hence invertebrates of leaf-litter and earthworms have been proposed as indicators of successful native forest restoration.[37] Further, because large trees deliver much greater ecosystem services than small trees, and take decades to become 'large', the removal of large trees during construction has a long term negative impact.

Literature on costs of landscaping for WSUD is slightly conflicting. Some studies show that landscaping costs are cost neutral or less than conventional developments,[38,39] while others highlight an increased landscaping cost associated with an increase in natural areas.[40,41] One study from the USA[42] stated that landscaping costs are 15% higher for WSUD developments. Differences are likely due to the assumptions used when comparing the two types of approaches. A report to the European Commission[43] highlights that costs associated with the restoration and landscaping of urban park areas have far higher costs per square metre than restoration of rural habitats. This is likely due to the focus on creating high amenity environments within urban parks. While the literature tends to be vague regarding costing assumptions, it is often inferred that costs associated with conventional planted, landscaped areas are assumed to be the same as for bioretention practices. In New Zealand, this is generally a poor comparison for landscaped areas with annual plant species, as such landscaping typically has a high level of service (for example, specifying removal of all weeds), may be irrigated, and may have annual plant replacement, fertiliser applications and/or mulch replacement. Most NZ WSUD will not need irrigation, nor fertilisation, and in contrast with parts of the USA, are only mulched once, at establishment as after 18 to 24 months the devices are fully covered with a dense plant cover.[44] In NZ, WSUD landscaping generally specifies maintenance of a dense, perennial plant cover, so few bare areas are

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[36] Widdowson., J.P. and McQueeb, D. 1992. Rehabilitation after opencast mining in Southland, in *Issues in the restoration of disturbed land*, eds. P.E.H. Gregg, R.B. Stewart and L.D. Currie. Occasional Report No.4. (Palmerston North, NZ: Fertiliser and Lime Research Centre, Massey University).

[37] Smith, C.M.S., Bowie, M.H., Hahner, J.L., Boyer, S., Kim, Y.N., Zhong, H.T., et al. 2016. Punakaiki Coastal Restoration Project: A case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sand mining closure site, West Coast, New Zealand. *CATENA* 136, 91–103.

[38] USEPA. 2007. Reducing Stormwater Costs through Low Impact Development (LID) strategies and practices. Publication Number: 841-F-07-006.

[39] ECONorthwest. 2007. The Economics of Low Impact Development: A Literature Review. Eugene. OR.

[40] Water by Design. 2010. A Business Case for Best Practice Urban Stormwater Management Practice. Version 1.1 (SE Queensland).

[41] Lewis, M., James, J., Shaver, E., Leahy, A., Wihongi, P., Sides, E., and Coste, C. 2013. Water sensitive design for stormwater. Prepared by Boffa Miskell for Auckland Council. Auckland Council guideline document, GD2013/004

[42] Rozis, N. and Rahman, A. 2002. A Simple Method for Life Cycle Cost Assessment of Water Sensitive Urban Design. Global Solutions for Urban Drainage: pp. 1-11. doi: 10.1061/40644(2002)148 American Society of Civil Engineers.

[43] Naumann, S., Davis, M., Kaphengst, T., Pieterse, M., and Rayment, M. 2011: Design, implementation and cost elements of Green Infrastructure projects. Final report to the European Commission, DG Environment, Contract no. 070307/2010/577182/ETU/F.1, Ecologic institute and GHK Consulting.

[44] Simcock, R. 2017. Water Sensitive Design in Auckland, New Zealand. Chapter 28: 380–392. eds. S.M. Charlesworth, and C.A. Booth. Sustainable surface water management: a handbook for SuDS, 1st edn. John Wiley & Sons Ltd, Wiley-Blackwell Press.

present (reducing weeding requirements).[45] However, maintenance costs can be inflated if devices have design features that increase the frequency of maintenance (e.g. narrow inlets and large leafed deciduous trees, or large plants along path edges that will require regular trimming) then maintenance costs can inflate (see later section for issues and checklists).[46] The largest differential between conventional and WSUD approaches is probably for intensive living roofs that have deeper media (e.g. >300 mm) and/or that require 'at heights' trained staff to maintain them and high aesthetic values to be achieved.[47]

3.5 Water reuse/ rain tanks

Using water from roof areas for potable and non-potable uses can significantly reduce the volume of water discharged to downstream receiving environments. More recent WSUD subdivisions and developments in Australia have even used tanks to drain parking areas in order to reuse the water for gardening purposes.[48] Conventional subdivisions, on the other hand, will generally connect to mains water supply for both potable and non-potable water uses.

In general, in New Zealand, a 10,000 litre rain tank can cost between $4,800 and $6,500. Additional costs are incurred if the rain tank is installed underground, or requires concrete bedding. Costs for pumps, piping, connections, electrical work and filters would be additional to this.

The costs associated with the maintenance of rain tanks include: yearly tank inspections, cleanouts and replacement of filters, electrical work on pumps and replacement of pumps as well as a potential cost for council inspections on private rain tanks. The latter is required due to the ease and frequency of rain tank inflows being disconnected, tanks being removed, drawdowns failing and potential mistakes in plumbing that can occur with dual-purpose tanks used to supply toilets.[49]

It is difficult to quantify the cost differences to home owners of constructing and maintaining water tanks for reuse purposes. An Auckland study[50] noted that due to the low value and cost of water within New Zealand, savings gained from using water tanks for non-potable water within cities, are often very small. Over the life cycle, the WSUD approach cost between 4% and 18% more than the conventional approach of using mains water supply, depending on the level of the discount rate that was used in the analysis. However, the inclusion of savings to each household from reduced potable water charges diminished this difference (the maximum difference between options being 6%). For both approaches the total acquisition costs (i.e. design and construction costs) dominated the analysis. More

[45] Lewis, M., Simcock, R., Davidson, G., and Bull, L. 2010. Landscape and ecology values within stormwater management. Prepared by Boffa Miskell for the Auckland Regional Council: Auckland Regional Council Technical Report TR2009/083

[46] Simcock, R. 2014. Green Infrastructure – insights from Portland, Oregon. Landcare Research Science Series no.43

[47] Fassman-Beck, E., and Simcock, R. 2013. Living Roof Review and Design Recommendations for Stormwater Management. Auckland UniServices Technical Report to Auckland Council: Auckland Council Technical Report 2013/045.

[48] Activating WSUD in NZ Research Project: Melbourne Study Trip – November 2018. https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design

[49] Bracey, S., Scott, K. and Simcock, R. 2008. Important Lessons Applying Low Impact Design: Talbot Park. NZ Water Stormwater Conference Paper.

[50] Vesely, E.-T., J. Heijs, C. Stumbles, and D. Kettle. 2005. The Economics of Low Impact Stormwater Management in Practice – Glencourt Place. NZWWA Conference. Auckland, New Zealand.

recently, work undertaken by Auckland Council[51] estimated net annual water savings of $58 and net annual power savings of $40 resulting from the use of rain tanks for non-potable household uses. In terms of operation and maintenance costs, they**Error! Bookmark not defined.** e stimate an average annual maintenance cost of $425–645 per household. However, this private saving may be offset by reduced revenues to the bulk Mains water supplier.

In Sydney, Australia,[52] the costs of installing rain tanks in two separate subdivisions were investigated and compared with the costs of a conventional subdivision. For the Pioneer Street subdivision, WSUD was cost neutral when compared with the conventional design. However, at Heritage Mews, the WSUD option offered significant savings (approximately 25%). The authors found that the larger the site and the larger the capacity of the rain tanks, the greater the opportunity for savings. The study only examined the construction costs of rain tanks. A similar study in the Lower Hunter region of Australia[53] also investigated the cost of rain water tanks. They found that the installation of rain tanks was a more economically viable solution than conventional piped infrastructure which was connected to mains water supply. They estimated that, at a household level, the tanks were 0.9% more economically efficient that traditional water supply.

3.6 Vegetative practices, including trees

The use of rain gardens, vegetated swales and filter strips, can provide significant water quality benefits while also reducing the total volume of stormwater runoff.

<u>Total Acquisition Costs</u>

Studies from the USA[27,29] generally state that rain gardens, swales, and filter strips allow for reduced stormwater infrastructure costs, as they will often reduce the need for piped reticulation systems. Swales can replace piped systems, and can be used as conveyance channels while providing for a degree of water quality treatment. This was the case in Kirimoko Park (Wanaka, New Zealand), where savings of 50% of the total construction cost were realized through using swales instead of pipes. With respect to rain gardens,[29] lot level costs can be decreased by 25–30% when using rain gardens rather than a conventional detention pond and pipe system. The study, however, discusses bioretention rain gardens (i.e. where the water will infiltrate into the ground), as opposed to biodetention rain gardens, which still require a piped system to discharge stormwater. In contrast, the Stormwater Centre factsheet on bioretention[54] states that bioretention is relatively expensive. This is mainly due to the fact that rain gardens consume a fair amount of land for the catchment area treated (approximately 3–5% surface area to catchment area).

A study in South East Queensland, Australia2010[40] indicates a 32–82% increase in TAC, on a per lot basis, as opposed to conventional developments just using rain tanks. Another Australian study[55] compared costs of biofiltration systems with a conventional reticulated

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[51] Kettle, D., and Kumar, P. 2013. Auckland Unitary Plan stormwater management provisions: cost and benefit assessment. Auckland Council technical report, TR2013/043.
[52] Boubli, D. and Kassim, F. 2003. Comparison of Construction Costs for Water Sensitive Urban Design and Conventional Stormwater Design.
[53] Coombes, P.J., Kuczera, G., Argue, J.R., and Kalma, J.D. Undated. Costing of Water Cycle Infrastructure savings arising from Water Sensitive Urban Design Source Control.
[54] US Stormwater Centre Bioretention Factsheet: http://www.stormwatercenter.net/ : accessed on 22 August 2009
[55] Lloyd, S.D., Wong, T.H.F, and Chesterfield, C.J. 2002. Water Sensitive Urban Design – A Stormwater Management Perspective. Centre for Catchment Hydrology Industry Report 02/10.

system (no treatment), and a reticulated system and wetland to provide treatment. The study[55] found that using biofiltration would increase construction costs by approximately 22% over the “no treatment” option, as opposed to a 47% increase with the wetland scenario.

Operation and Maintenance Costs

Long-term maintenance is particularly crucial with regard to the effective functioning of all stormwater practices.

Swales are relatively inexpensive to maintain, given that the key maintenance requirements relate to mowing, clearing debris and the occasional regrading of the swale. Mowing costs are in the order of 40–80 c/m^2 (excluding traffic management). This cost could be avoided if native tussock grasses, sedges and/or rushes (often *Apodsmia similis*, oioi) are used because these plants do not need mowing. Instead, some weed management is usually required (involving herbicide application).

Rain gardens, on the other hand, are slightly more expensive to maintain given the likelihood of having to clean them out and replace the filter media at least once within its working life span. The South East Queensland case studies[40] highlight that maintenance costs for bioretention devices are 11–28% more expensive than conventional developments using rain tanks. Based on modelling undertaken for this project using COSTnz, net present value annual maintenance costs for rain gardens in New Zealand are generally in the order of \$3.20–8 per m^2 of the rain garden surface area, while swale maintenance costs are approximately \$4.30–6.10 per linear m (average 2–3 m top width) per year in 2017 dollars. A recent study in Christchurch[56] highlights that rain gardens in industrial developments have higher maintenance costs than those estimated through COSTnz, namely \$62–76 per m^2 (undiscounted cost). A US study[57] states that the average annual cost of rain garden maintenance is estimated to be 5 and 7% of the capital cost.

3.7 Infiltration practices

Infiltration practices differ from other types of stormwater practices in that they infiltrate water back into the ground, thereby reducing the total volume of runoff generated. The most common types of infiltration practices are trenches, dry wells and permeable paving. In some areas infiltration devices include dry detention ponds. Rain gardens can also be designed to maximise infiltration into underlying subsoils – such devices may have internal water storage zone that lies below the rain garden media that provides more time for water to exfiltrate; the volume of water that can be exfiltrated can also be increased by maximizing the rate of media permeability. In areas of New Zealand with low summer moisture deficits (Auckland, Dunedin), media with permeabilities in excess of 1500 mm/hr can support plant growth if the media can support about 100 mm of plant-available moisture[58]. The Kirimoko subdivision in Wanaka use a rapid-permeability media to enhance their volume of exfiltration. In Taupo, natural Pumic Soils in gullies with high infiltration rates (>300 mm/hr) are used as infiltration devices; low bunds and planted flax ‘baffles’ are

[56] Rees, J. 2018. Rain Garden Maintenance Costs in an Industrial Development. New Zealand Water 2018 Conference Paper.
[57] Clary, J., and Piza, H. 2017. Cost of Maintaining Green Infrastructure. Reston, VA, American Society of Civil Engineers.
[58] Simcock, R., Blackborne, S., Fassman-Beck, E., Ansen, J., and Wang, S. 2014. Resilient raingardens: selecting fill media and mulch, and influences of urban design. Water NZ Conference May 2014, Christchurch

used to detain stormwater to increase time for infiltration – a very cost effective infiltration practice.[59] Costs, therefore, relate to the type of infiltration practice being constructed. In the city of Portland, Oregon, another cost-effective method to remove stormwater flow within combined sewer catchments is ‘downspout disconection’, which takes advantage of infiltration.[60, 61]

From a construction or total acquisition cost standpoint, infiltration practices tend to be substantially cheaper than other types of stormwater practices, since, like swales, their existence negates the need for a piped stormwater system. This is particularly so with infiltration trenches. On the other hand, costs associated with the purchase and installation of permeable paving can be quite high (depending on the product). Total acquisition costs are therefore dependent on the type of infiltration practice being constructed. Many of the studies from the USA and UK cited in this report are based on infiltration trenches and permeable paving which infiltrate water into the ground. Subsoil drainage and storage systems (as would be required in large parts of Auckland) are not factored into the cost.

The real concern with infiltration practices is with their long term functioning, as infiltration practices have a fairly high failure rate and, therefore, will have a shorter life span than other types of stormwater practices.[54]

[59] Taupo District Council 2009. Taupo District Council Stormwater Strategy https://www.taupodc.govt.nz/repository/libraries/id:25026fn3317q9slqygym/hierarchy/our-council/policies-plans-and-bylaws/district-strategies/stormwater-strategy/documents/Stormwater-Strategy.pdf and Todd C, Simcock R, Scott F 2007. Gully Management that maximises urban stormwater treatment and ecological values. 5th South Pacific Stormwater Conference, Auckland.

[60]. Environmental Services City of Portland (undated). How to manage stormwater. Downspout Disconnection. https://www.portlandoregon.gov/bes/article/240623

[61] Environmental Services City of Portland (undated). Stormwater Solutions Handbook. https://nacto.org/wp-content/uploads/2012/06/City-of-Portland-Bureau-of-Environmental-Services.-2004.Stormwater-Solutions-Handbook..pdf

4. New Zealand cost data and LCC analysis

4.1 Existing New Zealand cost data and models

Two New Zealand cost models can be used to undertake a LCC analysis of green infrastructure, namely, the Landcare Research COSTnz Model[62] and NIWA/ Cawthron "Urban Planning that Sustains Waterbodies" (UPSW) Costing Model.[63]

COSTnz is a site-specific model and requires a good understanding of local site conditions, contaminant inputs, and stormwater device design. In general, the life cycle costs are assessed using a unit-based approach. COSTnz was developed in 2009 and is no longer publicly available for use. However, the authors of this report have access to the model and were able to update it with new data to allow estimation of current costings.

The UPSW LCC Model is a catchment-scale model that was developed by running a significant number of COSTnz scenarios in order to determine $/ha costs for that apply to a range of generic stormwater treatment scenarios.

Much of the costing work presented in this report is based on these two models.

4.2 Data collection

As part of this research programme, a request was made to a number of local and regional authorities, consultants, developers and contractors for construction and maintenance cost information.

A construction and maintenance cost protocol was developed and circulated to 29 organisations to request assistance with the collation of new cost data. Cost information was requested for wetlands, rain gardens, swales, permeable paving, rain tanks and green roofs.

The authors gratefully acknowledge the following companies for assisting us in this data collection process and for providing data (the list below is given in alphabetical order):

- AR and Associates
- Auckland Council – Healthy Waters
- Auckland Motorway Alliance
- Auckland Transport
- Christchurch City Council
- CKL
- Gisborne District Council
- Greater Wellington Regional Council
- Hamilton City Council
- Meridian Land Development Consultants
- Mnt Difficulty Wines

[62] Ira, S. J. T., Vesely, E-T., McDowell, C., and Krausse, M. 2009. *COSTnz* – A Practical Life Cycle Costing Model for New Zealand. NZWWA Conference, Auckland.

[63] Ira, S.J.T., Batstone, C., and Moores, J. 2012. The incorporation of economic indicators within a spatial decision support system to evaluate the impacts of urban development on waterbodies in New Zealand. 7th International Conference on Water Sensitive Urban Design Conference, Melbourne, Australia.

- Queenstown Lakes District Council
- Remarkables Primary School
- Remuera Golf Club
- Southern Land
- Wellington Water

All data received have been amalgamated with existing cost data, and no individual costs are referenced.

4.3 Total acquisition costs

Total acquisition costs include the costs of designing, consenting and constructing a particular green infrastructure practice. Figure 4-1 below displays the range in total acquisition costs for swales, rain gardens, wetland and green roofs. In each case the number of data points is provided in brackets behind the device type labels on the x-axis. It should be noted that costs are provided in \$/m^2 of surface area of each particular practice, with the exception of swales which is \$/ linear m of swale (and assumes a swale width of 2–3 m).

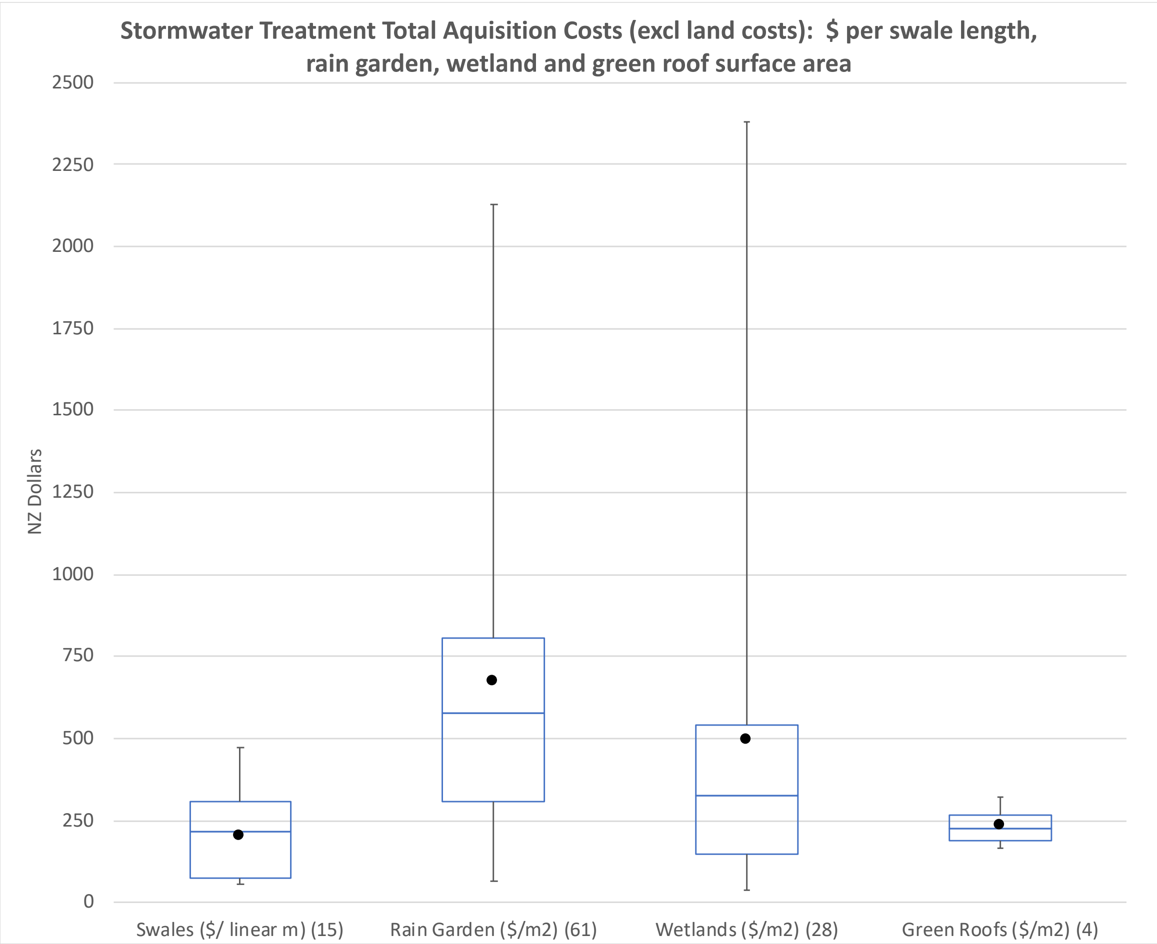


Figure 4-1 Green Infrastructure Total Acquisition Costs.

The wide range in cost estimates for wetlands and rain gardens is a function not only of the larger dataset, but also of the different types of construction techniques which can be used for these practices. In many instances, the cost is linked to the type of soil and ground conditions in which the practice is built, along with the materials used. For example, rain gardens which are contained within concrete vaults would fall in the upper cost spectrum of the box and whisker plot, while an bioretention rain garden without underdrains and concrete would be at the lower end. Likewise, where clay liners (or similar) are needed for wetlands within permeable soils or high groundwater levels, costs are higher than wetlands constructed within clay soils. The costs shown relate solely to the practice itself, and do not include costs relating to an associated piped network. For green roofs, the cost relates to the green roof components only (i.e. not the materials to build the roof structure).

The total acquisition costs relating to rain tanks were not included in Figure 4-1, as they are highly variable and relate mainly to the size and type of tank being installed. Further refinement of modelling work using COSTnz undertaken for Greater Wellington Regional Council[64] indicates that the total acquisition cost of an above ground tank can be calculated as follows:

$$Low\ Cost\ Rain\ Tank\ =\ (4800 + rain\ tank\ cost) + ((4800 + tank\ cost) * 0.05)$$

$$High\ Cost\ Rain\ Tank\ =\ (6500 + rain\ tank\ cost) + ((4800 + tank\ cost) * 0.075)$$

The equations include 5–7.5% for design, consenting and project management fees which would be over and above the traditional subdivision and building design costs. The 4,800 and 6,500 constants relate to costs associated with installation, along with the need for electrical connections, pumps, pipework, concrete base slabs, water filters, first flush diverters, shut-off values and reinstatement.

The total acquisition costs for permeable paving solutions were likewise not included in Figure 4-1 as they are also highly variable and dependent on the type of paver used and whether or not underground detention storage is included. As for rain tanks, further refinement of the Wellington COSTnz[64] work indicates that the total acquisition costs of permeable paving can be calculated as follows:

$$Low\ Cost\ Permeable\ Paving = (85\ +\ 1m^2\ of\ pavers) + \big((85\ +\ 1m^2\ of\ pavers) *\ 0.05\big)$$

$$High\ Cost\ Permeable\ Paving = (120\ +\ 1m^2\ of\ pavers)\ +\ ((120\ +\ 1m^2\ of\ pavers)\ *\ 0.075)$$

The equations include 5–7.5% for design, consenting and project management fees, which would be over and above the traditional subdivision and building design costs relating to standard concrete (or other) driveways or parking areas. The 85 and 120 constants relate to costs associated with installation, along with the need for a 250-mm depth of clean aggregate reservoir and 50-mm sand bedding layer, geotextile liners, concrete borders to support the pavers, paving fill (for modular paving) and novacoil underdrainage. This equation relates to permeable paving used on driveways or low use off-street parking areas.

[64] Ira, S J T. 2017. Summary of Life Cycle Costs for Stormwater Infrastructure Solutions. Report prepared for Greater Wellington Regional Council as part of the Te Awarua-o-Porirua Collaborative Modelling Project.

While the rain tank and permeable paving equations included in this section provide an indication of the potential cost of these practices, it is recommended that the actual cost of the product, supporting infrastructure and installation is obtained directly from the supplier/builder.

4.3 Maintenance costs

This section provides a summary of the likely maintenance activities, frequency of those activities and costs for the different green infrastructure practices discussed in Section 4.2. Fact sheets for swale, rain garden, and wetland maintenance have been developed and are available to download at the project website.[65] The fact sheets provide a summary of the key factors which influence maintenance costs along with tips for on-going maintenance.

It should be noted that the tables in this section of the report do not provide exhaustive lists of all types of maintenance which may be needed for each practice, but rather provide an indication of the most common maintenance activities, along with a proposed frequency and cost. Careful selection and thought is required if the tables are used to generate life cycle costs or maintenance budgets. The unit costs provided are best estimates of cost at the time of writing this report and have a base date of 2018. While the indicative unit cost estimates can be used to provide a relative comparison of maintenance activities of one practice against another, it is recommended that decision-makers ground-truth these cost estimates using their own cost data for budgeting purposes.

The frequencies provided in the tables are based on the former Auckland Regional Council's Technical Publication 10,[66] on the NZTA Stormwater Treatment Standard[67] and on Auckland Council's TR2010/053,[68] as well as advice from council engineers, maintenance engineers, landscape maintenance experts.

The maintenance tables (Tables 4-1 to 4-6) for wetlands, rain gardens, swales, and green roofs include 3 maintenance models based on the level of proposed maintenance frequency, namely amenity, functional, and bare minimum. This approach acknowledges that the two key drivers of maintenance costs are the frequency of the maintenance and the unit cost of the activity.

While the bare minimum frequency provides for the lowest level of maintenance frequency, the rates for this level of maintenance are higher than that provided for the amenity and function levels. The reason for this is that it would take a maintenance person longer to weed, remove litter, landscape and maintain vegetation every 6 months than if they were doing it monthly or bi-monthly as the level of weed infestation would be far greater. Where only one rate range of unit cost rates is provided per activity, we recommend that the highest value be used if the "bare minimum" frequency is selected.

[65] https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design .
[66] Auckland Regional Council. 2003. Stormwater Management Devices Design Guideline Manual. Technical Publication 10.
[67] NZTA. 2010. Stormwater Treatment Standard for Highway Infrastructure. ISBN 978-0-478-35287-0
[68] Healy, K., Carmody, M., and Conaghan, A. 2010. Stormwater Treatment Devices Operation and Maintenance. Prepared by AECOM Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2010/053.

Based on the 3 maintenance models, life cycle cost models were developed for rain gardens to ascertain which maintenance scenario would be the most cost effective over a 50 year life span. Figure 4-2 shows the NPV$ for each maintenance model scenario. The high (orange) NPV$/m2/yr cost results were based on the high unit cost estimate in Table 4-1 and the low (blue) NPV$/m2/yr cost was based on the low unit cost estimate in Table 4-1. Figure 4-2 highlights that choosing a bare minimum approach to rain garden maintenance is not cost effective. The high amenity maintenance option is the most expensive and should only be used for areas which have very high amenity values (e.g. Wynyard Quarter, Waitangi Park in Wellington, etc.), while the most cost effective maintenance scenario is the functional maintenance approach. This approach focusses on undertaking landscaping during the growing seasons, coupled with the optimum level of drainage maintenance to ensure that the drainage function of the practice is not compromised through lack of ongoing maintenance.

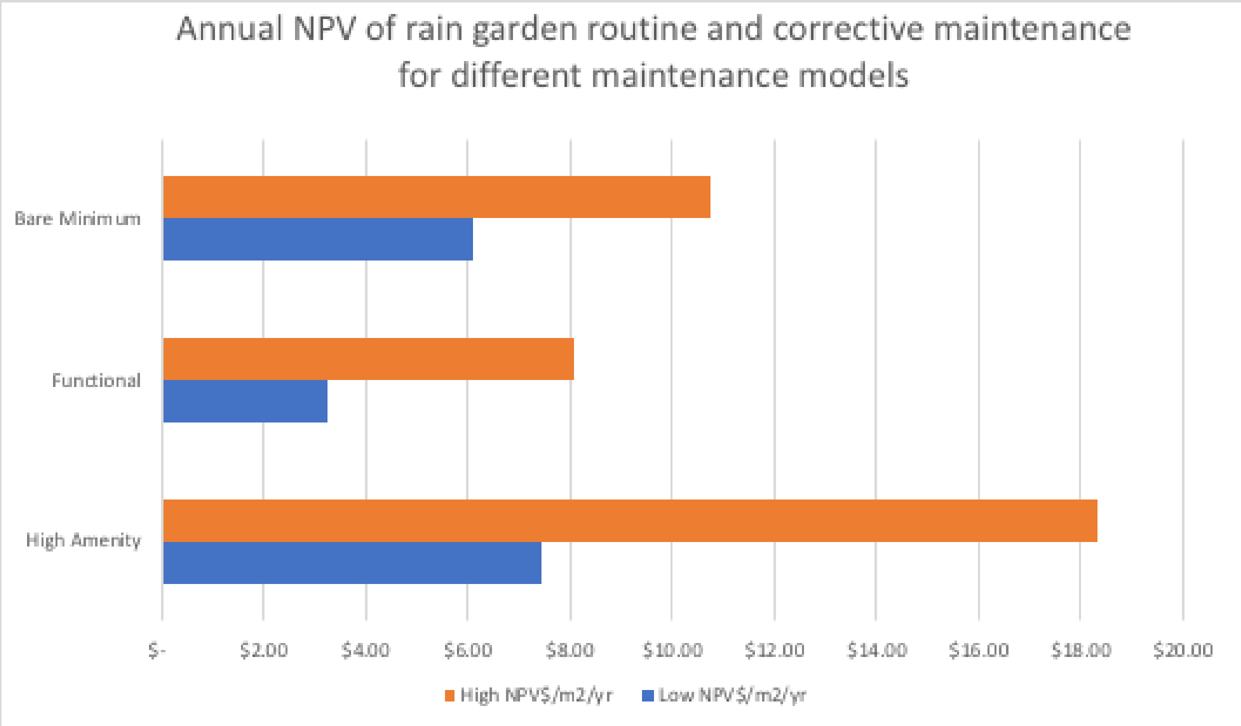


Figure 4-2 Annual Net Present Value (NPV) costs of rain garden maintenance activities.

Table 4-1 Rain garden maintenance activities and unit costs

ROUTINE MAINTENANCE	Frequency (Per Year)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
Routine Landscape Maintenance: Undertaking general landscaping inspections, removing litter, maintaining vegetation, weeding:					m^2	$0.50	$6.00
High Amenity High amenity maintenance activities may be needed only in high intensity or amenity areas: • trimming of hedges, deheading of flowers or seed heads (e.g. rengarenga lilies, annuals), removal of dog pooh (otherwise regarded as a fertiliser) and summer irrigation. • maintenance as needed in functional category below.	12			12	m^2	$1.00	$2.60
Functional • 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, • It includes up to 5% replanting or remulching (especially at inlets, corners, and places damaged by cars / road workers and other people). Includes checks to determine if irrigation is needed during unusual droughts (1 in 5–10 year events)		9			m^2	$0.50	$1.30

ROUTINE MAINTENANCE	Frequency (Per Year)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
• It does not include trimming vegetation infringing on footpaths due to poor plant selection or placement or roads more than once per annum, or higher amenity requirements.							
Bare Minimum: • Ensuring inflows and overflows are clear by removing sediment/ litter / leaf litter / vegetation, removing litter from drainage areas/edges, removing weeds that could smothering desirable plants and undertaking an inspection (lack of maintenance tends to lead to infestation by weeds, smothering of desirable plants, in some places leads to litter build-up and therefore a larger effort is needed to maintain the rain garden infrequently).			2		m^2	$2.60	$6.00
Trees:			0				
• Checking stakes/supports and then their removal where required	6	3		6	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 - 2	1		1 - 2			
• 24 monthly pruning for first 6 years to develop healthy structural form and lift canopy to required sight lines *	0.5	0.5		0.5	m^2	$1.00	$1.40

ROUTINE MAINTENANCE	Frequency (Per Year)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
note nikau need 6 monthly-checks until lower 2 m is clear							
Functional Drainage Maintenance: • Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets. • Flush out under-drainage. Note: Biofilter infiltration rate / performance is best scheduled after rainfalls that are large enough to create ponding (usually 25 mm events). Inlet, overflow and outlet clearance should also be assessed as part of routine landscape maintenance (pers. comm. AMA Peter Mitchell).	4	2	1		per rain garden	\$120.00	\$312.00
Traffic Control Costs: Where traffic management is needed • Traffic lane closure (static or mobile works)	As needed	As needed	0	As needed	m^2	\$1.00	\$3.20
• Road Closure setup costs – static closures					per closure	\$1,240.00	\$2,500.00
• Road Closure setup costs – mobile closures					per closure	\$560.00	\$870.00
Minor repairs: • Repairs to grills on outlets/ inlets; additional soil/ mulch needed; erosion	1	1	0		per rain garden	\$96.00	\$120.00
Make good following vandalism:	3	2	1	3		\$120.00	\$132.00

ROUTINE MAINTENANCE	Frequency (Per Year)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
• Relates to primarily vegetation and graffiti removal; trees are expensive to replace and should be protected					per rain garden		
Initial aftercare of plants (first 3 years)	6	4	1	6	m^2	$1.20	$3.48

CORRECTIVE MAINTENANCE	Frequency (Number of Years Between Each Event)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
Additional mitigative maintenance actions: Additional landscaping/maintenance may be required due to poor design of rain gardens. This can have a dramatic effect on maintenance cost and usually relates to: · removal of deciduous leaves and gross pollutants from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. · additional trimming of vegetation around signs, lights, rubbish bins or other infrastructure placed in raingarden (services and signage should not be placed in raingardens). Surface removal of silt/fine sediment/ concrete cutting wash and deposits washed into the raingarden that will impact either infiltration or plant performance · removing dead plants due to ponding because of incorrect rain garden mix/over-compaction of mix so that infiltration rates are too low, or blocked underdrainage/poor outlet	As needed	As needed	As needed	As needed	m^2	$2.60	$6.00

CORRECTIVE MAINTENANCE	Frequency (Number of Years Between Each Event)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
design. Or dead due to unusually severe drought without adequate irrigation, due to spray damage from poor maintenance, or poor maintenance technique (e.g. over-trimming at the wrong time of year). Usually requires re-mulching while plant cover re-establishes.							
Forking of surface to relieve compaction and restore permeability after damage from vehicles or foot traffic that lowers infiltration rates; usually also requires mulching to provide protective cushion while plants recover							
· Fixing erosion of outlets due to poor slope control or undersized rain gardens.					m^2	$0.50	$0.75
· Road closures for "centre road" rain garden maintenance.					m^2	$1.00	$3.20
Infiltration Testing (if needed)	2	4	10		per test	$100	$520
Removal & disposal of sediments (including replacement with new media) + cartage*	50	50	15		m^3	$55	$147
Complete replanting*	50	50	15	25	m^2	$1.50	$7.20
Major maintenance of drainage system, e.g. replacement of parts	15	15	5		per rain garden	$1,200	$3,900
Traffic Control Costs: Where traffic management is needed • Traffic lane closure (static or mobile works)	As needed	As needed	0	As needed	m^2	$1.00	$3.20
• Road Closure setup costs – static closures					per closure	$1,240	$2,500
• Road Closure setup costs – mobile closures					per closure	$560	$870

CORRECTIVE MAINTENANCE	Frequency (Number of Years Between Each Event)				Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum	Non-WSUD Landscaping		Low	High
Council Inspections – cost to private rain gardens	3	3	3		per inspection	$105	120

*Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the rain garden

Table 4-2 Wetland maintenance activities and unit costs

ROUTINE MAINTENANCE	Frequency (Per Year)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum*		Low	High
Routine General Maintenance (tree and shrub trimming/lifting, mowing access track**, maintaining healthy vegetation cover, fertilising, removing litter including dog pooh), includes plant and weed assessment	12	4	1	m^2	$0.24	$0.60
Removing debris (e.g. litter, dead vegetation) from outlet and inlet /forebay structures, reinstating any scour/erosion	12	4	1	per wetland	$48	$164
Inspections (e.g. botulism issues, QA, inspection of embankments, spillways, outfalls, overall functioning of facility, integrity of fences and stakes if present)	1	1	0.5	per visit	$300	$480
Scheduled Routine Mechanical Maintenance (pumps, outlets)	1	1	0.5	per wetland	$384	$660
Make good from vandalism (trim /replace plants, remove graffiti)	2	1	0	per wetland	$25.20	$97.80

ROUTINE MAINTENANCE	Frequency (Per Year)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum*		Low	High
Weed Management	4	2 - late spring & summer to prevent seeding	0.5	m^2	$0.30	$0.35
Aquatic weed management	2	1	0.5	m^2	$0.29	$0.53
Additional visits for initial Aftercare of Plants (for first 2 to 4 years until 'completion' standard is achieved), includes initial tree form prune and canopy lift that ensures adequate light to retain dense groundcover and achieves safe sightlines (canopy base at 2–4-m height depending on specification) ***	0	2	2	m^2	$0.30	$0.35

*Use high rate if "bare minimum" frequency is selected
**mowing relates to access tracks only (other mowing is associated with non-functional components of the wetland system)
***intensity of initial aftercare more dependent on initial weed pressure, plant density and growth rates, i.e. high intensity / frequency where weed pressure is high and growth rates slow
Note: rates and activities assume no watering or mulch replacement is needed as wetland has reached the completion criteria

CORRECTIVE MAINTENANCE	Frequency (Number of Years Between Each Event)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum		Low	High
Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments/baffles, erosion)	10	10	5	per wetland	$12,000	$18,804
Replacement of parts (grates, trash screens)	20	20	10	per wetland	$1,200	$7,200
Replanting the wetland zone*	50	50	50	m^2	$11	$15
Desilting and disposal of sediment from forebay*	25	25	20	m^3	$105	$310
Desilting and disposal of sediment from main pond*	50	50	50	m^3	$105	$310
Council Inspections – cost to private wetlands	3	3	3	per inspection	$105	$120

*Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the wetland

Table 4-3 Swale maintenance activities and unit costs

Routine Maintenance	Frequency (Per Year)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum*		Low	High
Routine General Maintenance for grass swale (mowing, edge-spraying or trimming, including around overflow/outlets, weeding). Minimum only for 'meadow' approaches in low-biomass with low fertility (Otago, Hawke's Bay, Canterbury dry swales with browntop or rush swales)	12 to 14	6	2	m^2	*$0.43*	$0.76
Routine General Maintenance for planted swale in perennial vegetation (maintaining healthy vegetation cover, weeding, edge trimming, mulch or rip-rap replacement)	6	3	1	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)	6	4	2	m^2	*$0.60*	$3.50
Routine General Maintenance – mowing requiring hand mowing or weed whacking rather than tractor mowing	12	6	2	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)	4	2	1	per swale	*$36*	$48
Deciduous Trees – sweep and remove leaves. Flaxes – trim off seed heads in summer where impinging on footpaths or roads	4	2	0	hr	*$45*	$60
Make good following vandalism (bollards, repair of barriers, restaking trees) Note: where trees are in grassed swales use protection against weed whackers to avoid trunk damage	2	1	0	per swale	*$174*	$288

*Use high rate if "bare minimum" frequency is selected

Corrective Maintenance	Frequency (Number of Years Between Each Event)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum		Low	High
Maintaining even, dispersed flow - removing accumulated sediment; regrading, filling and decompaction to remove tyre ruts or scoured areas*	25	25	10	per swale	*$300*	$600
Disposal of sediment to landfill*	25	25	10	m^3	*$55*	$148
Re-grassing (assume turf mat or coir/wool seeded mats used given swale is online)	25	25	10	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)	45	25	10	m^2	*$15*	$20
Replanting/grassing (where road closures are required)	25	25	25	m^2	*$0.83*	$2.55
Minor repairs to inlet or outlet structures and/ or erosion mitigation material (such as rip rap)	10	10	5	per swale	*$48*	$240
Replacement of bollards (discontinuous kerbing)	10	10	5	per 10m	*$60*	$180
Replacement of underdrain	25	25	10	m	*$22*	$28
Replacement of specimen trees following death or damage (e.g. from vandalism. Mowers, weed whackers, storm damage, drought or water logging)	10	10	0	per tree	$250	$400
Council Inspections – cost to private swales	3	3	3	per inspection	$105	$120

*Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the swale

Table 4-4 Green roof maintenance activities and unit costs

Routine Maintenance*	Frequency (Per Year)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum**		Low	High
Inspections (as above but different unit) due to working at heights certification needed	2	2	1	labour cost per hr	$22.50	$45.00
Mowing of sedum-based roof garden (not lawn mowing)	2	2	1	per m^2	$0.43	$0.76
Removal of woody weeds that could damage membrane (e.g. silver birch, pohutukawa, cabbage tree, poplars). Should also remove plants that are dead for >3 months over the summer so not contributing to evapotranspiration. General weeding/trimming/ slow-release fertilizing/edge, drain and overflow clearance/irrigation checks (low rate - standard landscaper). Up to 2% plant or mulch replacement (especially at inlets, corners, and places damaged by other roof workers or dug up by bad birds)	6	2	0.5	labour cost per day	$160	$360
As above (high rate – working at heights certification)	6	2	0.5	labour cost per day	$400	$720

*Assumes all roofs have access to irrigation and someone checks if the plants need irrigation and the rate that is applied, plus the frequency
** Use high rate if "bare minimum" frequency is selected

Corrective Maintenance*	Frequency (Number of Years Between Each Event)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum		Low	High
Corrective Maintenance Repair Costs (plants/ media)	25	25	10	per m^2	$2	$75

Corrective Maintenance*	Frequency (Number of Years Between Each Event)			Unit	2018 Costs	
	High Amenity	Functional	Bare Minimum		Low	High
Corrective maintenance Repair Costs (perimeter drainage edges and overflow gravel mulch topping up/replacement) (estimate based on roof perimeter)	25	15	10	lump sum	$1000	$3000
Corrective Maintenance Repair Costs	50	50	15	per m^2	$100	$120
Working at Heights Certification	3	3	3	per course	$2,000	$2,500
Council Inspections – cost to private green roofs	3	3	3	per inspection	$105	$120

* Assumes all roofs have access to irrigation and someone checks if the plants need irrigation and the rate that is applied, plus the frequency

Table 4-5 Rain tank maintenance activities and unit costs

Routine Maintenance	Frequency (Per Year)	Unit	2018 Costs	
			Low	High
Inspection of tank, orifice outlet, pipework/gutters, first flush device, pest screens, erosion protection. Inspection of electrical parts. Maintenance of screens/filters. Clean out as necessary. Check surrounding area for unwanted plant growth, pest access and nuisance potential	1	per inspection	*$195*	$290

Corrective Maintenance	Frequency (Number of Years Between Each Event)	Unit	2018 Costs	
			Low	High
Maintenance of filters, pumps, etc	5	per tank	$100	$130
Replacement of water supply pump	10–15	per pump	$1,200	$3,000
Minor Repairs to concrete and structural components (e.g. sealing cracks, tank stand, etc.)	10–15	per tank	$130	$690

Corrective Maintenance	Frequency (Number of Years Between Each Event)	Unit	2018 Costs	
			Low	High
Minor repairs to overflow area (e.g. scour or uneven flow – recontour and top up with mulch, realignment of t-piece to ensure distributed flow, check soakage areas are still vegetated and functioning as planned (dispersed flow)	10–15	per tank	$130	$690
Council Inspections – cost to private rain tanks	3	per inspection	105	120

Table 4-6 Permeable paving maintenance activities and unit costs

Routine Maintenance	Frequency (Per Year)	Unit	2018 Costs*	
			Low	High
Inspections and regular cleaning of organic sediments and debris and check of intactness. Includes yearly clean for weed/moss control if not part of design. NB to ensure inspections coincide with storm events to check drainage function. May require mowing for planted, grassed paving devices (these may also require weed control as per above) Note: if trees are plantied in pervious paving, then need an annual check of trunk to ensure paving is not girdling the tree and that the paving surface is not a trip hazard	2–6	per driveway	*$105*	$180
Minor repairs	0.5 – 1	per driveway	*$120*	$360

Corrective Maintenance	Frequency (Number of Years Between Each Event)*	Unit	2018 Costs*	
			Low	High
Cleanout sediment, oils, etc and removal of top layer of stone/ gravel and re-establishment (top up joint chip or sand between pavers). Re-establishment of plants in planted systems, especially flowing extremely hot, dry years; may include fertilisation	5–10	m^3	$160	$185
Top-up of low fines joint mix or growing media (planted devices)	5–10	m^2	$10	$16
Disposal of unsuitables	5–10	m^3	$55	$147
Replacement of permeable pavers (if necessary)	10–25	m^2	$110	$250
Uplift pavers, replace sand and bedding (and replant in planted devices)	10–25	m^2	*$90*	$110
Erosion repair	5	per driveway	*$300*	$600
Council Inspections – cost to private permeable paved areas	3	per inspection	105	120

*For larger installations such as parking lots use a lower frequency and a higher cost.

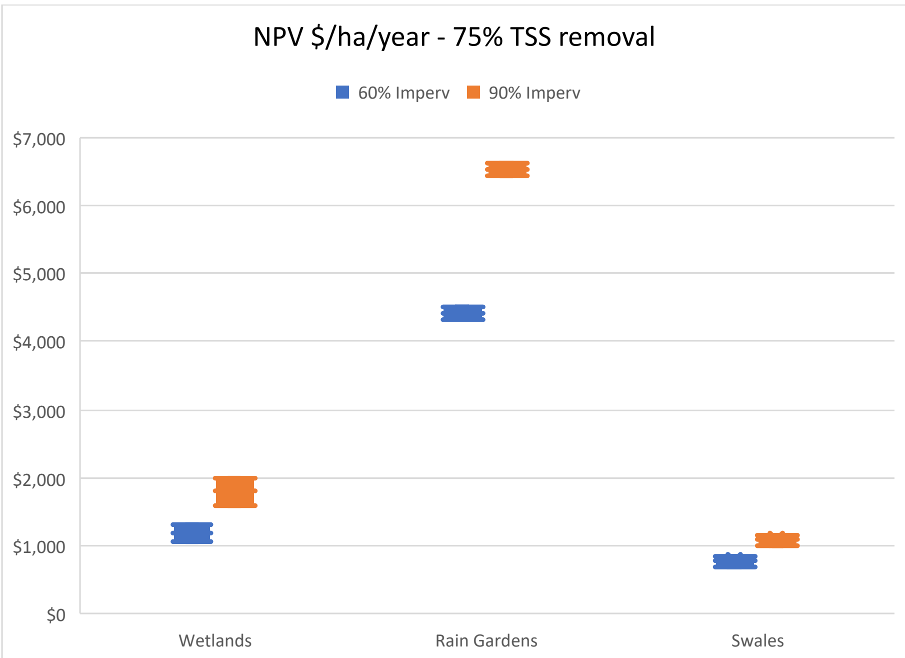
4.4 Summary of updated LCC

Life cycle costs have been calculated for each of the identified green infrastructure practices using the COSTnz model template.

With respect to wetlands, rain gardens and swales, the life cycle cost models built as part of the UPSW Costing Model study[17] were updated, and the indicative estimate LCCs shown below is for the range of NPV$ per ha treated (Figure 4-3). The estimates are exclusive of land costs. The range of cost reflected in Figure 4-3 is reflective of the range of devices modelled for the different theoretical catchments generated as part of the UPSW cost model.[69] Due to the large range in TAC costs collected as part of this research, the median TAC value was used to update the UPSW cost model. With respect to the maintenance cost, the functional maintenance model and low cost estimate was used. The rationale for this is that the devices are assumed to be public assets and council contracts are generally wide-reaching and allow for lower costs to be achieved.

All models have the same life cycle costing assumptions, as follows:

(1) The base year for the COSTnz model is 2007. As a result, all costs were inflated to a base year of 2017 using a 2.8% inflation rate.
(2) A life cycle analysis period and life span of 50 years was used for all model runs.
(3) A discount rate of 3.5% was used for the discounted life cycle costs.
(4) For those models based on the UPSW Costing Model, see Cawthron Report No. 2082[69] for further detail and explanations around the assumptions.
(5) Decommissioning costs were not included in the models as none of the solutions would be decommissioned after 50 years.



[69] Ira S. 2011. The Development Of Catchment Scale Life Cycle Costing Methods For Stormwater Management. Report commissioned by Cawthron Institute. Cawthron Report No. 2082. 35 p. plus appendices

Figure 4-3 Box plots of the range in NPV $/ha/year for 60% imperviousness and 90% imperviousness at a treatment removal percentage of 75% for for swales, rain gardens and wetlands.

New cost models using COSTnz were created for green roofs, permeable paving and rain tanks. The life cycle costing assumptions for these practices is consistent with what is described above. However the range of costs reflect the low and high cost estimate used within the life cycle model. Life cycle costs for these practices are shown in Table 4-7. As a point of comparison, indicative cost estimates for an inert roof and concrete driveway are also provided. It is noted that the permeable paving costs relate to modular paving, as described in Section 4.3.

	Low	High
Green Roofs (NPV $/m2/yr)	$ 270	$ 710
Inert Roof (NPV $/m2/yr)	$ 160	$ 380
5000 litre rain tank (NPV $/tank/yr)	$ 360	$ 800
Permeable Driveway (NPV $/m2/yr)	$ 10	$ 60
Concrete Driveway (NPV $/m2/yr)	$ 9	$ 10

Table 4-7 Indicative life cycle cost estimates for green roofs, permeable paving and rain tanks.

5. Maintenance discussion

This section reviews three specific methods of Zero Additional Maintenance developed in Australia, with the aim of assessing their potential to significantly reduce the maintenance costs of WSUD in NZ, and therefore remove or reduce this major perceived barrier. This section also draws together insights from the Activating WSUD case studies. These case studies showed influences that elevate or reduce the construction costs of general landscaping (including how they are allocated), and demonstrated how ongoing maintenance costs can be avoided or saved through maintenance-led design.
The section concludes with a list of design-related maintenance issues for green infrastructure and recommended 'fixes'.

5.1 Zero additional maintenance

Zero additional maintenance (ZAM) is a term coined in Australia to describe research that aimed to design devices that can be installed into typical, residential streetscapes to provide the water-quality benefits of WSUD with 'no different' maintenance than conventional roadsides,[70] i.e. they operate as a conventional streetscape from a council or landowner perspective. The objective was specifically developed to offer a cost-effective way to transition to a water sensitive city with respect to ongoing costs (capital costs may be similar, although existing catchpits receive bypass flow). The first ZAM guide was released in 2015 by Manningham City Council (Melbourne). Although ZAM-WSUD devices were developed for suburban residential streetscapes, they are also considered applicable to new urban developments, car parks and industrial sites using biofiltration treatment areas at 1-2% of impervious catchment.

By 2018, three ZAM devices had been developed:[71] ZAM raingardens and "TreeNet" are designed to be retrofitted into 'nature strips', i.e. grassed or vegetated verges. The August 2018 update highlights the role and value of existing street trees to contribute to bioretention for free. 'T*reeNet'* was developed in South Australia. This device is retrofitted into streetscapes to deliver road runoff to street trees, with the benefit of improving tree drought resilience and groundwater recharge. A third device combines Gross Pollutant traps with surface rubbish bins that can be emptied using a standard automated rubbish truck. The key features of each of these devices, as described in August 2018 version of the handbook, is discussed below, with a focus on their potential application to New Zealand.

[70] Manningham City Council, Melbourne Water, CRC for Water Sensitive Cities, Monash Water for Liveability Centre 2018. ZAM-WSUD Handbook. https://www.clearwatervic.com.au/user-data/resource-files/zam-wsud-handbook---with-attachments-30-8-18.pdf
[71] Updated versions of the handbook will be available online via the Clearwater website: www.clearwater.asn.au/resource-library/publications-and-reports/zero-additional-maintenancewater-sensitive-urban-design-zam-wsud-handbook.php

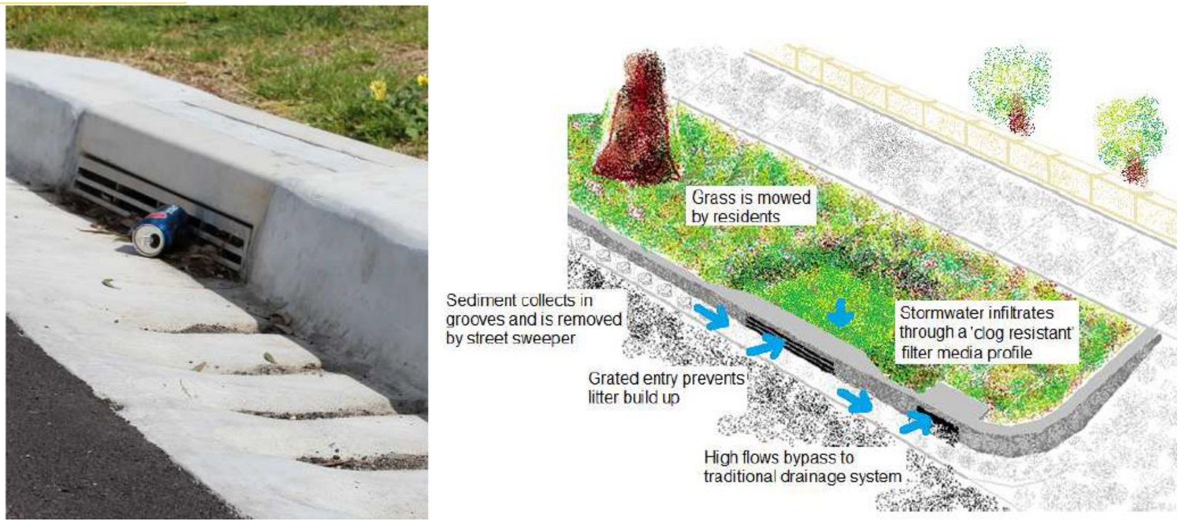


Figure 5-1 Photo of grassed ZAM device and, right, a schematic showing key features of retrofit bioretention. Source: 2018 ZAM-WSUD Handbook.

5.1.1 ZAM – WSUD Australia

ZAM rain gardens require the following 'conventional' street maintenance actions:

1. Street sweeping – removing fines (typically every 5–6 weeks),
2. Automated gross pollutant collection (from the road surface),
3. Catch pit emptying (removing coarse material),
4. 'Normal' grass verge mowing or landscape vegetation maintenance. This may be resident-led mowing of specific turf grass cultivars.

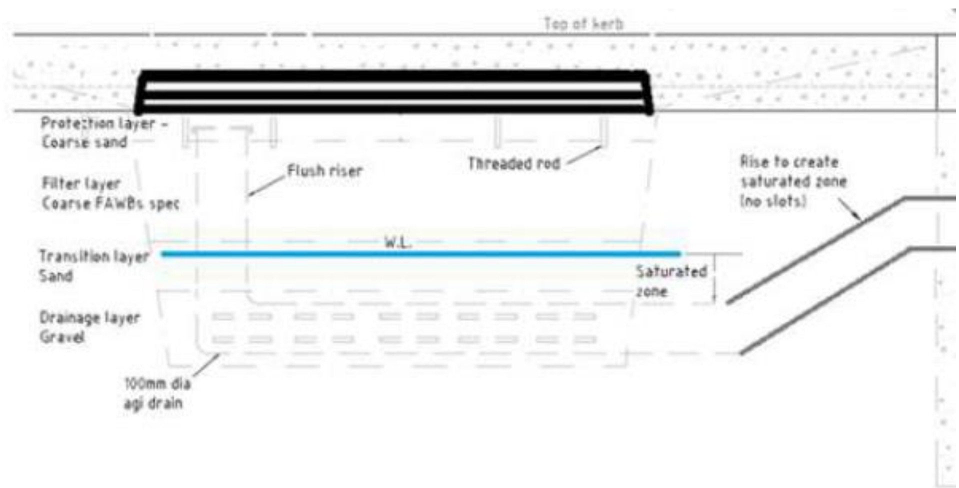
ZAM rain gardens are designed to exclude coarse material in a way that maximises the value of street sweeping. Rain gardens connect to an existing stormwater catch-pit (under-drain) which performs the overflow function, so are ideally placed immediately upstream of existing catch pits. The rain gardens are designed to enhance stormwater quality by infiltrating road runoff through raingarden sand filter media to remove nutrients and other pollutants. Consistent with conventional rain gardens/bioretention devices, they are also expected to provide 'broad water-cycle benefits' listed as: waterway health, nitrogen reduction, urban summer cooling, flood risk reduction, and groundwater recharge. Features are as follows.

1. A series of specifically-shaped 50 mm wide (1V:4H) and spaced 'waffle-grooves' in concrete edge prior to inlet captures silt and sand sediment and allows its removal by routine street sweeping) to avoid media clogging (Figure 5-4).
2. Horizontal slatted 'litter guard' with 18–20-mm gaps between square-profile bars horizontally across the inlet prevents coarse litter entering the device.
3. Concrete apron minimum 75 mm wide and 150 mm thick along the full width of the 'raingarden' side of the inlet to allow mowing without using specialised edge trimming equipment or spraying. For 'vegetated' systems, the guide suggests using a concrete edge to separate the area from mown grass (i.e. a mowing strip, Figure 5-5).
4. Coarse sand 'protection layer' through which grass grows that resists clogging by 'absorbing silt within void spaces'– this sand is mostly 0.5 – 2 mm with <3% vis-á -vis <0.15mm (fine sand or less) and permeability of 1000 to 1600 mm/hr. This

protection layers acts as a weed mulch in landscaped devices but is also placed under the turf.

5. Resilient grass cultivars[72] selected for survival and growth in sandy soils, regularly mown to remove nitrogen. If installed as instant turf, the sod must be grown in sand or sandy-loam media , and roots washed of soil before placement.

   Or
6. Perennial unmown, ‘slow-growing plant species’ to minimise ongoing maintenance. Species recommended include two species also native to NZ (*Ficnia nodosa* and *Baumea rubiginosa*[73]). These may achieve better evapotranspiration/ stormwater attenuation than grass and also lower the risk of lawn clipping mobilisation, fertilisation, and mower-scalping but probably have lower N and P removal than mowing where clippings are removed.
7. Clog resistant filter media profile with 200-300 mm/hr hydraulic conductivity, specified according to FAWB particle size distribution (Figure 5-3).
8. An internal, saturated water storage zone to improve resilience during extended dry periods created by using a raised elbow on a solid pipe connected to a slotted pipe underdrain (Figure 5-2).
9. High flow bypass to a traditional catchpit and pipe drainage system (if gross pollutant removal is wanted, it suggests fitting Gross pollutant traps into catchpits).
10. Recommended for verges at least 1.5 m wide, preferably 2m+ and where the footpath is less than 100 mm above the level of the top of the kerb to ensure batter slopes do not exceed 1V:5H (for safety of pedestrians and mowers).



Saturated zone creation using unslotted pipe bends

Figure 5-2 Cross-section through a ZAM raingarden showing creation of saturated zone. Source: 2018 ZAM-WSUD Handbook.

[72] Grasses were selected that were resistant to pedestrian traffic and Melbourne conditions. The cultivars were sterile male ‘Kenda’ and ‘Village Green’ kikuyu for sunny sites (<20% shade) and ‘Empire’ Zoysia in 20-40% shade; both tropical grasses that are probably suitable for Auckland and Northland, but vulnerable to frost damage. Both grasses spread from surface runners, so edge management is required. In NZ, kikuyu is invasive in many riparian areas, swales and wetlands; typically high growth rates require high mowing frequency.

[73] Other species were – *Juncus pallidus, Juncus amabilis, Juncus subsecundus Goodenia ovata, Carex tereticaulis, Carex apressa* and three *Melaleuca* species. Ideal plants have dense foliage 300 to 1 m height and have aesthetic benefits

Figure 5-4 Sediment groove installation. Source: 2018 ZAM-WSUD Handbook.

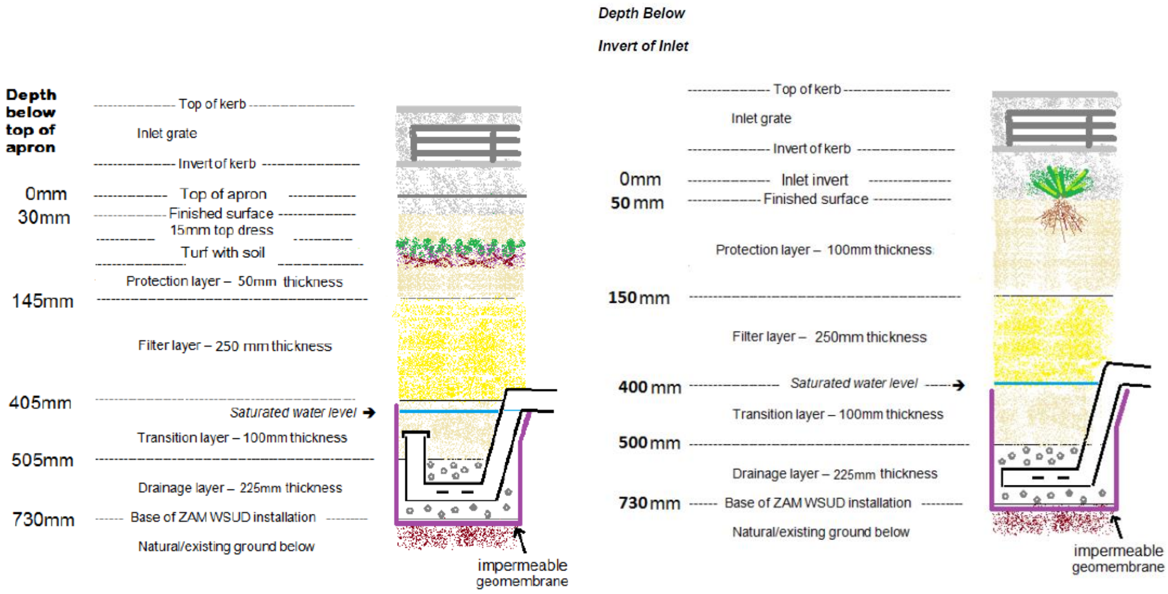


Figure 5-3 Technical specifications for Turf (left) and planted ZAM installations (right); greater depth and/or volume may be needed to support larger plants. Source: 2018 ZAM-WSUD Handbook.

The specifications for the filter layer media and protection layer media (Table 5-1) include moderate permeability of 200–300 mm/hr for the filter layer and high permeability for the protection layer. However, a test method used is not specified. The test method would usually specify a moisture content, level of compactive force, height and diameter of the ring that the media is placed into. Although these sands are resistant to compaction even at high moisture content, the dry bulk density under which the test is still likely to influence the result and it is would not be standard practice to have a single measurement of conductivity. Such tests are usually repeated at least 3 times, and results reported as averages or ranges (as given for the filter layer).

Table 5-1 Particle size distribution specification for filter layer and protection layer for ZAM devices.

Description and equivalent particle size (mm e.s.d.*)	Filter layer specification	Protection layer specification Burdett's 20/30 sand PSD
Fine gravel (2.0–3.4 mm)	< 3%	2%
Coarse sand (1.0–2.0 mm)	7–10%	13%
Medium to coarse sand (0.25–1.0 mm)	60–70%	82%
Fine sand (0.15–0.25 mm)	10–25%	1%
Very fine sand (0.05–0.15 mm)	5–10 %	2%
Silt and clay (<0.06 mm)	< 3% (<0.05 mm)	Trace
Hydraulic conductivity, mm/hr	200–300	1316

* e.s.d. – equivalent spherical diameter. Probably presented by volume, although this is not specified

Table 5-2 Fertiliser specification to be mixed into upper protection layer

Constituent	Quantity g/m² of biofilter area
Granulated poultry manure fines	500
Superphosphate	20
Magnesium sulphate	30
Potassium sulphate	20
Trace element mix	10
Fertiliser N:P:K (16:4:14) ***(nitrogen: phosphorous: potassium)***	40
Lime	200

Figure 5-5 Concrete apron on grassed ZAM device avoids need for spray-strip or other edge management treatment. Source: 2018 ZAM-WSUD Handbook.

The practice notes helpfully include specific actions to minimise trip hazards, identifies suitable road gradients, vehicle exclusion methods, vandalism protection and structural integrity, and has a 'Construction Toolkit'. It suggests offering residents the choice between turf and planted ZAM-WSUD assets to improve community acceptance.

The primary advantages of this ZAM approach are as follows.

1. It suits areas with isolated devices as maintenance does not require new training, or contract variation, so has highly predictable, 'no additional' cost (i.e. no impact on rates).
2. The 15-mm deep, protection layer of coarse sand protects against clogging and reduces weed growth (especially in vegetated devices). It should also help protect the underlying media against compaction as it acts to cushion or spread a load and is not compactable.
3. It suits retrofits where there is high local resistance to rain gardens due to their 'look', as the mown turf looks very similar to conventional mown verges.
4. Reasonably seamless integration into areas with mown grass and with street trees – although the slight depression is likely to result in different grass height and colour in summer due to different stress. The surface profile grade transitions are specified to ensure mowers do not bottom out to avoid grass scalping).[74] The approach assumes that normal mowing practices (by residents or others) provide regular removal of vegetation and therefore remove nutrients (N and P) from the biofiltration system.
5. Turf can be established at some times of the year as instant turf, although trials used seed establishment, and this requires an intensive watering regime (daily for the first 10 days then less frequently for at least the first 6 weeks in Melbourne).
6. ZAM TreeInlet system has very small footprint below 300 mm so can be installed in most verges even with dense underground services.
7. ZAM TreeInlet system harnesses contribution potential of trees, especially to enhance infiltration (where soils are suitable) and should enhance tree resilience to drought stress.

However, there are some limitations to this approach to consider, particularly for greenfields areas.

1. Street sweeping is needed – in busy streets with high traffic flows, streets with a high proportion of residential parking, and/or narrow streets it is difficult to effectively street sweep because cars are in the way. An advantage of conventional rain gardens can be reduction or elimination of street sweeping by using inlet 'sumps' that are located to allow safe and efficient access from the footpath.
2. Specific additional GPT collection methods are needed. This could potentially be more expensive than removal from rain gardens (especially if traffic controls are needed).
3. The efficiency of grooves may be specific to street sweeper design and frequency; grooves maybe a risk to cyclists and pedestrians if not correctly sited.
4. 'Standard' mowing grass verges introduces a range of risks, depending on the location and maintenance methods used in the wider grassed verge. These are mainly scalping, use of fertilisers/pesticides, and washing of grass clippings into

[74] Note efficient widths match the mowers used: hand mowers 0.5 m, small ride-on mowers 1.1 m and larger mowers up to 2 m width. Trees should be placed to allow efficient mowing passes.

overflow (if not removed or forced into sward). It is also expensive. In the USA and parts of Europe, mowing frequency is reduced to semi-annual approaches under 'meadow' mowing regime, but this requires specific species selection.
5. Capital costs may be higher in new developments where rain gardens can be constructed without catchpits or underdrains (i.e. some infiltrating rain gardens).

5.1.2 Tree-based ZAM-WSUD systems

The 2018 ZAM-WSUD update includes a section on 'tree based WSUD systems'.[75] It emphasises trees have a crucial role by increasing infiltration, groundwater recharge, water uptake and evapotranspiration; in particular, tree roots allow relatively rapid redistribution of water across a root zone. In areas with perched or high groundwater tables, trees lower ground-water tables so increase soil water storage capacity – thereby increasing flood protection. It promotes *TreeNet* inlets as a low-cost system suitable for retrofit into urban streetscapes with trees. These inlets were developed in South Australia to deliver road runoff to street trees to improve drought resilience.

The inlets include three features that minimise maintenance requirements:

1. a raised inlet invert prevents gravel entry
2. a local depression diverts solids away from the inlet (by creating a vortex)
3. inlets are cleaned by existing street sweepers

Conflicts with underground services are minimised because the area that is disturbed to install the device is small, particularly below 300-mm depth, and it can be installed using 'non-destructive excavation equipment' that minimises damage to the tree. This means is can be applied to most verges. The guidance recommends placing inlets at the drip line of a tree to avoid impacts on structural tree roots and tree canopy, or about 1.5 m upstream of new tree trunks.

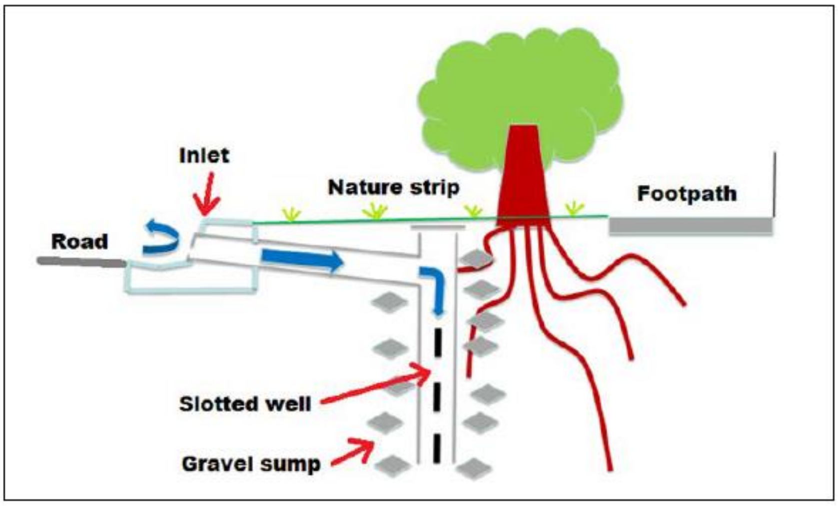


Figure 5-6 Schematic diagram of TreeNet inlet system. Source: 2018 ZAM-WSUD Handbook.

[75] Manningham City Council, Melbourne Water, CRC for Water Sensitive Cities, Monash Water for Liveability Centre 2018. ZAM-WSUD Handbook. https://www.clearwatervic.com.au/user-data/resource-files/zam-wsud-handbook---with-attachments-30-8-18.pdf

Figure 5-7 Photographs of installed TreeNet inlet system. Source: 2018 ZAM-WSUD Handbook.

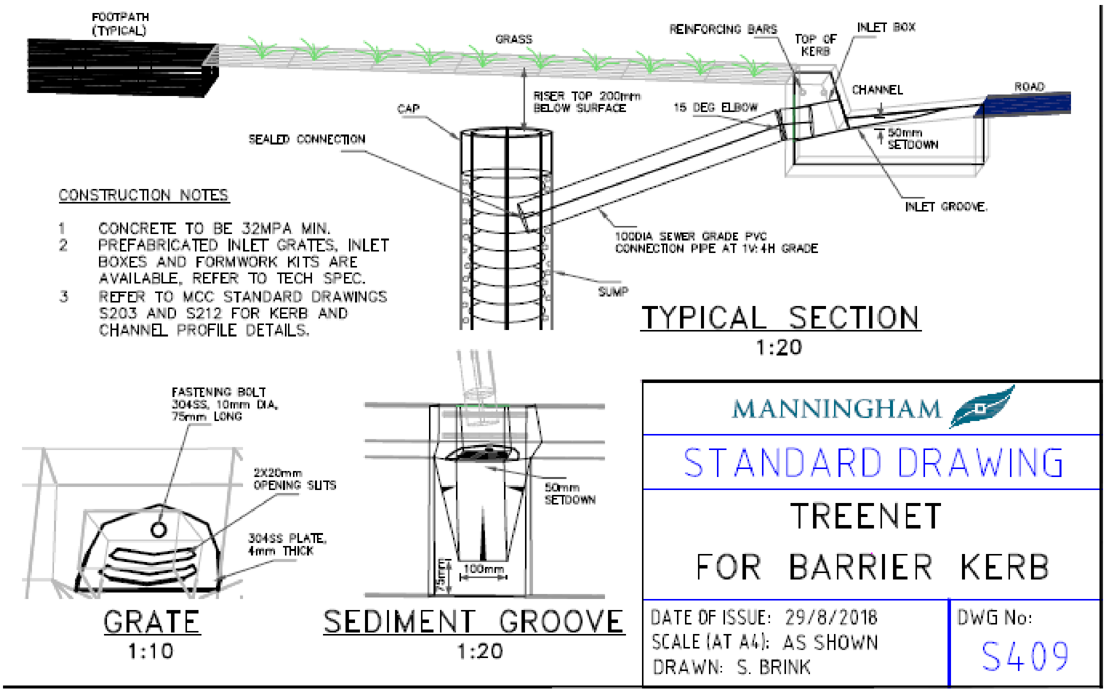


Figure 5-8 Part of Standard Drawing for TreeNet, 2018. Source: 2018 ZAM-WSUD Handbook.

5.1.3 Riversafe ZAM gross pollutant trap

This combined gross pollutant trap (GPT) and street litter bin was designed to be emptied by a 'standard domestic garbage truck', achieving ZAM when installed where litter bins are already present and emptied at a suitable frequency to prevent over-filling of the GPT.

Figure 5-9 Automated emptying of a Riversafe bin. Source: 2018 ZAM-WSUD Handbook.

5.1.4. Applying ZAM in New Zealand

To apply the ZAM bioretention device technology in NZ systems the following nine considerations should be reviewed:

1. The design specification for the number and shape of sediment grooves has been developed based on type of sediment and 6-weekly street sweeping by MacDonald Johnston VT605 Sweeper. This may need to be adapted to NZ street sweeper configurations and sweeping frequency (which is typically lower).
2. Identify functionally-equivalent, locally-available, coarse sands for the 'protection layer'. In some areas of NZ local sand and sand mixes that meet specifications for underlying sand media are also needed. The particle sizes quoted are based on Melbourne sands.
3. NZ bioretention devices generally use an organic mulch to perform the protection function in 'vegetated' devices. Organic mulches can enhance nutrition (avoiding need to amend the upper root zones before planting), help cool root systems and conserve moisture during establishment but are typically applied at 50–70 mm depth and decompose over 12–24 months. Gravel mulch is not a substitute, as it is not as effective as coarse sand at capturing silt.
4. The ZAM approach uses concrete 'apron' strips to avoid need for separate edge maintenance for mown devices. It specifies that chemical weed spraying should be avoided in general. In NZ some road maintenance contracts use chemical spraying (and are costed based on this) so ensure this is excluded from bioretention devices.

5. Galvanised materials should probably not to be used for grates where the contaminants of concerns include Zn. The prototype used hot-dipped galvanised steel with large surface area of roll-over kerbs for ‘cost considerations’, but the guide recommends use of 304 stainless steel for grates because this is more resistant to damage from street sweeper brushes.
6. The saturated zone is probably not required in many NZ areas as our rainfall is regularly spread and moisture deficits are short-lived and not severe, however, they may be valuable for Nelson/Blenheim, East Coast, and Central Otago towns and cities, and also where ground-water exfiltration is wanted.
7. Turf grasses that perform under NZ conditions are needed, especially in cooler season areas (south Island and Taupo) of New Zealand, as this study used tropical grasses. Where Nitrogen removal is a priority, grass growth curve should correspond to temperature – tropical species have growth in summer but not winter.
8. Focus on balancing fast plant establishment (initial nutrient pulse and reduced moisture stress by irrigation) with transition to slow, long-term growth that also maintains aesthetic values (critical if community is to maintain them)
9. Design details that specify minimum width and slopes should be retained as they are important for efficient, low risk mowing.

The merits of ZAM rain gardens maybe overstated in larger greenfield areas, where the overall maintenance can be designed to be low. This is because a common definition of rain gardens is ‘low maintenance’, partly because at about 1–5% of a suitable catchment they are self-watering and self-fertilising, i.e. they do not need regular watering or fertilising. A plant selection that suits the site and media conditions is fundamental and critical. Most media are deliberately low in organic matter to optimise nutrient retention, and therefore stuiable plants do not need high fertility conditions. Sandy media typically dry out, so raingarden plants need to be able to tolerate drought, so plants that grow best in organic-rich, fertile, moist conditions are unsuitable. ZAM identifies that plant selection is important and provides mown turfgrass cultivars and perennial plant species that they find tolerate the hot, droughty, very low organic content media, with minimal nutrients from stormwater because (most sediment is street-swept). The ZAM prescription uses an initial fertiliser amendment of the protection layer to provide enough nutrients to allow the selected plants to establish a full cover – nutrient stress then keeps plants growing slowly and this minimises edge trimming required.

Adopting retrofit ZAM may not deliver benefits from rain garden designs that eliminate mechanised street sweeping and some gross pollutant removal activities: reduced carbon emissions, and increased efficacy of sediment removal on streets where access is difficult. This approach is widely used in Portland, Oregon, where thousands of street-side rain gardens have been retrofitted with easily- accessed sediment forebays. The key design features of these forebays are self-cleaning, non-blocking inlets that have a 200–300-mm wide flat-based inlet and 50–150-mm drop onto a level concrete settling area, shaped to allow efficient removal with a spade or shovel. Inlets are placed to avoid the need for traffic controls.

A similar approach is promoted by Kevin Beuttell,[76] who also promotes reducing maintenance costs by designing raingarden 'meadows' that need a single annual mow, and using wildflowers initially to enhance aesthetics). He warns that grasses are likely to increase in dominance as thatch builds up, so flowers may need to be re-introduced (this can be achieved using 'plugs' or bulbs). Kevin also highlights the value of public participation, raising the potential value of raingardens to create restorative landscapes for people through public involvement.

5.2 Tips for reducing maintenance costs

As discussed previously, costs can be avoided or saved during the maintenance phase, providing the device has been designed to facilitate on-going maintenance. Table 5-1 provides a summary of the key influences on maintenance costs which need to be taken account of at the design stage. It is noted that many of the key influencers relate to care of the vegetation, inlets and outlets, traffic management and device shape/area requirements. In general, regular routine maintenance that is scheduled during the growing season and to occur after large rain events will reduce requirements for large-scale corrective maintenance and renewals. These design-related maintenance issues were drawn largely from the case studies and walking tours of the Activating WSUD research programme. Both are available on the website.

5.2.1 Device-specific "tips"

A set of fact sheets on maintenance tips for green infrastructure have been developed, which are also available on the project website.[77] The fact sheets provide detailed information on the design related maintenance issues for a number of different types of green infrastructure practices, and are highly illustrated with examples drawn from across New Zealand.

Table 5-1 Design related maintenance issues for green infrastructure and recommended fixes

Design related maintenance issues	Recommended fix
Inlet and outlet design – the most common cause of high maintenance is poor inlet design or construction which leads to blockage. Blocked inlets and outlets prevent devices working, and can lead to overloading of individual inlets and consequent erosion/scour at the overloaded inlets.	Design of inlets and outlets that takes account of the surrounding topography and land use. Design self-cleaning inlets that allow flow into the device without initial sediment build-up. These may have sheet flow or a vertical drop to an erosion-resistant surface. Design inlets that are not easily blocked by plant growth. These have a L configuration where the bottom of the L is level with the swale or rain garden. Ensure inlets and outlets are easily visible from vehicles.
Device shape, depth and volume in relation to watershed – these influence how much stress the plants are under – narrow devices surrounded by impervious areas are highly vulnerable, especially along roads and carparks.	Ensure optimal device shape (e.g. minimum 1 – 1.5m width) to reduce edge effects where possible. Ensure plants that are vulnerable to breakage, especially trees, are not planted within the reach of car bumpers.

[76] https://www.ecolandscaping.org/04/rain-gardens/keeping-rain-gardens-thriving/
[77] https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design

Design related maintenance issues	Recommended fix
People and vehicle pressure – unless designs physically exclude people and vehicles, then areas with high pedestrian counts are more vulnerable to damage and littering, and need more maintenance to maintain aesthetics. Small rain gardens, protrusions, and unprotected corners are highly vulnerable to physical damage and have higher maintenance.	Use durable, sustainable edge protection measures which can withstand damage by vehicles and people (e.g. wooden bollards are easily broken as opposed to using natural rock boulders to stop vehicles driving on swales, industrial areas will require broad concrete kerbs). Avoid placing overflow grates where cars can hit them (e.g. on corners). Provide obvious, wide pedestrian crossing points that are consistent with 'desire lines' with dense plants on each side to discourage short cuts. Use street furniture such as seats, rubbish bins and light stands to protect edges but put these outside the devices.
Lack of easy access to stormwater devices is a common problem, especially for wetland and pond forebays, and can cause maintenance delays and increased cost.	Ensure that the design allows for access to the device. For large devices such as wetlands, include mown grass or unmown sedge 'sacrifice' areas where excavated sediment can be dewatered and trucks loaded.
Devices which require traffic management plans have high maintenance costs. Cones, spotters and attenuators are expensive and can increase maintenance costs threefold or more.	Careful thought needs to be given to the location of the device, its inlets and sediment forebays, within the road reserve as well as the need for traffic management during routine maintenance activities such as mowing, edge maintenance or weeding. In devices with a limited number of inlets, these should be placed in areas that are safe and efficient to inspect and clean.
Placing services in devices, especially the base of swales and within rain gardens (lights, posts, signs) cause maintenance problems from people disrupting the device, e.g. by spraying or trimming, and can block inlets. They also reduce the below-ground treatment volume of the device. Over-spraying can cause bare patches and die-off allowing weeds to infest the area.	Ensure services are placed outside of stormwater treatment devices. Ensure retrofit signs, lights and other services are not placed in devices, and absolutely not within 1 m of inlets or overflows.
Plant selection – plants not matching site conditions or planned maintenance – e.g. too tall or wide (requiring trimming) or too short and open (not able to supress weeds). Mass planting of single species and clones of plants, increasing risk of catastrophic failure. Do not plant large-leafed deciduous trees in or adjacent to devices without planning and budgeting for autumn leaf removal and increased inlet clearing frequency.	Specify groundcover species that will reach required height and maintain a density that will exclude weeds. Obtain the assistance of an ecologist or landscape architect to ensure a suitable landscaping plan is developed. Current thinking is to place trees immediately adjacent to devices to enhance tree stability and device exfiltration (where this is practical).
Aesthetic requirements – in most cases, high aesthetics is usually linked with higher maintenance costs. However, the highest level of maintenance occurs in beds that have annual plantings (no stormwater devices should have annual plantings as they cannot be sustained) or floral displays that require dead-heading.	Use native plants and non-deciduous trees to reduce maintenance requirements. Trees usually lower the maintenance requirements of groundcovers underneath them but will require canopy lift to ensure light levels remain high enough to sustain a dense, weed-resistant groundcover.
Initial establishment success and weed competition – adequacy of initial care and hardening off of plant materials. Plants should reach a high cover (>80%) that can be sustained.	Ensure that maintenance of vegetation and adequate cover of weed-excluding mulch is included in the defects liability period and responsibility for plant maintenance is established.

Design related maintenance issues	Recommended fix
The moisture content of material of disposed material has a significant effect on disposal costs. The wetter the mixture, the greater the weight of the material and therefore the higher the cost.	Design set aside areas which can be used to place, dewater and dry out sediment which has been removed from the treatment device.
High sediment loads require more maintenance to maintain performance.	This can be mitigated by enforcement action to prevent sediment generation from sources (silt fences, mulching, etc.) and by using forebays to capture sediment, or using swales as pre-treatment devices. Areas near roundabouts or landscaping yards would be expected to have more spills of soils/mulch and compost than other areas.
Swales: regular mowing can be an expensive activity, especially if traffic management measures are needed to facilitate mowing.	Integrate mowing into adjacent mown areas if design mowing height can be readily achieved (100 mm)> Use dense, shorter and slower-growing grasses combined with less fertile growing media at establishment (e.g. browntop turf) that can be mown less frequently but remain aesthetically pleasing. Replace mown grass with 30–120-cm-high perennial vegetation such as oioi, sedges, rushes, native irises and low flaxes or prostrate groundcovers such as coprosmas and meuhlenbeckia as these do not need mowing.
Swales: avoid swales that require several different operations to manage vegetation	Design edges and overflows that do not need separate trimming or spraying treatment (e.g. use a 'mowing strip' at grade, including around grates). Avoid steep slopes or 'signs' that need weed-eating at the base. Avoid using rhizomatous grasses that 'escape' from a swale (e.g. kikuyu) and prevent their establishment in adjacent vegetation.
Swales: avoid steep swale side slopes and angular profiles as these are prone to scalping, difficult and expensive to mow, and plants are more likely to be stressed.	If possible swale total width should be bigger than 1 – 1.5 m. See local design guides for recommended cross-sections and long-sections.
Swales: use resilient sustainable material for check-dams	Check dams should be stable and erosion resistant surfaces such as a concrete ledge or rock mulch should be placed below the dams. Ensure that sufficient check dams are designed and that discharge points have flat bases and not notches (the latter concentrate flow).
Rain gardens: Level of service/amenity specified including litter and weed tolerances and edge management (trimming frequency or herbicide use) affects cost. Rain gardens that have 'ecological' levels of service can have low maintenance focused on removing aggressive weeds, retaining sight lines and edges whereas those maintained as amenity 'gardens' can have very high costs.	Discuss the level of service requirement with the developer and council/network operator to ensure agreement over future maintenance frequencies and activities is reached. Include all or one side of rain gardens within the existing landscaping to avoid the need to manage 'hard' edges that often requires regular trimming (no trimming should be needed where these are part of landscaped areas).
Rain gardens: "Online" rain gardens that are not protected from erosive flow in large storm events	Design rain gardens as off-line systems with a high flow bypass where possible.

Design related maintenance issues	Recommended fix
often result in expensive corrective post-storm maintenance.	
Rain gardens: Surface sealing, sediment accumulation or compaction lowers infiltration rates and increases risk of vegetation smothering /death leading to replanting, and surface (mulch and upper soil layers) removal and replacement. This is a common occurrence when rain gardens are built in areas which are under construction and unprotected.	Protect rain gardens from construction sediment and compaction until site construction is complete. Alternatively: a) use pre-treatment controls such as swales, street sweeping or filter socks (or similar) to exclude and reduce sediment build-up during construction, or b) use temporary 'sacrificial' cover of instant turf underlain with permeable mat that protects integrity of media.
Rain gardens: Inadequate re-wetting across all parts of raingarden due to uneven stormwater distribution leading to plant stress in 'drier' areas can be caused by inlet location/number and rain garden shape, uneven surface or bypass flow (inadequate compaction of media at edges) and is exacerbated by very high infiltration rates (>1000 mm/hr).	Consider the inlet design and location with respect to rain garden shape and size during the design process. Ensure construction checks of media at edges and avoid small/narrow areas where applying adequate compaction is difficult, especially between overflows and edges. Use flow spreading structures in large raingardens of deliver stormwater near centre.
Rain gardens: Avoid using gravel or rock mulch as it is very difficult to remove sediment from, provides little filtering, and increases risk of surface blocking if plants cannot grow through it.	Use non-floating organic mulch that binds together. Such mulch includes fine, long, shredded bark or wood ('triple shredded'); using part-composted mulches, and/or blending 25% compost with mulch and thoroughly watering at installation to achieve density >1 T/m^3 (TR2013/056[78]). Use a coarse, washed sand mulch with permeability > 1000 mm/hr (Australian research recommends using 0.25 – 2 mm diameter sand with no fines).
All devices with trees: Unprotected trees become liabilities if trunks are damaged so that rot can enter. Poorly secured or installed trees can fall over or die, preventing delivery of functional and aesthetic values that are greatly enhanced by tree canopy (especially large trees).	Ensure trees are placed far enough from edges of devices that they are unable to be reached by vehicles and protect with planting and/or above-ground stakes. In mown areas use short, physical tree protection collars to protect from weed-whackers and cluster or align to enable efficient mowing. Protective collars should be flexible so they do not restrict trunk growth. Leave a gap between paving and tree trunk mulched with loose material to avoid poured permeable paving cutting into trunks as trees mature. Ensure trees are secured adequately until their roots establish using 'anchors', multiple low stakes (not single stakes next to the trunk) and/or placing in competent soils adjacent to devices rather than in the non-cohesive, single-grained, loose soils typically used in bioretention devices.
Wetlands: Wetlands without forebays are expensive to maintain as sediments can quickly fill the shallow wetland areas requiring clean-out and replanting of the wetland.	Ensure all wetlands are designed to incorporate a forebay.

[78] http://knowledgeauckland.org.nz/assets/publications/TR2013-056-Mulch-specification-for-stormwater-bioretention-devices.pdf

Design related maintenance issues	Recommended fix
Wetlands: Wetlands incorporate a number of mechanical features such as values, sluices, gates, pumps, locks and access hatches – regular checking of these mechanical components ensures that the wetland will operate correctly and will avoid the need to replace broken or jammed parts before their time.	Ensure all values, sluices, gates, pumps, locks and access hatches are easily accessible so that they can be regularly checked to ensure they are in working order. Ensure high plant cover with some deeper pools to moderate summer water temperatures and use pre-treatment swales to reduce nutrient inputs
Wetlands: Complaints about mosquitos breeding in wetlands or botulism in water fowl (dead/dying ducks) requires increased inspections. Both can lead to expensive intervention and renewal works.	Ensure the wetland is designed to eliminate "dead" zones and conditions which encourage mosquito breeding. Create conditions where water is flowing and which are optimal for the survival of mosquito predators.
Wetlands: Woody vegetation or trees can cause problems on dam/ wetland embankments – if the vegetation dies, voids can be created in the embankment which lead to a weakening of the structure.	Do not specify woody vegetation or trees on wetland embankments. Use woody vegetation on areas of cut slopes that have been specially prepared to provide adequate rooting depth and volume to sustain growth
Pervious paving: Pervious paving is highly susceptible to clogging from sediments. High sediment generating areas which discharge onto pervious paving surfaces will clog regularly, causing failure of the device.	To increase the life of pervious paving, only use it in low contaminant generating areas such as low use roads, parking or driveways. If practical, pre-treatment of parking or road areas could be provided via swales or filter strips. Ensure adjacent landscaped areas are below grade to physically prevent water containing sediment washing into previous paving, ideally separate with protective barriers. Do not plant deciduous trees or trees with dense blossom fall adjacent to pervious paving as these can block the surface.
Pervious paving: Standing water can result from seasonal high water tables.	Check ground water levels and geology/ soils before making a decision to use pervious paving as a stormwater management approach.

5.2.2 Case study and workshop findings from Activating WSUD

The Activating WSUD case studies and workshops were also useful to draw out common influences that elevate, or reduce construction and maintenance costs of landscaping, including WSUD devices, and also how costs were allocated between landscaping and WSUD devices. These indicated the construction costs could be greatly influenced by the following four factors.

- The cost of hard landscaping: the materials selected, quantity used and difficulty/complexity of construction. However, higher-quality materials may be used to set a 'tone' in the expectation of higher revenues. For example, Kirimoko used steel edging of permeable pavement, and natural stone to face or replace timber retaining walls, both of which are relatively expensive. In Auckland's Wynyard Quarter, Jellico St rain gardens use basalt tessellated edges, some of which require (expensive) support to maintain raingarden media voume; these edges are also more expensive to maintain (they increase the length of edge). Another highly variable cost is protective edging or bollards for any devices, for example, Remarkables School has a short section of hardened glass barrier to enable unrestricted views of the lake; the majority of the barriers are much cheaper metal railing.

- The cost of soft landscaping: The cost of soft landscaping varies greatly depending on the method of vegetation establishment, the size, age and species selected, and the order volume (providing economies of scale). For example, swales can be vegetatated using grass establishment by seeding, with or without erosion blankets if 'offline' (receiving no runoff). Where swales are online, more expensive ready-lawn sods may be required to avoid erosion. Swales are increasingly vegetated using no-mow, nursery-grown groundover plants to increase amenity and decrease ongong maintenance costs by avoiding mowing; these are the most expensive to establish. The cost of soft landscaping is also influenced by the depth of devices as increased depth increases the cost of excavation (and disposal of unsuitable materials) or, on sloping sites, requiring construction of retaining walls. Increased depth also increases the volume of media required, especially if specialist, engineered-media are imported. However, savings in media depth and/or volume can be offset by restricting the size and species of plants able to be grown, and reducing the resilience of plants to drought in particular (less media stores less water, increasing plant drought stress where plants are unable to exploit soils outside the devices).
- How the costs are allocated in a project: For example, the structural support required for a living roof may be included in the roof cost, or in the building cost. In Auckland, green roof depths over 100-mm depth are not required to achieve stormwater volume treatment (50–75-mm depth is adequate if moisture storage is adequate[79]). Therefore, any depth over 100 mm may be required for landscape aesthetics, not stormwater performance; arguably the increased cost should therefore not be allocated to the stormwater device but to landscaping. Costs of trees placed in a bio-swale or raingarden may be allocated to general landscaping, or the device. As no current NZ guidance/stormwater models provides for benefits provided by trees, trees might be more properly excluded from WSUD costings (i.e. they are part of landscape). Therefore, the additional costs of making devices suitable for trees should also be landscaping costs, not device costs (these are usually a minimum depth and volume of media). This is despite strong evidence that trees enhance stormwater performance and are integral to delivering values related to wellbeing, shade, temperature control, and wayfinding.
- The 'base cost' used in a comparison: Life cycle costing allows a better comparison of 'apples with apples'. For example, a conventional flat roof may be covered with a membrane that is replaced every 10 years; the living roof membrane will be more expensive but not need replacing for 30 years because it is protected from UV and heat extremes (and is engineered to be resistant to roots). A mown grass swale established using ready-lawn is cheap to establish but may require mowing 12–15 times per year (see section on the true cost of mowing).

[79] Fassman-Beck, E A and Simcock, R. 2013. Living roof review and design recommendations for stormwater management. Prepared by Auckland UniServices for Auckland Council. Auckland Council technical report TR2013/045

6. Case study

As part of the overall research project examining the implementation of WSUD in New Zealand, the research team has investigated a case studies showcasing different aspects of green infrastructure, urban design, costs, benefits and maintenance topics. These case studies can be found on the project website.[77] One of the main purposes of the Kirimoko Park case study was to better understand cost and maintenance aspects of the WSUD design at the subdivision scale. The research team:

- investigated the split of costs into TAC, routine maintenance and corrective maintenance to better understand where costs fall within the life cycle period;
- compared costs of WSUD as constructed vs a hypothetical conventional alternative, as a proportion of total development costs (to better understand how WSUD affects subdivision development costs); and
- investigated the cost-effectiveness of WSUD devices vs conventional devices.

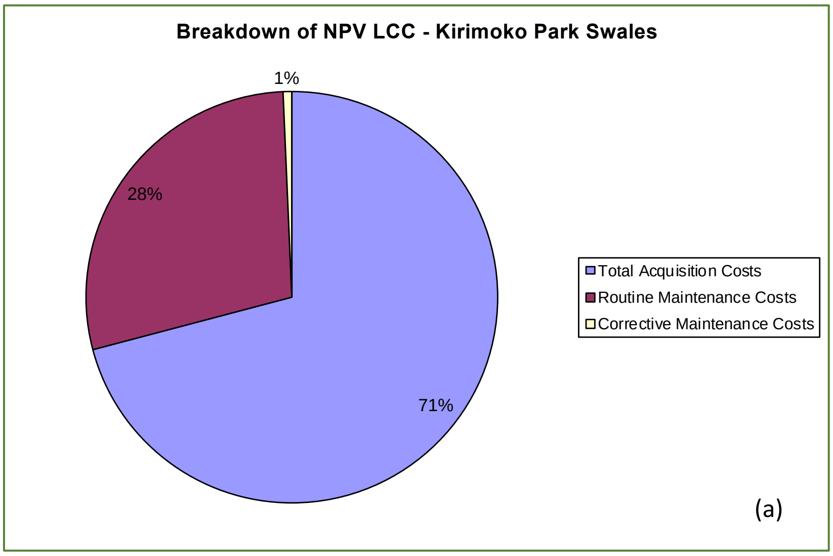
A more detailed analysis of the cost invetsigations is presented in this report.

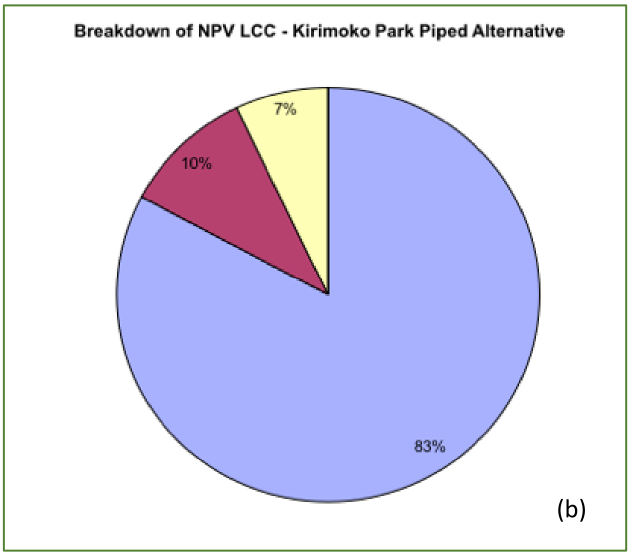
The Kirimoko Park subdivision is about 2 km north of the Wanaka town centre and 1 km east of Lake Wanaka. Stage 1 of the development was completed between 2011 and 2013, in the south west corner of the site across an area of approximately 4.15 hectares. Stage 2 was a similar size and completed in 2014 / 2015 (4.17 hectares) and Stage 3 was completed 2015–2016 (approximately 3.58 hectares). The Kirimoko Park WSD Concept Plan highlights that virtually all primary and secondary stormwater flows are managed on the surface, through swales, raingardens, detention/infiltration basins and fords, with very little or no piping.

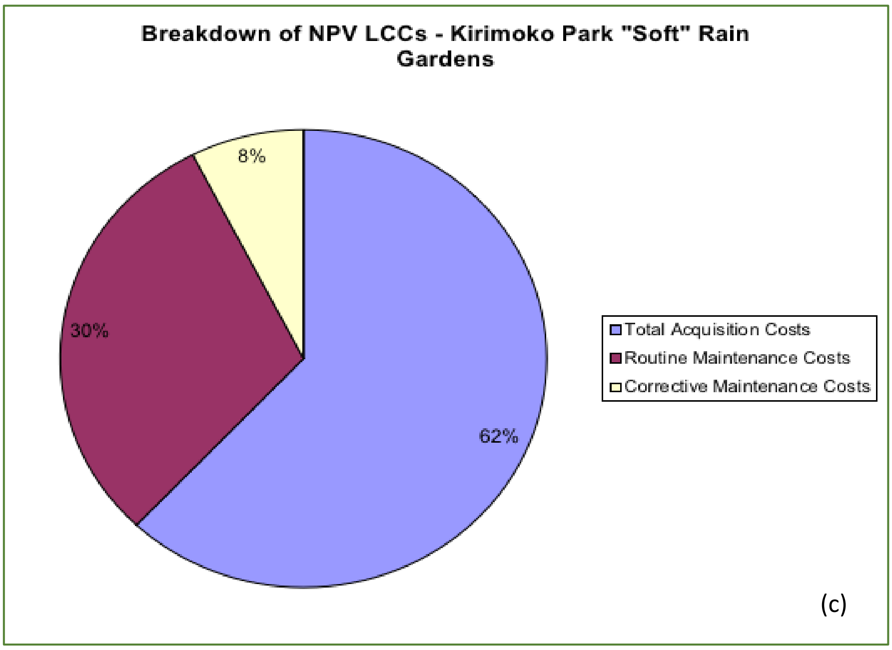
Indicative life cycle cost estimates were generated for swales, pipes, concrete edge and soft infiltration rain gardens (Table 6-1 and Fig. 6-1(a)-(d)). These estimates were generated using COSTnz and are 2018 net present value estimates over a life span of 50 years.

Table 6-1 Unit costs of stormwater infrastructure at Kirimoko Park, Wanaka

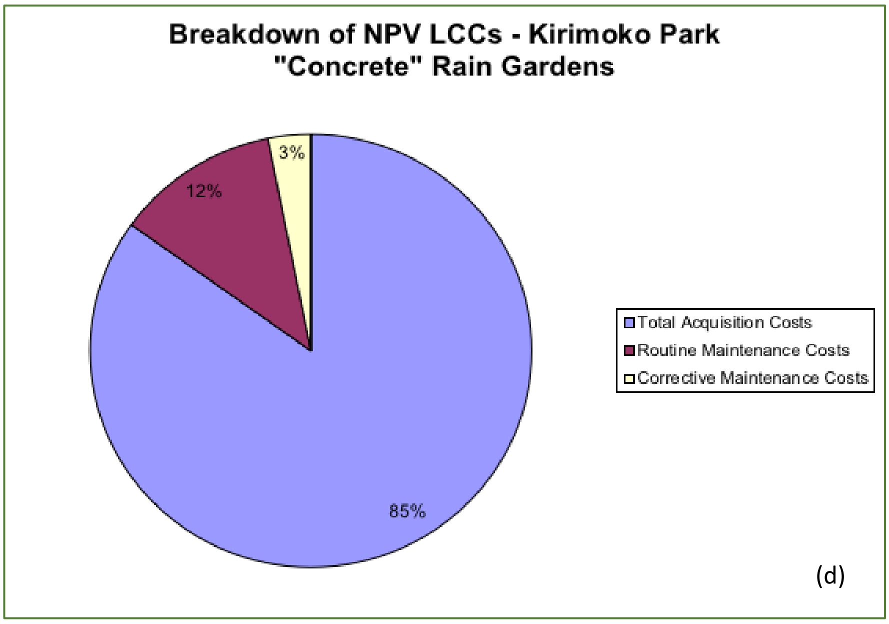
Stormwater Practice	LCC $/unit/year
Stage 1 “concrete” edge rain gardens	$44/m^2
Stage 2 and 3 “soft” infiltration rain gardens	$12/m^2
Swales	$9/ linear m
Pipes	$11/ linear m







Figures 6-1 (a) – (d)
Proportion of cost over time for different types of stormwater infrastructure at Kirimoko Park, Wanaka.



Figures 6-2 and 6-3 show the magnitude of the cost over time for rain gardens and swales. In each case the spikes in the graphs are indicative of costs associated with corrective maintenance activities such as clearing out sediment, disposal and replanting.

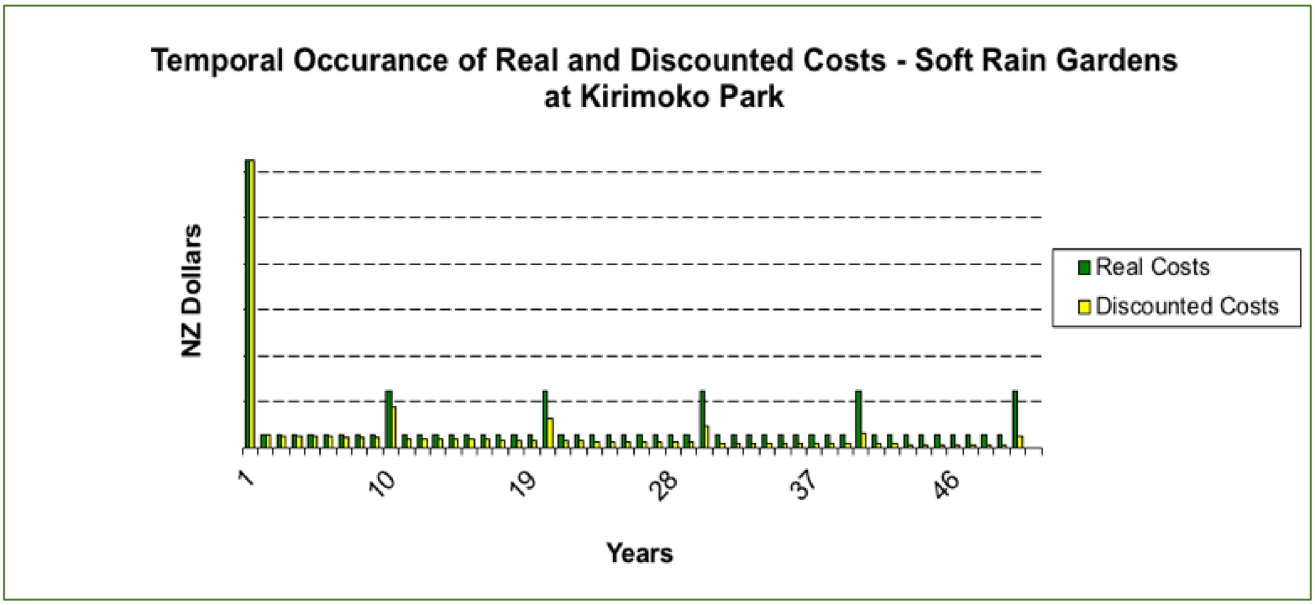


Figure 6-2 Temporal occurance of costs for soft rain gardens at Kirimoko Park, Wanaka.

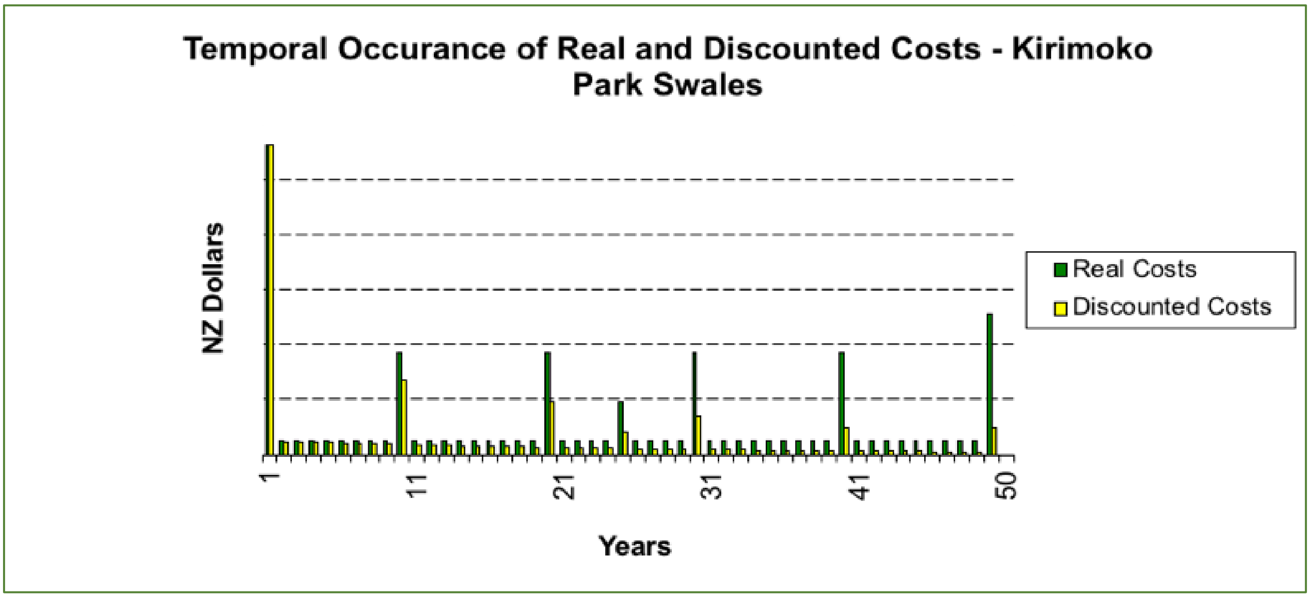
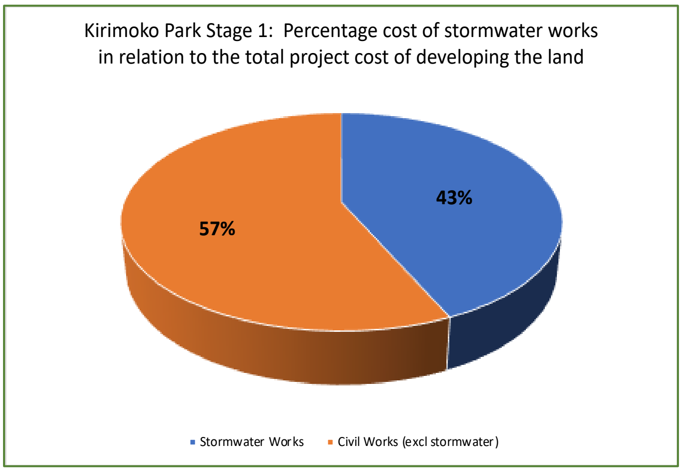


Figure 6-3 Temporal occurance of costs for swales at Kirimoko Park, Wanaka.

Overall, the water sensitive design approach of using swales over pipes, reducing the amount of earthworking needed, and using narrower road widths resulted in an average saving of 22% over a traditional piped, kerb and channel approach to development. Landscaping features are integrated into the green infrastructure practices rather than being additional to it. No savings were realised through Stage 1 due to the use of expensive imported basalt materials, concrete edged rain gardens and pipes. Figure 6-4 shows that a WSUD approach can also reduce the total proportion that stormwater infrastructure contributes to the overall development cost.



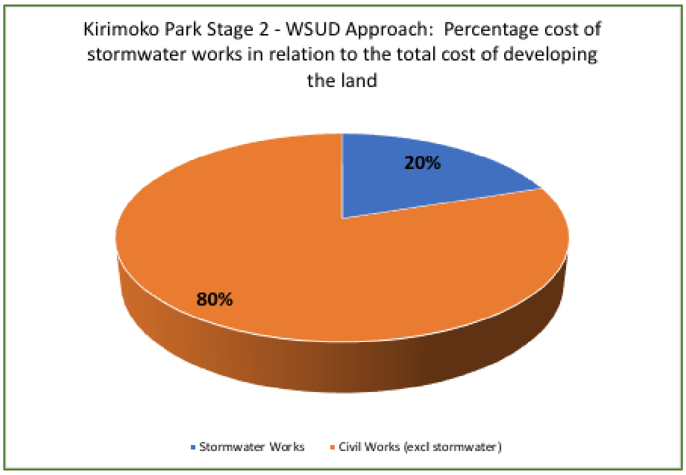


Figure 6-4 Percentage cost of stormwater works in relation to the total project cost of developing the land for Kirimoko Park Stage 1 and 2.

As part of the analysis into the costs associated the green infrastructure at Kirimoko Park, the cost efficiency of different devices in relation to the amount of contaminant removed was calculated. The results shown in the table below clearly highlight that, if removal of sediment, zinc and copper are clear objectives for management, then a combination of swales and rain gardens would be far more cost-effective than using pipes and catchpits.

Table 6-2 Cost efficiency of swales and rain gardens vs catchpit and pipes

	LCC \$/kg/yr TSS	LCC \$/g/yr zn	LCC \$/g/yr cu
Swales/ Rain Gardens	\$20 - \$50	\$120 - \$170	\$720 - \$770
Catchpits and Pipes	\$150	\$2,400	\$5,650

7. Summary and recommendations

7.1 Summary

This report has described the research and findings undertaken to better understand the full life cycle costs of WSUD. Additionally, it has included guidance for operations-led design and construction that impact maintenance costs, focusing on actions that result in Zero Additional Cost or inflation of costs over and above costs of maintaining common conventional landscapes. New cost data have been collected for a range of green infrastructure practices (rain gardens, swales, wetlands, permeable paving, rain tanks and green roofs), and costs of WSUD subdivisions have been analysed and presented.

Updated TACs have been provided for swales, rain gardens, wetlands and green roofs, and equations for determining the TAC of permeable paving and rain tanks has been developed. A key focus of the research has been to better understand and quantify the maintenance activities and costs associated with green infrastructure practices. Maintenance cost information is notoriously difficult to obtain as costs are often buried within general council/ operator maintenance contracts. To fill this gap we have developed a maintenance model framework based on potential maintenance activities, the frequency of these activities and their unit cost. The framework is based on 3 differing levels of proposed maintenance frequency, namely amenity, functional and bare minimum. While the bare minimum frequency provides for the lowest level of maintenance frequency, the rates for this level of maintenance are higher than those provided for the amenity and function levels due to the increased effort needed to restore the GI practice to a functioning form. Overall, from a stormwater management perspective, the most cost effective maintenance model is the “functional” level of maintenance.

The research has highlighted, among other things, that cost information is highly variable, difficult to obtain in a form that is usable and transferable, often only focusses on costs to the public operator, and that financial decision-making models need to take into account avoided costs and cost efficiency in addition to life cycle costs. The current models generally do not take into account the avoided costs of environmental remediation, flood remediation and property clean-up costs, and avoided project construction and landscaping costs. Key savings from a WSUD approach to site development can be made via reduced earthworks, reduced impervious surfaces and reduced hard infrastructure such as pipes, catchpits and kerbs. The models assess projects or infrastructure delivery neither in terms of cost effectiveness indicators such as water quality, hydrological and habitat quality (aquatic and terrestrial) cost effectiveness, nor their effect on housing affordability or private development yield. In general, the short-term cost of delivering the project or infrastructure tends to be the singularly most important decision-making criteria. Financial decision-making models also do not account for where costs fall within the urban development value chain (i.e. whether they are developer-related, public utility, private business or house-hold costs). While the costs may lie with different stakeholders, 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 increases the price of their goods or services, or everyday household costs).

The findings indicate that in order to reduce maintenance costs, designing for maintenance is key. The ZAM approach in Melbourne has been explored and recommendations for this approach, within the New Zealand context, have been made. Maintenance tips, fact sheets, and checklists have been summarised and are included in this report and on the project website.

More focus in New Zealand needs to be placed on operation and maintenance of GI practices. Given that maintenance costs comprise a significant portion of the cost of a GI practice over its life cycle, design of GI should be led by seeking the most cost efficient maintenance outcome instead of focussing on short-term construction and consenting goals. The bare minimum approach for ongoing maintenance of GI leads to spiralling renewal, rehabilitation and corrective maintenance costs.

Internationally, local and national governments can take a lead by building the first examples of WSUD themselves, and/or provide grants/subsidies for private developments that are at the leading edge. These demonstration sites reduce the risk and allow local experience to be developed through design/planning, construction and maintenance. At the same time, the most effective councils will also:

- reduce cost of planning / permitting delays associated with WSUD developments (e.g., fast-tracking consenting).
- invest in their staff by offering training within consents, planning and monitoring related to WSUD; ensuring 'box tickers' have suitable boxes to tick, and field monitoring detects contractors doing poor installation and gets problems fixed proactively. For example, inexperienced contractors will overfill raingardens, lower overflow grates, and worry if water ponds in a raingarden (ponding up to 24–48 hours is expected). Many landscapers are uncomfortable with very sandy, low-organic matter media, as i) it differs from their established media (loams enriched with compost), ii) they want lush-looking landscaping using high-nutrient media, and iii) many don't appreciate that most street runoff will supply both nutrients and water for plant growth.
- invest in research to confirm design and performance of WSUD specific to their region and ecosystems to reduce risks for suppliers and installers. This can deliver standard designs that are accepted as providing volume/quality treatment for the region, and should include specific methods for testing and/or certifying products, such as rain garden media or permeable paving.
- support WSUD with policies that recognise benefits of WSUD that align with local priorities (e.g. swimmable beaches) and signal existing conventional developments will be required to reach similar performance levels in the future. At a minimum, requiring all new council developments and redevelopments to include WSUD, (e.g. in Portland this was Gold LEED or five star-greenstar rating)
- require Council Controlled Organisations (CCOs) to adopt WSUD and ensure their Key Performance Indicators include outcomes that are at least consistent with , and not counter to, WSUD.

Finally, financial decision-making models need not only to assess life cycle costs of GI, but also provide an assessment of cost efficiency and avoided costs relating to WSUD features incorporated into the project as a whole. The "More than Water" assessment tool that has been developed by the research team as a quick-win aims to help address these identified gaps. This tool aims to signal to decision-makers that presenting cost information without including an assessment of the benefits and economic efficiency of a proposal is a fundamentally flawed exercise. WSUD projects need to be assessed in terms of their long-term economic performance and contribution to sustainable environmental management, rather than solely on their short-term impact on infrastructure investment costs.

7.2 Research recomendations

We make the following recommendations for research:

5. Survey representatives of local councils and stormwater utility operators to 'ground truth' the maintenance model framework. Specifically, a project could be set up with 3 or more councils to:
    a) Understand their existing maintenance processes and costs (if these can be unravelled from existing maintenance contracts);
    b) Ground-truth the maintenance models described in Section 4;
    c) Trial the maintenance assessment checklist on GI which they maintain;
    d) Track and document costs associated with the trial to compare with existing processes.

6. Refine the assessment criteria within the MTW tool. Specifically,
    a) the impact of green infrastructure on housing affordability needs to be further investigated and quantified at the house lot scale.
    b) the indirect or intangible costs of environmental impacts associated with the manufacturing, mining or procurement processes of different materials used in GI practices, e.g. the cost of carbon generated from the concrete containment of GI practices, or the cost associated with mining particular soil amendments (such as perlite) to be used in GI soil media.

7. Update the existing COSTnz life cycle cost model to include the information provided in this report and make it freely available to the New Zealand stormwater community.

8. Quantify the contributions of a) large native NZ trees and b) soil amendments and amendment depths in general landscaping areas. Contributions include effectiveness for stormwater quantity and quality mitigation on an annual and seasonal basis in a range of climates, and the wider benefits provided by large trees and landscaping, including health and well-being.