Water Sensitive Cities Australia

WSUD Life cycle costing

Supplementary report 1: Life cycle costing standards and learnings

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WSUD Life cycle costing – Supplementary report 1: Life cycle costing standards and learnings

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1. Introduction

Water Sensitive Cities Australia (WSCA) is undertaking a project to develop a life cycle costing (LCC) tool for water sensitive urban design (WSUD) and similar assets in Australia.

This document summarises the outcomes of a literature review of LCC for WSUD assets and is one of 2 supplementary reports that support, and should be read in conjunction with, the following reports:

- *WSUD Life cycle costing – Context analysis report* summarises stage 1 investigations, including the approach taken, key findings and recommendations
- *WSUD Life cycle costing – Supplementary report 2: Stakeholder consultation* synthesises insights from a survey of WSUD practitioners nationwide as well as consultation with an expert in WSUD life cycle costing.

This report documents the literature sources and findings of the review into WSUD LCC, LCC standards and WSUD guidelines, fact sheets and design drawings. A concise summary of the key findings and recommendations from the literature review is provided in the context analysis report.

1.1 Literature review approach

We collected literature reporting on industry projects and research undertaken on the LCC of WSUD assets in Australia over the past 3 decades to:

- understand the history of work on WSUD LCC in Australia
- understand how the LCC process has been applied to WSUD assets in Australia
- identify the LCC needs of stakeholders and longstanding and pervasive issues that this and future projects need to address
- collect reported cost data and estimates that may be useful for this and future projects
- identify if and how to transfer cost data to locations and contexts where this information is not available but is still required for decision making.

We also reviewed industry accepted guidelines and standards for LCC in Australia (Appendix A). This included relevant references from Standards Australia; Australian National Audit Office (ANAO), Australian Institute of Quantity Surveyors (AIQS) and the New South Wales Government. These standards and guidelines describe the accepted life cycle costing analysis processes.

Appendix B lists the WSUD guidelines and drawings for the focal WSUD assets (biofilters, passively watered trees and permeable paving) we reviewed to identify a consistent basis for the LCC of these assets in terms of their naming conventions, design and life cycle activities.

1.2 Methods

Via an internet search for Australian WSUD LCC literature, we collected documents that:

- reported on projects involving or addressing the LCC of WSUD assets in Australia
- contained Australian cost data or estimates, particularly for the focal assets
- were authored by an authoritative source (e.g., an industry association or group)
- were published in the past 3 decades.

Table 1 identifies the documents reviewed.

1.3 Limitations

The documents reviewed are not exhaustive and do not include reports prepared for specific projects that are not publicly available and may contain sensitive data. We are aware of several WSUD life cycle asset management plans that include LCC information. We propose approaching the owners of these assets and associated reports in later stages to seek their interest in contributing learnings and costing data.

Table 1

WSUD life cycle costing literature

Author	Title	Year	Type	Geographic scope
Blacktown City Council	WSUD asset life cycle cost: Reference guide	2020	Reference guide	Blacktown City, New South Wales
eWater	Life cycle costing of treatment measures	2013	Website manual	Australia
Manning, C	Life cycle cost database: Needs analysis	2023	Industry report	Australia
Melbourne Water	Water sensitive urban design: Life cycle costing data	2013	Literature review	Melbourne, Victoria
Taylor, A	An introduction to life cycle costing involving structural stormwater quality management measures	2003	Industry report	Australia
Taylor, A	Structural stormwater quality BMP cost/size relationship information from the literature	2005	Industry report	Australia
Taylor et al.,	National needs analysis: Life cycle costing data and tools for water sensitive urban design assets.	2010	Industry report	Australia
New WAter Ways & Urbaqua	Maintenance of WSUD assets by local governments in Perth	2021	Industry report	Perth, Western Australia
Urbaqua	Costing WSUD and conventional drainage maintenance in Perth	2020	Industry report	Perth, Western Australia
Water by Design	A business case for best practice urban stormwater management	2010	Business case	Queensland
Water by Design	Guide to the cost of maintaining bioretention systems	2015	Guideline	Queensland

2. WSUD Life cycle costing history

Several noteworthy projects have been undertaken to improve the LCC of WSUD assets in Australia over the past 3 decades. This section summarises those projects chronologically.

2.1 2000s

2.1.1 2003 – Cooperative Research Centre for Catchment Hydrology

Taylor (2003) undertook research with the Cooperative Research Centre for Catchment Hydrology to develop a theoretical framework and a set of simple tools to support LCC of WSUD assets in Australia, referred to as structural stormwater quality management measures in their paper. This was based on the Australian Standard for life cycle costing AS/NZS 4536:1999 Life Cycle Costing – An Application Guide. To date, this represents the only work we know of that sought to develop LCC tools for WSUD assets that was objectively based on the Standard. Asset types considered included gross pollutant traps, sediment basins, buffer strips and grass and vegetated swales, permeable or porous paving, bioretention and infiltration systems, extended detention basins, constructed wetlands and ponds. This work responded to several issues affecting the LCC of these assets that are still prevalent today (Taylor & Wong, 2002):

- concerns about the cost of assets
- little or no consistency in the way stormwater managers record life cost data
- poorly established asset or financial management systems to record cost data. This was noted as being particularly the case for small to medium-sized local governments.
- difficulties in retrieving life cycle costings from cost data that wasn't recorded properly in the earlier life cycle stages of assets (e.g., planning and design)
- simple sources of uncertainty that severely comprise the usefulness of cost data (e.g., whether GST is included, what costing elements the cost data includes and when expenditure occurred). Without an understanding of when costs were incurred, it is not possible to adjust cost data for inflation in the future.
- developers wanting to minimise acquisition costs and stormwater managers wanting to minimise ongoing life cycle costs, particularly maintenance costs.

They identified the following costs commonly associated with WSUD assets:

- site selection processes
- grant application costs (i.e., to obtain State or Commonwealth funding for capital works)
- feasibility studies
- conceptual, preliminary, and detailed designs
- project and contract management costs
- construction/purchase costs, including related costs such as the cost of environmental impact assessment, gaining environmental permits and subsequent environmental management (e.g., erosion and sediment control)
- routine maintenance costs, including related costs such as disposal of wastes, health and safety training of staff, etc.
- renewal and adaptation costs (e.g., unusual costs associated with reconstruction of the asset or adding new features)
- decommissioning costs.

These costs were placed in the context of the life cycle phases defined in the Australian Standard for life cycle costing AS/NZS 4536:1999 Life Cycle Costing – An Application Guide as follows:

- Acquisition, which should include the following (where relevant):
  - Identification and definition of the need for the stormwater management measure
  - Conceptual design
  - Preliminary design
  - Detailed design and development
  - Construction (or purchase of a proprietary product)
- Use and maintenance
- Renewal and adaptation
- Disposal/decommissioning.

Figure 1 presents a conceptual cost distribution graph representing the above.

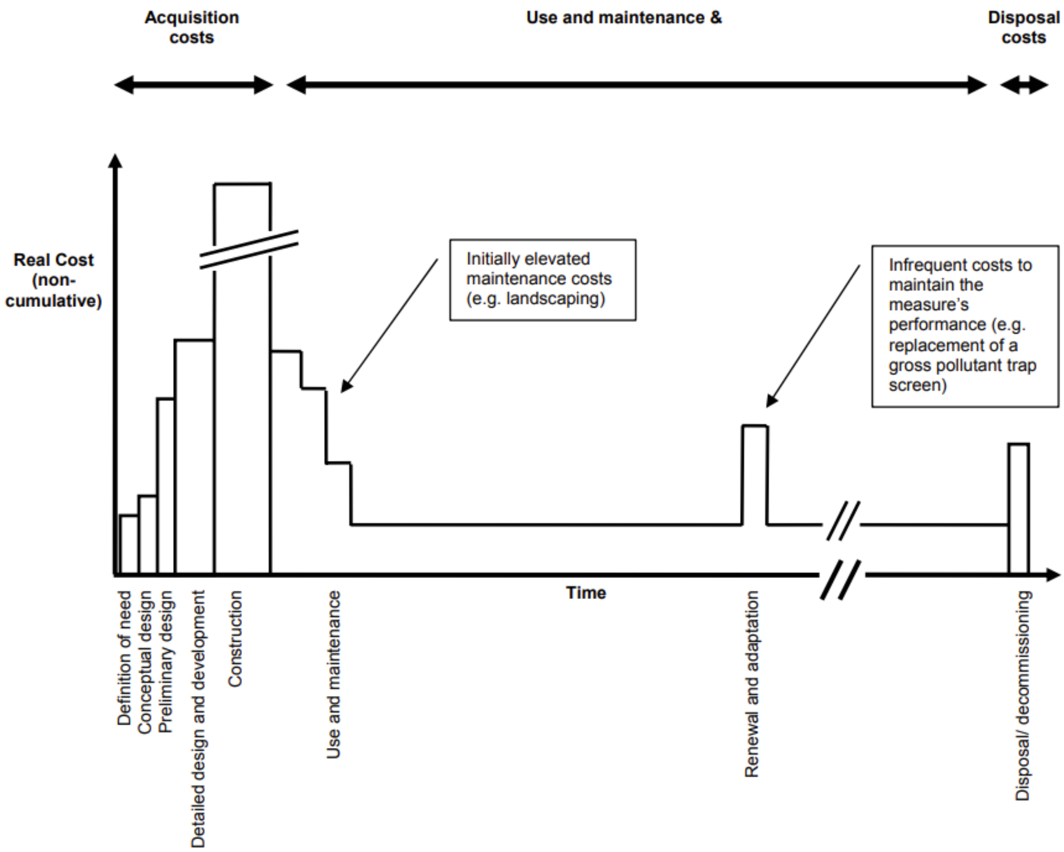

Figure 1
Conceptual cost distribution graph for a WSUD asset

They developed a simple LCC recording sheet to:

- collect critical LCC data
- collect data in a consistent and simple manner
- minimise the risk of common mistakes that occur when recording data that can make LCC difficult.

The design of the recording sheet was based on the Australian Standard AS/NZS 4356:1999 Life Cycle Costing – An Application Guide.

The following were proposed as potential uses for the simple recording sheet (Taylor, 2003):

- paper-based system for collecting LCC data
- framework for an electronic database to record data
- framework for a simple spreadsheet to record data
- checklist to ensure asset or financial management systems record data.

Based on the AS/NZS 4356:1999, they also developed a simple LCC model for a hypothetical asset (i.e., a constructed wetland) to demonstrate how data recorded observing the sheet could be used to track the costs of an asset over its life cycle and estimate cost elements and the life cycle cost. The model was a discounted cash flow spreadsheet as presented in Figure 2.

Cost element[1]	Estimated cost ($)[2] cl									
Financial Year Starting:	20…	20…	20…	20…			20…	20…	20…	20…
Acquisition costs[3]:										
▪ Total costs associated with defining the need for the BMP (e.g. running site selection processes, feasibility studies, grant application costs):										
▪ Total conceptual, preliminary and detailed design costs:										
▪ Total construction costs (including project management costs, contract management costs, and cost of environmental assessment, permits and management):										
Maintenance costs[3]:										
▪ Costs associated with typical maintenance events (e.g. cleaning out a gross pollutant trap), including costs associated with relevant administration, BMP inspections, staff training and waste disposal:										
Renewal and adaptation costs[4]:										
Disposal/decommissioning costs[5]:										

Figure 2
Simple life cycle costing model

They provided the following 6-step LCC process for WSUD assets, which was also based on the Australian Standard. They noted that this ‘ideal process’ is primarily designed for detailed analysis of new products (e.g., electrical appliances), and consequently needs to be simplified for practical application to WSUD assets.

1. Prepare a LCC analysis plan

This is essentially a project planning step, which outlines the objectives and scope of the analysis, identifies limitations and constraints, identifies the options to be evaluated (if relevant), and estimates the requires resources to undertake the analysis.

2. Develop or select a LCC model

In its simplest form, a LCC model is an accounting structure that breaks down the life cycle costs into cost elements (as shown in Figure 2) and allows users to estimate costs associated with each element. An example of a simple LCC model is a discounted cash flow spreadsheet that tracks all the significant costs shown in Figure 2 over time and calculates a life cycle cost.

3. Undertake LCC model analysis

This step represents one of the more advanced elements of the LCC analysis. It may include identifying cost drivers by examining model inputs and outputs to determine those elements that most significantly impact on the overall LCC. Sensitivity analysis may also be undertaken to determine the impact on the results of variations to assumptions and uncertainties (e.g., discount rates). Finally, the outputs of the LCC analysis are compared against the initial objectives of the LCC analysis plan.

4. Document the LCC analysis

The Australian Standard for LCC encourages structured documentation of the analysis including a report containing: an executive summary; purpose and scope; LCC model description; LCC model analysis; discussion; and conclusions and recommendations. Again, it is suggested that for application in stormwater management, this step needs to be tempered with considerations of practicality.

5. Review LCC results

The Australian Standard encourages having an independent analyst review results to ensure objectivity.

6. Update the LCC analysis

The Standard recommends updating the LCC model as knowledge grows on asset costs over its life cycle. This process is represented by the dotted line in Figure 3.

LCC typically captures traditional costs that have a market (e.g., construction expenses) and therefore provides only one input into an evaluation process, which should also consider the environmental and social benefits and costs of decisions to ensure optimal outcomes for the community. Other methods to assess these benefits and costs include the following:

- Life cycle assessment, which is defined as the “compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system through its life cycle” (AS/NZS ISO 14040: 1998, p. 2)
- Benefit–cost analysis that places an approximate monetary value on environmental and social costs/benefits using valuation methods
- Multi-criteria analysis within a ‘triple-bottom-line’ assessment framework, which considers traditional costs, environmental costs/benefits and social costs/benefits.

They developed a theoretical framework for an evaluation process that captures the above (Figure 3).

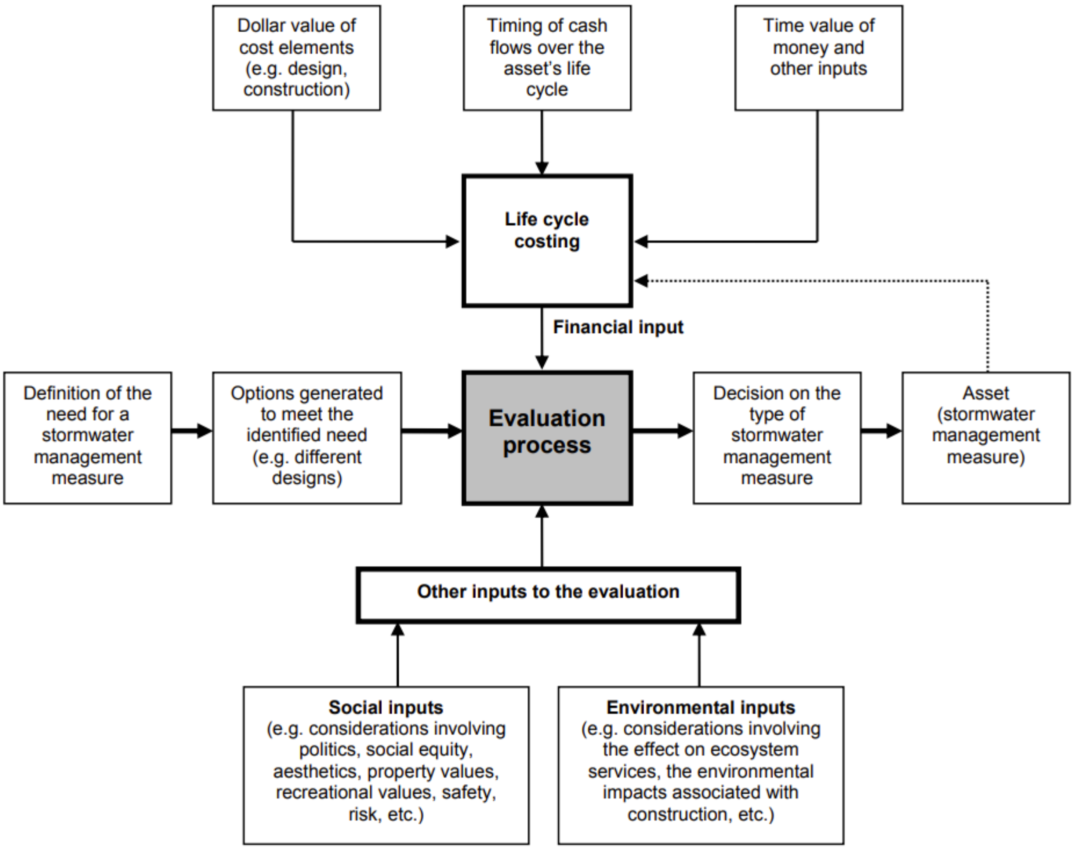

Figure 3
Theoretical evaluation process

2.1.2 2005 – Cooperative Research Centre for Catchment Hydrology

Building on his previous work, Taylor (2005) collected cost data from Australia and elsewhere to:

- inform the development of a LCC module in the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) software to be used in the design stage of assets to estimate cost elements and LCC
- provide guidance to stormwater managers who require costings while the LCC module was being developed
- help users choose inputs into the LCC module if they do not wish to use default values.

Cost data was reported for the following asset types.

- gross pollutant traps
- constructed wetlands

- infiltration trenches/systems
- permeable paving
- buffer/filter strips
- grassed/vegetated swales
- bioretention systems
- sand filters
- sediment basins/traps
- ponds
- rainwater tanks.

2.1.3 2005 – eWater Cooperative Research Centre

The eWater Cooperative Research Centre developed a LCC module in the MUSIC software (see eWater, 2013). Developing the module involved:

- generating statistical models for predicting the cost elements and LCC of WSUD assets based on design attributes (e.g., area of treatment zone, catchment area) and historic cost data collected by Taylor (2005) and the CRCCH (eWater, 2013)
- integrating these models and LCC functionality into the MUSIC software.

The design of the module was based AS/NZS 4356:1999.

A general overview of the functionality of the module is outlined below.

Users specify the following properties for the asset (Figure 4) (eWater, 2013):

- real discount rate: the rate (%) used to discount all future costs back to a base date
- annual inflation rate: the rate (%) used to convert costs to a new base date
- base year for costing (base date): the calendar year the LCC results will be reported in
- span of analysis: the length of time over which the LCC analysis will be done.

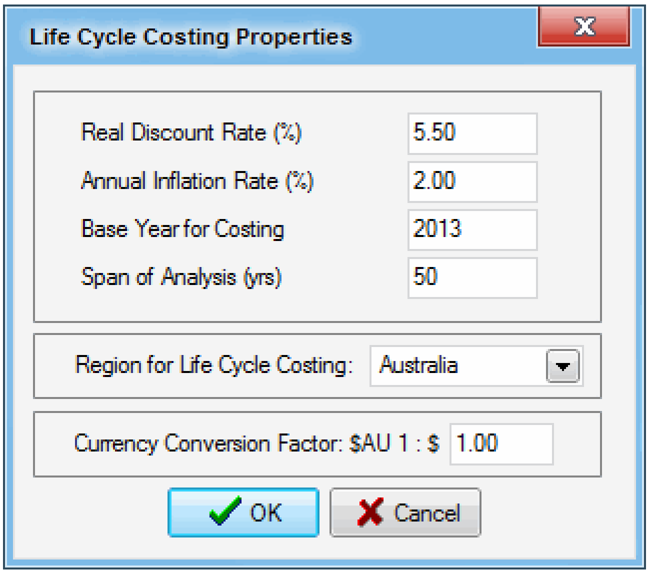

Figure 4
Life cycle costing properties

Once the above is specified, users run the analysis to estimate the following cost information for the asset (Figure 5) (eWater, 2013):

- life cycle cost: the sum of all discounted costs over the life cycle of the asset expressed in dollars relevant to the base date
- equivalent annual payment: the LCC divided by the expected life of the asset in years
- equivalent annual payment per kg of pollution treated: the above divided by the kilograms of pollutants treated by the asset each year.

This information may also be generated for treatment trains (i.e., a system of assets providing a combination of primary, secondary, or tertiary stormwater treatment) (see Water by Design, 2009).

Users may also generate and export the following (eWater, 2013):

- relative cost distribution: a graph showing the relative contribution of each cost element to the LCC of the asset or treatment train
- temporal cost distribution: a graph showing when costs are incurred over the life cycle of the asset or treatment train (figure 6)
- sensitivity analysis: a graph showing how the asset's predicted LCC varies depending on the discount rate.

Users can manually enter costings into the life cycle model (e.g., using costings from local sources) if they don't want to use default values (eWater, 2013).

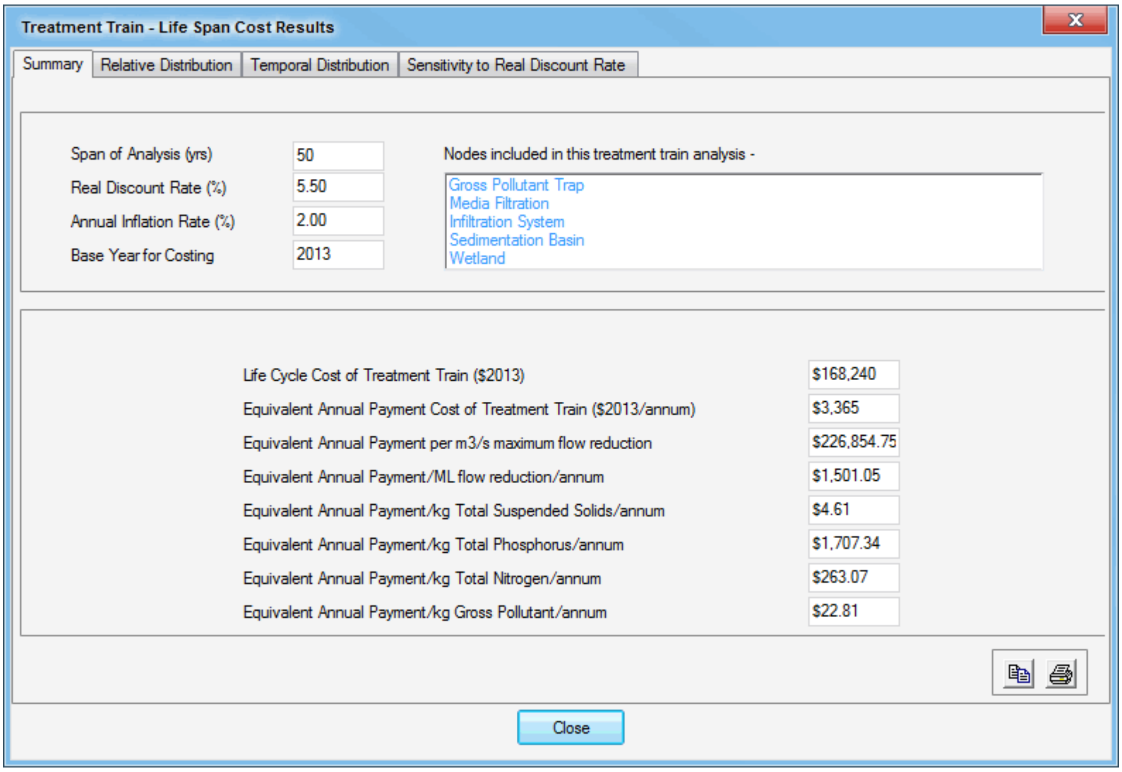

Figure 5

Life cycle costing summary results

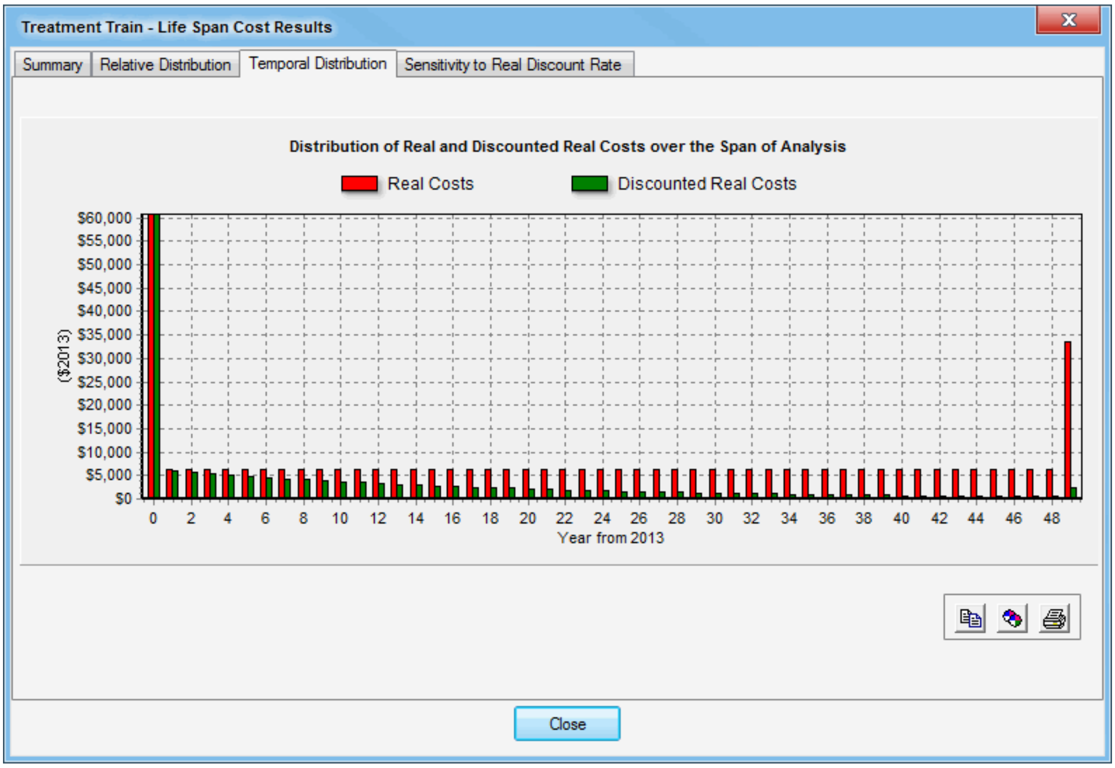

Figure 6

Temporal cost distribution graph

2.2 2010s

2.2.1 2010 – Sydney Metropolitan Catchment Management Authority

Taylor et al. (2010) undertook a series of workshops in Sydney, Melbourne, Adelaide, Perth and Brisbane with practitioners involved across the life cycle of WSUD assets to:

- map processes involved across all WSUD asset life cycle stages
- identify key stakeholders involved in each stage
- identify the LCC needs of these stakeholders
- prioritise these needs against other WSUD-related capacity building needs
- recommend tasks that would meet the prioritised needs.

Workshops involved discussions with small groups of practitioners and an anonymous survey.

This work responded to research from across Australia highlighting inadequate LCC collection and estimation tools as a significant barrier to the adoption of WSUD (Rahman, et al. (2005). Taylor et al. (2010) noted that while some attempts had been made to overcome this issue, as described above, the following work remained:

- identifying the needs of different stakeholders who are involved in the life cycle of WSUD assets
- collecting easily accessible and reliable cost data and development of estimation tools that meet these needs.

For the latter, Taylor et al. (2010) noted data for the MUSIC LCC module was collected in 2003-04, at which time reliable cost data was sparse, and that the design of many WSUD assets had since changed. Further, the module was mostly used at the design stage, so wouldn’t likely provide any information about other stages including planning, construction and maintenance. And previous projects that collected cost data were time consuming and limited by poor record keeping. They recommended future projects learn from these experiences and identify cost-effective ways of collecting data at the outset, starting with understanding the needs of different stakeholders.

Taylor et al. (2010) found the life cycle of WSUD assets involves 3 primary stages and 15 secondary stages (Figure 7), with a high degree of consistency across the 5 cities.

Primary stages	Secondary stages (may overlap)
1. Design and planning	Planning activities (e.g. strategic asset planning, and early 'due diligence' work associated with development proposals).
	Setting WSUD-related objectives and/or policy.
	Conceptual design (includes site assessment work, stakeholder consultation and may involve development assessment).
	Business case development / cost assessment.
	Functional / sketch design.
	Detailed design (may involve development assessment).
2. Construction and establishment	Tendering.
	Construction (including erosion and sediment control activities).
	Establishment (including erosion and sediment control activities).
	Handover of assets.
3. Maintenance and asset management	Operation of assets.
	Inspections and routine maintenance.
	Monitoring and auditing performance.
	Rectification / corrective maintenance (e.g. of poorly designed assets).
	Decommissioning, replacing or renewing.

Figure 7
Life cycle stages of WSUD assets

At a national level, the greatest demand for LCC was for bioretention systems (including raingardens), constructed wetlands and stormwater reuse systems (Figure 8), although some cities had specific needs (e.g., swales in Perth).

While stakeholders were diverse, they identified 3 main stakeholder groups:

- Conceptual designers: These are usually professionals preparing conceptual designs who require estimates of all cost elements (e.g., total acquisition cost, total annual maintenance cost, total renewal cost and decommission cost) and the LCC in a form that allows them to assess cost effectiveness or 'cost performance (Taylor et al., 2010). They may use estimates when running LCC analyses in MUSIC in place of default values. Taylor et al. (2010) referred to these data as 'WSUD cost estimates'.
- Strategic planners: These are usually professionals involved in the strategic planning of developments who require the same cost information as the above but need to access it directly (e.g., via a downloadable or online database) rather than through MUSIC. They also need to understand how costs are spread out over time for financial planning. Taylor et al. (2010) also referred to these data as 'WSUD cost estimates'.
- Detailed designers and construction and maintenance professionals: These are usually professionals involved in detailed design, construction and maintenance of assets who require detailed cost estimates for construction and maintenance in a bill or quantities or similar format to inform project-specific budgets, tenders or quotes. They also need to access the information directly (e.g., via a downloadable or online database). Taylor et al. (2010) referred to these data as 'WSUD construction rates estimates' and 'WSUD maintenance rates estimates'.

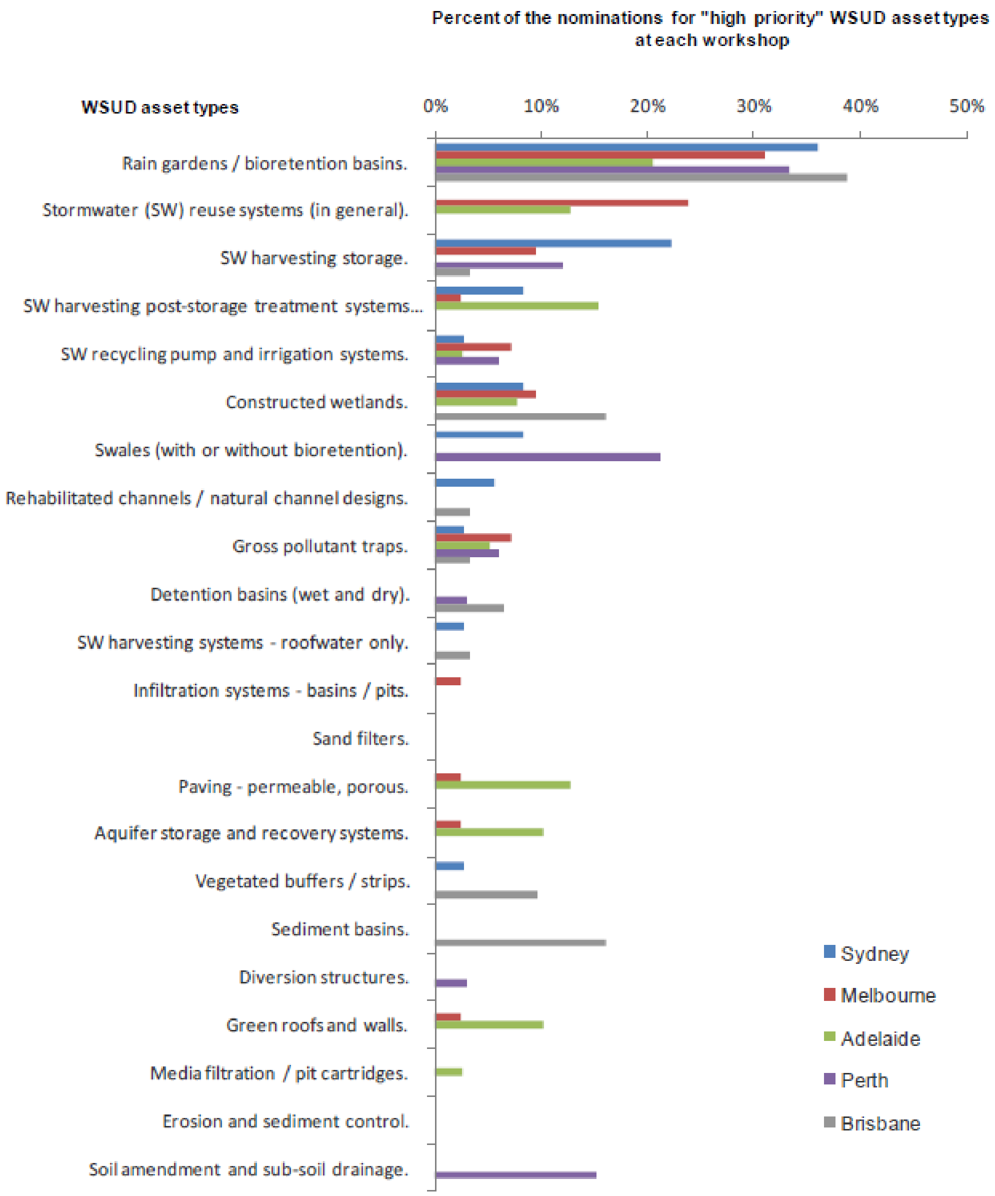

Figure 8
Priority WSUD asset types across Australian cities

Taylor et al. (2010) emphasised that all cost estimates should account for a limited number of factors that can significantly affect costs (e.g., design, geographic location, service level). They identified 7 possible LCC collection and estimation tools, recommending the following 5 as representing the best options for meeting all stakeholder needs:

1. LCC database

A downloadable database providing the following:

- WSUD cost estimates: estimates for all cost elements that can be quickly generated by users such as conceptual designers and strategic planners. These estimates were recommended to be in a format like those currently available in the MUSIC LCC module to support its continued use as a design support tool.
- WSUD construction rates estimates: estimated rates for typical construction items similar in format to those found in Rawlinson's Australian Construction Handbook.
- WSUD maintenance rates estimates: estimated rates, frequencies and resourcing requirements (e.g., plant, equipment, personnel) for typical establishment and maintenance activities.

The database should provide cost estimates for a broad range of WSUD asset and designs in different geographic regions, rather than national averages.

2. LCC recording template

A downloadable, standardised template based on the database that can be used by stakeholders to record cost data. The template should be informed by knowledge of how costs are typically estimated and recorded in current asset management and construction and maintenance processes and systems. This approach would allow the template to be integrated into asset or financial management systems, ensuring recording data is business as usual. This approach would also avoid the need for significant changes to construction and maintenance budgeting, quotation, tendering and reporting processes which may be difficult and time consuming. Cost data recorded observing the above could be used to update the database (e.g., by requesting digital copies of stakeholder databases that have been based on the template and used to record cost data).

3. LCC analysis spreadsheet

A tool for estimating the total costs incurred over user specified planning intervals (e.g., 10 or 20 years) and the LCC. The tool would use default cost estimates drawn from the database but also allow users to use their own costings.

4. LCC guideline and training

A guideline or manual including descriptions of the life cycle costing approach, the database and life tool, their limitations, and guidance on how to use them. Taylor et al. (2010) also suggested it be accompanied by a freely available tutorial video.

5. LCC website

A national website to house the above.

Taylor et al. (2010) recommended updating the tools periodically (e.g., every 5 years). They also recommended a fee system to fund ongoing maintenance and continual improvement:

- a modest fee for users accessing the WSUD cost estimates
- a larger fee for users accessing the WSUD construction and maintenance rates estimates.

They recommended securing an owner or long-term funder as a critical foundational step.

2.2.2 2010 – Water by Design

In 2010, Water by Design published a business case for best practice urban stormwater management. This work responded to perceptions in the industry that the costs of WSUD are a barrier to its widespread adoption. It involved developing a simple cost-benefit framework populated with the likely costs and benefits of using WSUD assets in several land use development contexts. Cost and benefit data was collected through a literature review, semi-structured interviews with industry stakeholders, and a case study for different developments from across Queensland.

2.2.3 2013 – Melbourne Water

Melbourne Water developed a LCC data table to assist local governments and others in Melbourne assess the LCC of WSUD assets. The project involved a literature review, survey, workshops with local governments, and the collection and analysis of LCC data from the region. This work appears to have responded to general uncertainty around the maintenance requirements and costs of WSUD assets for local governments in Melbourne. For example, Lewis (2013) reported that only 5% of survey participants have an in-depth understanding of the maintenance requirements of these assets and only 3% have an in-depth understanding of their costs.

Lewis (2013) noted the following limitations for cost data collected through the project:

- single source of data (e.g., based on a single contract)
- cost of equipment hire not included in data
- combined maintenance cost estimates for asset groups
- few sources of cost data for each asset type
- small cost data sets.

Key results from the project were:

- a good range of cost data for constructed wetlands
- a reasonable range of cost data for bioretention systems and tree pits under contract
- a poor range of cost data for sediment basins and gross pollutant traps

- no suitable cost data for swales, porous pavements, ponds, infiltration systems and sand filters
- some cost data sets (e.g., constructed wetlands) included data sourced primarily from confidential rates within a single contract.

Lewis (2013) noted proactive maintenance on WSUD assets is likely to produce significant LCC savings compared to reactive maintenance.

They provided the following disclaimer for the use of the cost estimates:

The cost estimates provided should be considered as a starting point only and represent the best cost estimates available based on current information (Oct 2013). The cost estimates will be reviewed and refined over time as better data becomes available. It should be noted that data are generally based on 'standard residential' developments and the cost of equipment hire is not included in the estimates.

2.2.4 2015 – Water by Design

In 2015, Water by Design published their *Guide to the Cost of Maintaining Bioretention Systems*. They drew on several case studies from south east Queensland (SEQ) and north Queensland to identify the main activities involved in maintaining bioretention systems and estimate costs. Cost data was collected from more than 100 bioretention systems in 14 data sets. Cost estimates did not include administration.

2.3 2020s

2.3.1 2020 – Blacktown City Council

In 2020, Blacktown City Council published a reference guide for WSUD asset LCC estimates. The reference guide was based on a project completed by Ideanthro and Renew Solutions in 2019 that collected and analysed cost data from the Blacktown local government area and other locations around Australia. Blacktown City Council (2020) noted very little new and useful cost data had been made publicly available in the past decade, so cost data from the previous decade had to be adapted (e.g., Melbourne Water, 2013; Water by Design, 2015). Further, the resulting cost estimates had large amounts of variability because the cost data did not account for key differences in design, location, data collection processes and other factors that can significantly affect costs. Given this, they recommended Blacktown City Council staff use locally sourced cost estimates when preparing budgets and quotes in place of those in the reference guide.

They also recommended the following ways for council staff to better record cost data;

- develop a standard way to capture cost data
- ensure cost data is useful for LCC (e.g., data collected on an asset-by-asset basis)
- record detailed costs and describe the activities undertaken
- store the cost data in an accessible format.

They provided the following disclaimer for the use of the cost estimates.

The cost estimates provided should be considered as a starting point only. They represent the best cost estimates available based on current information. The cost estimates will be reviewed and refined over time as better data becomes available.

2.3.2 2020 – Urbaqua

In 2020, Urbaqua collected and estimated maintenance costs for WSUD assets so they could be compared against conventional drainage infrastructure. The project involved collecting and analysing cost data from local governments and publicly available sources (e.g., such as those described above) to estimate costings. Key findings relevant to maintenance costs are presented below:

- Local governments generally do not collect data on maintenance activities, including costs.
- Many factors can influence maintenance costs including, but not limited to, asset type, location, access, size, community interest, construction, maintenance service level, need for traffic management, and external versus in-house delivery. Further, maintenance activities required during establishment are generally different to, and greater than, what is required in a fully constructed/operational asset.

2.3.3 2023 – Water Sensitive Cities Australia

Manning (2023) revisited the LCC needs of industry stakeholders though expanded the scope to include other water sensitive options (e.g., on-site wastewater systems). This work responded to the following needs for better LCC for water sensitive options as identified by partners of Water Sensitive Cities Australia (Manning, 2023):

- improve business cases
- allow planners and decision makers to confidently compare water sensitive options and support an ‘all options on the table’ approach (Manning, 2023)
- determine actual costs across a range of assets and locations to reliably inform annual maintenance budgets, including materials, plant and labour
- ensure an accurate and reliable understanding of maintenance costs are considered in the planning stage of the life cycle.

While the benefits of water sensitive options had been the focus of significant work by the former Cooperative Research Centre for Water Sensitive Cities (CRCWSC), resulting in the INFFEWS Benefit: Cost Analysis (BCA) and Value Tool (see Pannell, 2019 and Iftekhar et al., 2018), a significant gap still exists for costs. Manning (2023) noted the following pervasive and longstanding issues that are yet to be properly addressed despite the noteworthy attempts described above:

- patchy cost data with unknown or questionable quality assurance and control
- historical cost data that hasn't kept up with changes in asset designs, asset or financial management systems, and design and decision support tools.

Consistent with Taylor et al. (2010), Manning (2023) noted that the only mainstream LCC tool (i.e., the MUSIC LCC module) is mostly accessible to and used by only designers and therefore does not readily support the planning, construction and maintenance life cycle stages. It is also substantially out of date and no longer used by many designers. He confirmed the following needs from Taylor et al. (2010) as still being relevant today:

- improved identification of the needs of different stakeholders across the life cycle of water sensitive options
- easily accessible, reliable, and up-to-date cost data to support the above.

Manning (2023) supported the following recommendations from Taylor et al. (2010):

- Create a national LCC database that meets the needs of a range of stakeholders across Australia with agreed and documented definitions, assumptions and limitations.
- Identify a long-term project sponsor, champion and owner for the above.

To address the above, Manning (2023) scoped the development of a LCC database for water sensitive options. This involved consultations and a workshop with relevant stakeholders from around Australia to identify:

- stakeholders involved in each life cycle stage
- the LCC needs of stakeholders across these stages
- a desired mainstreaming outcome for the above.

Cost estimate needs for each life cycle are presented below (Manning, 2023). These stages are generally consistent with the stages described by Taylor (2003) and Taylor et al. (2010):

- Strategic planning
    - Suitable for decision support tools including BCA
    - Assumptions and uncertainty clearly articulated
    - Capital expenditure

- Financing and approvals
  - As above
- Design and procurement
  - Unit rates or bill of quantities (BoQ)
  - Suitable for informing procurement decisions
  - Capital expenditure
- Construction and establishment
  - Unit rates or BoQ
  - Suitable for informing construction and establishment plan including plant and labour provisions
  - Capital expenditure
- Asset handover
  - Unit rates or BoQ
  - Suitable for informing maintenance plan including plant and labour provisions
- Asset management including operation and maintenance
  - Unit rates or BoQ
  - Suitable for informing asset management plan, updates of maintenance plan including plant and labour, and annual budgets
  - Operating expenditure.

The exercise identified a gap in costings for the strategic planning and 'optioneering' stages of the life cycle of water sensitive options (Manning, 2023). Gaps in detailed construction, establishment and maintenance costs were also identified and noted as being important.

Through the scoping, Manning (2023) articulated the following problems affecting LCC for water sensitive options:

- Lack of confidence in LCC data
- Lack of cost data to assess options in the planning stage. As a result, water sensitive options are often considered too risky from a cost perspective even before they are evaluated against non-water sensitive options.
- Problems with maintenance undertaken by asset owners owing to deficiencies in skills and information about maintenance and its costs. Improved recording and estimation of costs increase understanding of the normal ranges and subsequently efficiencies and innovation.
- Lack of cost data for some types of water sensitive options (e.g., WSUD assets) owing to a focus on assets that we already have (e.g., pits and pipes) rather the ones we may want or even need in the future (e.g., green roofs and walls, permeable paving).
- Gaps in the spatial coverage of cost data. Recording and estimating costs from around Australia would allow practitioners to access and use data that reflects their geographic location and climate.
- Where cost data already exists, it often doesn't have an owner and is out of date (i.e., doesn't reflect current designs).

- There are no consistent standards for recording and managing data. Even consistent definitions for LCC and a common framework to record and manage it would benefit the industry.
- Cost data that does exist is underutilised in BCA including the INFFEWS tools. This cost data is typically used only in the design stage in tools like the MUSIC LCC module. This data may not be available, or in a useful form, to those undertaking BCAs to support decision making in the planning or other life cycle stages.

Manning (2023) reinforced the need to collect cost data and estimate costs to support the "identification, assessment, and approval of water sensitive options" (Manning, 2023). He articulated the following problem statement for these projects:

How can we create a national tool to transform our approach to understanding lifecycle costs so that we can better support an 'all options on the table' approach to decision making, and the goal of creating water sensitive cities?

Manning (2023) made the following recommendations for future projects:

- Focus on overall LCC as distinct to the construction, establishment and maintenance cost components, and then focus on 1 or 2 asset types such as permeable paving, biofilters or natural channels, to provide a proof of concept.
- Identify and confirm the project sponsor to champion and resource the subsequent stages, and importantly identify and confirm the long-term custodian of the product.
- Undertake a detailed risk analysis to identify risks and mitigation strategies for the product including its implementation and governance.

2.4 Key findings

Several noteworthy projects have been undertaken to improve the LCC of WSUD assets in Australia over the past 3 decades (e.g., Taylor & Wong, 2002; Taylor, 2003, 2005; Taylor et al., 2010; Manning, 2023). However, most recommendations haven't been implemented and there appears to be no national level, coordinated effort for improving LCC for WSUD assets in Australia (outside of this project) and this has been the case for the past 20 odd years.

Some previous projects (e.g., Taylor 2003, 2005; Taylor et al., 2010; Manning, 2023) provide a useful understanding of the LCC needs of stakeholders as well as longstanding and pervasive issues that should be addressed in this and future projects. All highlighted the need for appropriate and long-term funding, governance and management of a national-level LCC process and tool for WSUD assets.

Taylor (2003), Taylor et al. (2010) and Manning (2023) recommended developing the following components of a LCC process and tool for WSUD assets:

- **Cost database**: a database including cost data and estimates for input into a LCC analysis model to support decision making across the life of assets (e.g., planning, design, construction and other operational phases). This includes rates for construction and operational phase works items similar in format to those in Rawlinson’s Australian Construction Handbook. Cost estimates should also be formatted to allow integration into common asset planning, design and management processes and tools (e.g., Assetic, Predictor, INFFEWS, MUSIC).
- **Cost data recording templates**: a set of standardised templates for recording cost data for programmed upload into the cost database and integration into common asset planning, design and management processes and tools.
- **LCC analysis model template**: an Excel-based tool for estimating the total costs, or part thereof, incurred over user specified planning intervals (e.g., 10 or 20 years). The tool would use default cost estimates drawn from the database but also allow users to use their own cost data or estimates.
- **Guideline**: a guideline or manual including descriptions of the LCC analysis, its components and how to use them.
- **Training video**: a freely available tutorial video providing a quick overview of the same guidance found in the guideline.
- **National website**: a national-level website to host the above.

Some projects provide parametric cost estimates for the focal assets, but their usefulness is limited due to high variability likely owing to uncertainties in their costing basis (e.g., design, construction, operational phases and how these are influenced by local conditions, constraints and policy and other requirements). Notwithstanding the above, several drivers affect asset life cycle costs that must be accounted for when transferring estimates from one context to another.

3. Glossary

Asset: Any item that has a value to an organisation over time (e.g., building, physical plant, equipment, and computer software) (ANAO, 2001)

Asset life: the time interval between the recognition of a need or an opportunity through to the creation of an asst to its final disposal (ANAO, 2001)

Capital cost: the costs associated with the purchase or major enhancement of fixed assets. They are often referred to as one-off costs (Government of Western Australia, 2005). Costs resulting in the creation or improvement of the asset (Government of Western Australia, 2005)

Cost driver: an aspect of the asset that has a direct, significant impact on the scale of costs associated with the creation, use or disposal of the asset (ANAO, 2001)

Cost element: represents the component costs of the overall treatment measures lifecycle cost

Deferred maintenance: maintenance that was not performed when it should have been or was scheduled to be which, therefore, is put off or delayed for a future period (Government of Western Australia, 2005)

Discounted cost: the real cost discounted by the real discount rate which is equivalent to the nominal cost discounted by the nominal interest rate. The discounted cost is thus often referred to as the net (or discounted) present value (NSW Treasury, 2004)

Discount rate: rate reflecting the 'time value of money' that is used to convert cash flows occurring at different times (AIQS, 2021)

Discount rate: rate used to calculate the present values of future cash flows (Government of Western Australia, 2005)

Life cycle: The time interval between a product's recognition of need or opportunity and its disposal (AIQS, 2021)

Life cycle cost: the sum of the acquisition cost and ownership cost of an asset over its life cycle from design stage, manufacturing, usage, maintenance and disposal (ANAO, 2001). Cost of an asset or its part throughout its life cycle, while fulfilling the performance requirements (AIQS, 2021)

Life cycle cost: encompasses all costs associated with the asset's life cycle. These include all costs involved in acquisition (research and development design, construction) operation and maintenance, and disposal of the asset (Government of Western Australia, 2005)

Life cycle costing: Methodology for the systematic economic evaluation of life cycle costs over a period of analysis, as defined in the agreed scope (AIQS, 2021)

Maintenance: activities involved in keeping assets in an acceptable condition, including preventative maintenance, normal repairs, replacement of parts, and structural components or other activities needed to ensure preservation of the asset in a condition to provide an acceptable level of service (Government of Western Australia, 2005)

Operating costs: the day-to-day expenses incurred in the running of an organisation (Government of Western Australia, 2005)

Period of analysis: period of time over which LCC are analysed. It may cover the entire life of the asset or a selected stage or stages or periods of interest

Net present value: The sum of the present values of all benefits (including residual value, if any) minus the sum of the present values of all costs (AIQS, 2021)

Nominal cost: The expected price that will be paid when a cost is due to paid (i.e., including inflation and price movements due to changes in technology, markets, etc.) (NSW Treasury, 2004)

Real cost: the cost expressed in values of the base date excluding inflation but including price movements due to changes in technology, markets, etc. (NSW Treasury, 2004)

Replacement value: the expressed value of the current cost of replacing an asset

Residual value: or salvage value, is the value of the asset at the completion of its life cycle. The residual value is considered the net position of the income generated by the sale of the asset, less the cost of site remediation. The residual value can either be the agreed value (asset left in situ) or the realised value of the asset (removal of the asset from the site). Salvage is considered the realised value of the unimproved asset (Government of Western Australia, 2005)

Sensitivity analysis: testing the outcome of an evaluation by altering the values of key factors about which there may be uncertainty (AIQS, 2021)

Service life: period of time after practical completion that an asset or its components meet or exceed the performance requirements (AIQS, 2021)

Time value of money: a concept that acknowledges that money changes value over a period of time; that a sum of money today is worth more than the same sum of money at a future date, because that money received now can be invested to earn interest (Government of Western Australia, 2005)

Useful life: period of time after practical completion that a constructed asset or facility, or its component parts, meet(s) or exceed(s) the performance requirements (ISO 15686 11: 2014 and ISO 21930: 2017, AIQS modified, 2022).

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Appendix A – Life cycle costing literature

A literature review of life cycle costing guidelines and standards (Table A.1) was undertaken to provide guidance on prescribed processes for life cycle costing in the context of an asset. An asset is any item that has potential or actual value to an organisation over time (Australian Institute of Quantity Surveyors [AIQS], 2022; NSW Government, 2018).

An asset may be tangible or intangible. Examples of tangible or physical assets include equipment, infrastructure, or land. Examples of intangible or non-physical assets include brands, licences, and intellectual property (New South Wales Government, 2018). We have focussed on the life cycle costing of tangible or physical assets as this most closely aligns with the WSUD assets of interest for this project.

Table A.1

Life cycle costing literature

Author	Title	Year	Type	Geographic scope
Australian National Audit Office	Life cycle costing better practice guide	2001	Guideline	Australia
Australian Institute of Quantity Surveyors	Life cycle cost analysis information paper	2022	Information paper	Australia
Government of Western Australia	Life cycle cost guidelines for sport and recreation facilities	2005	Guideline	Western Australia
Institute of Public Works Engineering Australasia	International Infrastructure Management Manual	2015	Manual	Australasia
New South Wales Government	Standard life cycle costing	2018	Standard	New South Wales
New South Wales Treasury	Total asset management life cycle costing guideline	2004	Guideline	New South Wales
Standards Australia	AS ISO 55000:2014 Asset management – overview, principles and terminology	2014	Standard	Australia
Standards Australia	AS/NZS 4356:1999 life cycle costing – an application guide	1999	Standard	Australia & New Zealand

Key extracts from these standards and guidelines are provided in the following sections.

A.1 Defining the life cycle stages

The life cycle of an asset is defined as the interval of time starting from when the need for the asset is recognised through to its creation and finally, its disposal (Australian National Audit Office [ANAO], 2021). Standards Australia (1991) identifies the following key phases involved in this life cycle.

- Acquisition, which may include the following (where relevant).
    - Identification and definition of the need for the asset.
    - Conceptual design.
    - Preliminary design.
    - Detailed design and development.
- Construction or installation (e.g., if a proprietary product).
- Use and maintenance.
- Renewal and adaptation.
- Decommissioning and disposal.

Various language is used to refer to these life cycle phases, and the activities involved in them, which may be specific to the assets being consideration. The ANAO (2001) identify the following.

- Initial concept definition.
- Development of the detailed requirements, specifications, or documentation.
- Construction, maintenance, or purchase.
- Defects liability period and early stages of usage or occupation.
- Prime period of usage and functional support, with associated series of upgrades and renewal processes.
- The situation at the end of the asset's useful life.

The New South Wales Government (2018) identify the following.

- Demand/need: definition of the need for the asset.
- Planning: Concept design, specification and procurement of services to acquire the asset.
- Acquire: Detailed design, construction, and the integration and acceptance of the asset into asset management systems.
- Operate/maintain: use and maintenance of the asset, continual monitoring and improvement, renewal and adaptation.
- Dispose: decommissioning and disposal of the asset.

Figure A.1 presents these stages and activities.

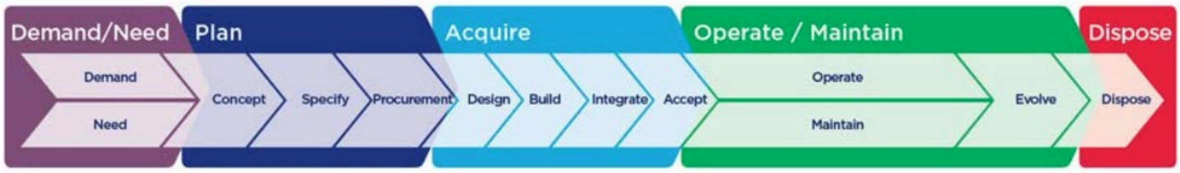


Figure A.1

Key life cycle phases (NSW Government, 2018)

The activities involved in these phases incur costs to the manager, owner, or user of the asset. Figure A.2 shows a distribution of these costs for a hypothetical asset reflecting the life cycle phases.

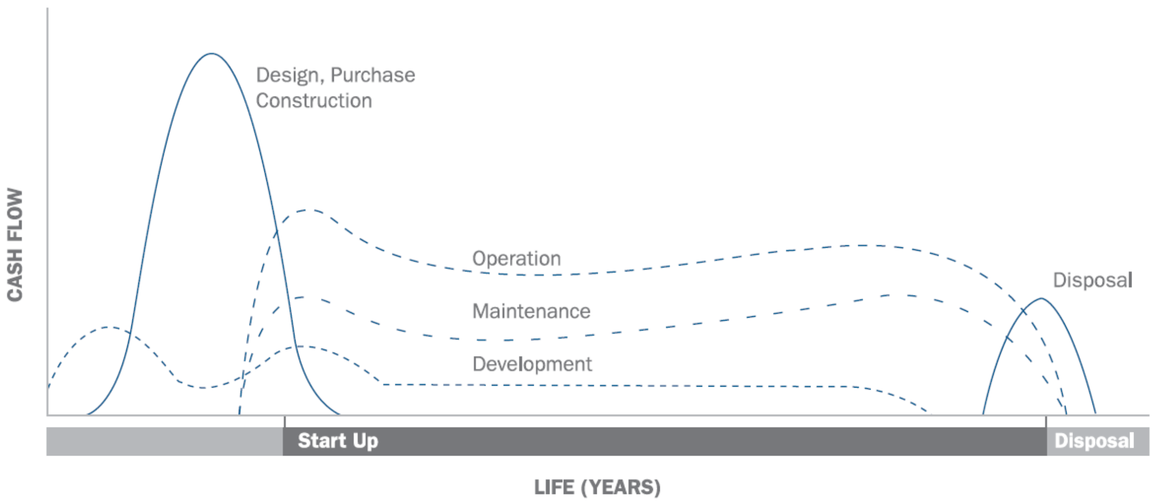


Figure A.2

Distribution of costs over life cycle phases ANAO (2001)

ANAO (2001) note that this diagram is not drawn to a consistent time scale with the operation and maintenance period generally being much longer than is indicated.

The AIQS (2021) provide a similar cost distribution which includes life cycle phases more closely aligned to Standards Australia (1999) (Figure A.3).

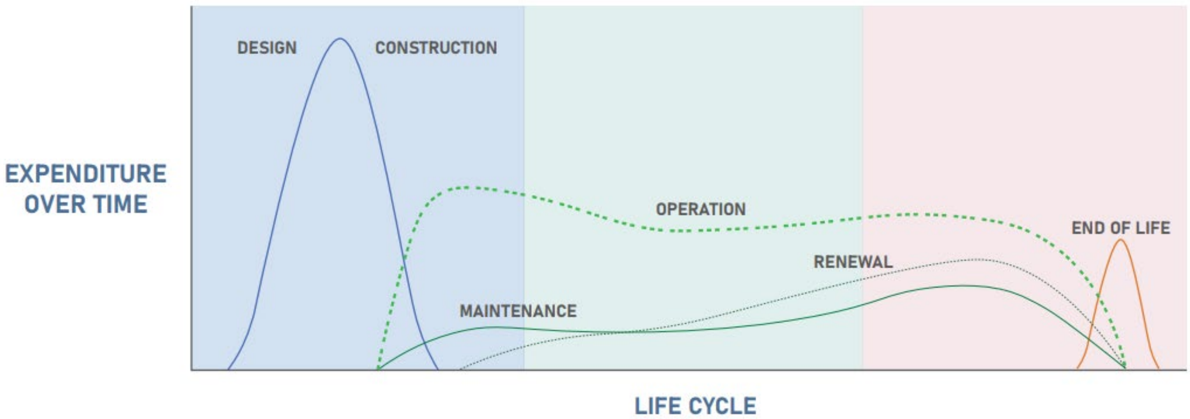


Figure A.3

Distribution of costs over life cycle phases AIQS (2021)

The NSW Government (2018) also provide cost distribution that matches the phases and activities they identify in Figure 4. The main difference with this approach is the much greater detail and breakdown of Demand/Need, Plan and Acquire stages leading up to construction.

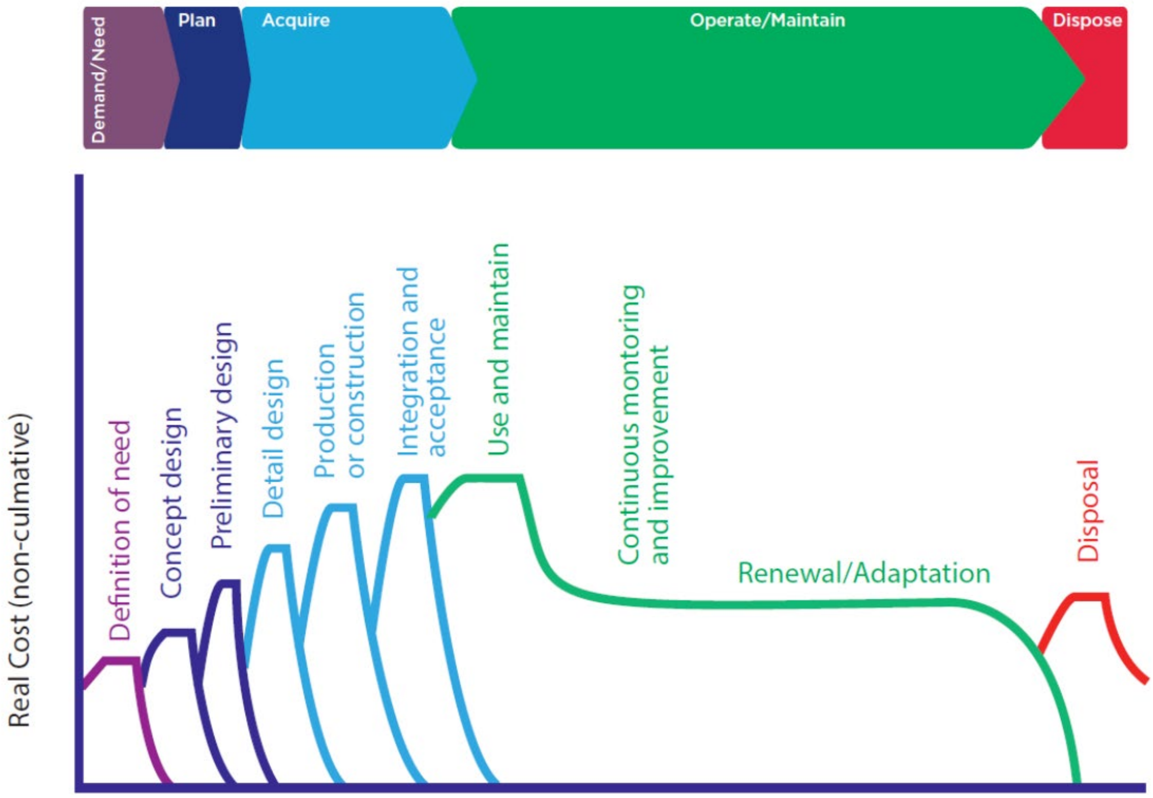


Figure A.4

Distribution of costs over life cycle phases NSW Government (2018)

While the language varies and there is no one right answer, it is necessary to choose a working basis of life cycle stages suitable for WSUD assets. For example the typical life cycle stages of WSUD assets could be defined as:

- **Planning**: Definition of need and project scoping
- **Design**: Concept design, functional design, detailed design
- **Construction**: Construction of asset and establishment
- **Operation and maintenance**: Regular ongoing and reasonably predictable works
- **Renewal**: Infrequent and/or irregular works to renew and refresh the function and performance of the asset
- **Adaptation**: Modification or reconstruction of the asset
- **Disposal**: Decommissioning of the asset

In practice, it is expected that most WSUD assets will be maintained in perpetuity. However, there are some circumstances where disposal of an asset may occur:

- The upstream urban developed area is decommissioned and returned to natural conditions
- The asset is replaced with another asset meeting contemporary standards and potentially changed upstream conditions
- The asset was not required to be maintained in perpetuity (e.g. temporary assets)

A.2 Life cycle costing

ANAO (2001)

Authoritative guidance for life cycle costing in Australia comes from Standards Australia in the AS/NZS 4536:1999 Life Cycle Costing – An Application Guide. The standard defines life cycle costing as "*the process of assessing the costs of an asset over its life cycle or portion thereof*" (p. 6)

As of the time of writing of this document, the Standards Australia website indicates that this Standard is "Withdrawn". Standards Australia advised us that this means the document is "no longer relevant, or its designation has changed" and that they "*will not undertake any review or revision work for this Standard indefinitely*". However, they also advised us that "*Withdrawn publications can still be used within an industry… when there are no replacement documents readily available*" which appears to be the case for this Standard. AS/NZS IEC 60300.3.3:2019 Dependability management, Part 3.3: Application guide — Life cycle costing, may replace AS/NZS 4536:1999 however this has not been confirmed by Standards Australia.

The description of AS/NZS IEC 60300.3.3:2019 Dependability management, Part 3.3: Application guide — Life cycle costing, is as follows:

"*This standard is to establish a general introduction to the concept of life cycle costing and covers all applications. Although costs incurred over the life cycle consist of many contributing elements, this document particularly highlights the costs associated with the dependability of an item. This forms part of an overall dependability management programme as described in AS/NZS IEC 60300.1. Guidance is provided on life cycle costing for use by managers, engineers, finance staff, and contractors; it is also intended to assist those who may be required to specify and commission such activities when undertaken by others. This standard is identical with, and has been reproduced from, IEC 60300-3-3:2017 Dependability management - Part 3-3: Application guide - Life cycle costing.*".

According to the Australian National Audit Office (2001) the process of life cycle costing involves:

- Assessing the associated costs with an asset over its life cycle
- Evaluating options that have an impact on these costs.

The life cycle cost (LCC) of an asset can be calculated using the following formula (ANAO (2001) & Government of Western Australia (2005) & NSW Gov (2018))

LCC =

- Acquisition cost +
- Lifetime operating costs +
- Lifetime maintenance costs +
- Disposal cost -
- Residual value.

While this formula is simple, estimating its terms can be difficult. This is particularly the case for future costs like operation and maintenance and adaptation and renewal costs which are subject to a level of uncertainty arising from several factors:

- the type and frequency of these activities and their costs

- the impact of inflation on individual and aggregate costs
- the predicted useful life of the asset.

The following outlines the definition and description of life costing by various organisations:

AIQS (2021)

- Generally, LCC analysis covers the entire life cycle of an asset.
- LCC analysis is an economic evaluation technique, for identifying and quantifying all costs, initial and ongoing, associated with a project or an asset over its anticipated life.
- Life cycle cost analysis aims to achieve the best value for money rather than the lowest cost
- As an economic evaluation technique, LCC analysis provides for identifying all costs, initial and ongoing, associated with an asset over its anticipated life
- It should involve bringing all project costs considered to their present value or equivalent future cost, allowing decision makers to reliably compare alternatives on an 'apples to apples' basis.

Government of Western Australia (2005)

- The costs to be included in the LCC analysis are those that are directly attributable to the ownership and management of the asset.

NSW Treasury (2004)

- Life cycle costing is a process to determine the sum of all the costs associated with an asset or part thereof, including acquisition, installation, operation, maintenance, refurbishment, and disposal costs.
- It is pivotal to the asset management process as an input into the evaluation of alternatives via economic appraisal, financial appraisal, value management, risk management and demand management.
- It adds all the costs of alternatives over their life period and enables an evaluation on a common basis for the period of interest (usually using discount costs). This enables decisions on acquisition, maintenance, refurbishment or disposal to be made in light of full cost implications.
- It is distinct from economic appraisal in that it generally:
    - considers all cost components with asset options over their life cycle
    - does not directly consider benefits or revenue streams that are generally assumed to be equal among the options being compared (benefits and revenues are considered in the evaluation of options).
- Life cycle cost analysis enables life cycle costs to be monitored over the life of an asset to ensure accurate and timely decision making as to how these costs can be minimised.
- Where ownership of the asset changes over time, each owner takes responsibility for decisions required during the period of ownership only.
- Costs are generally not expressed as real or discounted costs but as nominal costs (i.e., estimated costs that are to be paid when due) to enable comparison of the predicted cost and the actual cost.

A.3 LCC purpose

ANAO(2001)

- To meet demands for their products and services, organisations often need to make decisions when planning, acquiring, or managing assets.
- They often need to understand the cost consequences of these decisions.

NSW Gov (2018)

- AS/NZS 4356:1999 defines the following objectives of LCC:
  - Calculate a dollar value that represents the LCC of an asset as an input to a decision making or evaluation process, together with other inputs. The cost is based on a defined need associated with the asset.
  - Support management considerations that affect decisions during any life cycle phase.
  - Identify attributes of the asset which significantly influence the LCC (cost drivers) of the asset so they can be properly managed.
- The initial capital outlay cost is usually clearly defined and is often a key factor that can influence the choice of a particular asset given a number of alternatives from which to select.
- This initial cost is often, however, only a small portion of the costs over an asset's life cycle that need to be considered when making investment decisions.
- Additionally, there are operational costs which refer to labour/training, materials and consumables, energy (power, fuel), equipment and facilities; and engineering modifications incurred over the expected life of the asset.
- Life time maintenance costs refer to general maintenance that includes recurrent maintenance and capital maintenance (upgrading) costs.
- Disposal costs refer to system shut down; disassembly and removal; recycling or safe disposal related costs.

AIQS (2021)

- Historically, cost planning has focussed only on capital costs relating to acquisition of an asset.
- Project budgets and tenders have considered these costs alone.
- Cost planning processes rarely extend beyond project acquisition stage in any consistent or structured way.

ANAO (2001)

- The costs involved in acquiring new assets are usually well understood and supported by budgeting, tendering, and financial reporting processes.
- When planning an acquisition of an asset, organisations often spend considerable time and effort in making an economic evaluation of the initial (capital) cost.
- These costs can strongly influence the choice between multiple options when acquiring new assets.
- However, other future costs must also be considered as they often exceed the acquisition costs and can vary significantly between asset options and their ongoing management requirements.
- These future costs are often less understood and can be hidden within the general operational expenses of an organisation.
- They can include:
  - Operational needs
    - Equipment, labour, plant, insurances and overheads
  - Consumables
    - Power, fuel, water
  - Maintenance and minor repairs
    - Equipment, materials, parts, plant, overheads involved in maintaining asset to desired condition
    - Costs may arise through maintenance delivered by resources from within the organisation (i.e., staff) or outside of the organisation (e.g., contractors)
  - Upgrade and renewal
    - Major repairs, refurbishments, renewals and overhauls to extend the life of an asset

  - Disposal
    - Removing and disposing of the asset and reinstating the site to its former condition to a desired condition.
- If not considered in decision making process, these other future costs can significantly affect the long-term financial sustainability of organisations (Institute of Public Works Engineering Australasia, 2015).

NSW Treasury (2004)

- In the past, comparisons of asset alternatives, whether at the concept or detailed design level, have been based mainly on initial capital costs.
- Growing pressure to achieve better outcomes from investments in assets has driven ongoing operation and maintenance costs to be considered as they often cost more over the asset's life cycle.
- For example, the operating costs of a hospital consume an equivalent of the capital cost every 2 to 3 years and continue to do so for 40 years or more.
- The operating costs of a school can consume the equivalent of its capital cost every 4 to 5 years and remain in service for a century or more.
- Both the capital and ongoing operation and maintenance costs should be considered whenever asset management decisions involving costs are to be made. This is the life cycle approach.

AIQS (2021)

- Not undertaking full LCC analysis presents a range of opportunity costs and risks including, but not limited to:
  - Decision making based on initial capital costs alone
  - Minimising initial capital costs without knowledge of their long-term consequences
  - Acceptance of life cycle expectancy claims without full investigation and consideration of alternatives
  - Failure to make adequate provision of maintenance of operating costs
  - Difficultly in planning for future refurbishment, major adaptation, change of use or end of life events.
- According to ISO 15686-5: 2017, "*Lifecycle costing is relevant at portfolio/estate management, constructed asset and facility management levels, primarily to inform decision making and for comparing alternatives. Lifecycle costing allows consistent comparisons to be performed between alternatives with different cash flows and different time frames. The analysis takes into account relevant factors from throughout the service life, with regard to the client's specified brief and the project-specific service life performance requirements*".

ANAO (2001)

- Assets are formed from a series of actions including the upgrade and renewal of components as they reach the end of their useful life within the life span of the asset.
- The life span of the asset is influenced by both the failure of its components and its ability to provide a required service.
- Many assets reach the end of their useful life before they become unserviceable.
- The identification and documentation of the costs of assets over their life cycle, or part of their life cycle, is an important input into the decision making process for acquiring new assets or managing existing asset.
- Armed with an understanding of the costs of assets over these stages, organisations are able to:
  - Compare the life cycle costs of multiple asset options when acquiring new assets
  - Assess, budget and plan for the ongoing management requirements of existing assets including their maintenance, renewal, upgrade or decommissioning.

- The information generated by a LCC analysis can assist organisations at various stages in the life of an asset:
    - Planning and analysis of alternative solutions
    - Selection of preferred options
    - Securing funding
    - Review of predicted and actual outcomes.

Government of Western Australia (2005)

- Life cycle costing is a key asset management tool that takes into account the whole of life costs of planning, acquiring, operating and maintaining, and disposing of an asset.

New South Wales Government (2018)

- Proposed capital projects
- Asset type approvals or sub-component type approvals
- New asset proposals either within an existing system or a new system
- Significant configuration and operational changes
- Changes during the following:
    - Asset life cycle (e.g., maintenance requirements)
    - System requirement development (e.g., specifications)
- Consistent application of LCC will allow for benchmarking, comparison and performance evaluation of cost plans between different investment decisions
- The primary objective of the LCC model is to analyse alternative options for implementing a project, for example, technology, performance levels, maintainability and so on as well as to determine the option that provides the best value on a whole-of-life basis.

NSW Treasury (2004)

- The determination of costs is an integral part of the asset management process and is a common element of many asset manager's tools, particularly financial, risk and demand management.

ANAO (2001)

- The life cycle and costs of an asset can be influenced by several things including failure of its components and by its ability to continue to provide a required service.
- Many assets reach the end of their useful life before they become unserviceable.
- They often require a series of upgrades and renewals to their components as they reach the end of their useful life within the life of the overall asset.

The ANAO (2001) identifies the following reasons for doing life cycle costing:

1. **Planning and analysis**

- The best opportunities to achieve significant cost benefits occur during the early concept development and design phase of an asset.
- At this time, significant changes can be made for the least cost.
- At later stages of the asset's life cycle many costs have been locked in.
- To achieve the maximum benefit available during this stage, it is important to explore:
    - a range of asset options
    - the cost drivers for each option
    - the time period for which the asset will be required
    - the level and frequency of usage
    - the operating and maintenance activities and costs
    - quantification of future cash flows.

- The concept of the life cycle of an asset provides a framework to document and compare alternatives.

2. Selection of preferred option

- To make an appropriate choice between multiple options, it is important to consider both the immediate costs and the costs that will happen over the life of assets.
- LCC provides a sound basis on which to make whole-of-life comparisons and also supports the review and audit of the acquisition process.
- When a life cycle cost analysis has been prepared for each option under consideration, it is possible to:
  - Calculate the NPV of each option
  - Consider projected cash flows in the context of the funding available
  - Identify issues relating to the ultimate disposal of the asset.
- This information can be used by decision makers as part of the selection process in conjunction with… and the outcomes of other analyses.

3. Securing funds

- Within an organisation, there will always be competing demands for the available resources at a given time.
- Management of cash flow is simplified if the pattern is predictable over the long term.
- The life cycle analysis provides a sound basis for projecting cash requirements, which can assist a group within an organisation securing approval for an acquisition over…

4. Auditing and review

- The credibility of future life cycle cost analyses can be enhanced by the systematic collection of historical data related to previous projects.
- A comparison of projected life cycle costs with those that actually occur can provide:
  - Confirmation of the reliability of the life cycle model
  - Information to improve future similar life cycle models
  - An appreciation of the risks associated with various assumptions.
- A well-documented LCC process justifying a higher initial cost offset by lower long-term costs provides clear evidence for consideration during any review or audit process.
- It also provides a rationale for the decision, which will be valuable to help a new manager understand the reasons for a decision taken by others.

Government of Western Australia (2005)

- LCC is a valuable and powerful tool that can be used to gain support for the preferred project option.

AIQS (2021)

- Other criteria and metrics can be considered including carbon emissions, the circular economy, environmental and social impacts, and the sustainable development goals.

NSW Gov (2018)

- LCC analysis should consider environmental and social costs from across the life cycle to minimise impacts on the environment and the community.
- LCC provides an input into the financial aspects of risk assessments.

Government of Western Australia (2005)

- Maintenance competes for funds with other services and is often deferred when other projects are considered higher priority.
- The cost of the above is the increased risk of components failing, increased safety hazards, reduced service levels, and increased costs in the future associated with actions to remedy these things.
- The deferral of routine maintenance will mean your asset will deteriorate faster, making it harder for you to meet the deferred maintenance cost.
- In terms of the life cycle costing process, deferred maintenance is the cost of maintenance not undertaken to maintain the asset in a good and working condition.
- In this context, deferred maintenance is not considered a capital renewal cost.
- Identifying deferred maintenance will help establish the requirements for funding at the outset.
- Government of Western Australia provide guidance on identifying and quantifying the true costs of deferred maintenance.
- Capital and operational budget processes for local government assets are typically exposed to the pressures of annual budget bids in a very competitive financial environment.
- Exposing existing assets to this style of funding processes may lead to inadequate maintenance of funding that ultimately results in their premature deterioration.
- The dangers of a competitive funding process might include a lowering of priorities being placed on routine schedule maintenance for existing assets, and as a result, a deferred maintenance debt.
- When assessing a deferred maintenance exposure, a condition assessment inspection should be undertaken on the asset by suitably qualified professionals.
- A maintenance deficiency rating is then assigned, typically on a 1 to 5 scale based on the relative level of disrepair and effects on the overall asset, with 1 being catastrophic loss in service and 5 being serviceable.
- A rating of 1 would be assigned to component conditions that contravene requirements for the asset in terms of level of service (e.g., safety, performance).
- The costs of repairs are then assigned, usually by a quantity surveyor or qualified contractor, and should have the capacity to be reviewed in accordance with a recognised industry building estimates publication such as Rawlinsons Australian Construction Handbook.
- The purpose is to identify the true cost exposure and create a business case for funding and implementing an appropriate maintenance regime.

- AIQS (2021)
  - Management tool following the acquisition of the asset against which actual performance can be monitored providing a basis for improved budget planning and expenditure forecasts

A.4 LCC stages

NSW Treasury (2004)

- Life cycle costing can be carried out during any or all phases of an asset’s life cycle.
- Life cycle cost can be used to provide input into decisions regarding asset design, manufacture, installation, operation, maintenance, and disposal.

ANAO (2001)

- Three broad stages when LCC should be done:
  - Conceptual stage: when investment in new assets is being considered
  - Acquisition stage: when tenders for the creation of new assets are being created and assessed
  - In service stage: when decisions are being made on whether to maintain, improve or dispose of the asset.

A.4.1 Conceptual stage

ANAO (2001)

- Obtain estimates for all cost elements in a consistent way to ensure reliable comparison between asset options.
- Assess cost-performance trade-offs between asset options.
- Assess pattern of future costs over the life of assets to inform future long-term financial plans.

Government of Western Australia (2005)

- In contemporary project management, applying life cycle costing at the concept and design stages provides the greatest opportunity to minimise the life cycle costs of an asset. The later the LCCA is undertaken in the life of an asset, the further this opportunity diminishes.
- In all cases, however, life cycle cost analysis must be completed before decisions are made.

AQIS (2021)

- Applications include:
  - Comparative tool to evaluate different options, designs, components or materials in support of strategic planning and investment decisions typically applied during the asset planning and design life cycle stages

NSW Gov (2018)

- LCC is most effectively applied in the project's early design phase to optimise the total life cycle cost.
- However it should be applied during operation and maintenance phases to optimise maintenance strategies and facilitate efficient allocation of resources.

NSW Treasury (2004)

- By the end of the concept design stage, more than half of the asset's life cycle costs may be committed by decisions made on the asset's components, performance, etc. By the end of the design stage, even more of the asset's costs may be fixed.
- The interaction between potential savings and asset costs is shown in Figure 4.

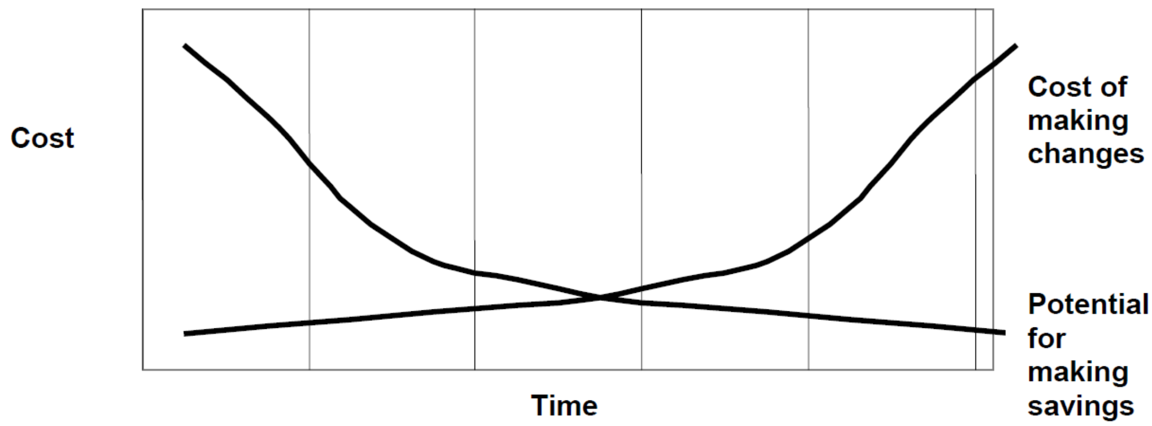


Figure 4: Potential cost and savings relationship over the life of an asset

- Decisions made in the early stages of the life cycle of an asset can have greater influence on its life cycle cost than those made later, consistent with the concept of discounted costs.

A.4.2 Acquisition stage

ANAO (2001)

- To support choosing the most cost-effective option
- Can also support the tender evaluation process by comparing cost estimates between the LCC output and quotations
- Life cycle cost and other claims made by suppliers can be translated into contractual requirements, particularly for types and designs of assets that the organisation has no experience with.

A.4.3 In service stage

ANAO (2001)

- Comprehensive and readily useable data base of life cycle costs:
    - Supports decisions to improve the cost-effectiveness of existing assets (e.g., by changing the maintenance regime)
    - Supports decisions to improve specifications for future assets (e.g., design)
    - Allows understanding of how costs vary with the age of the asset (e.g., for traditional infrastructure like roads, this usually involves an increase in costs).
- This information supports decisions on whether to:
    - Continue as is
    - Modify the asset to avoid increasing costs
    - Retire the asset and recycle or dispose of its components.

AIQS (2021)

- … management tool providing a basis for decisions such as… refurbishments, major adaptations, and replacements
- More commonly applied via the long-term operational and management procedures during the asset management life cycle stages

- Should inform decisions made relating to the costs of alternative management options in the in service stage (e.g., changing maintenance, adapting, upgrading or renewing, disposing and replacing, or keeping things as they are)
- The absence of historical data in a consistent cost format is often cited as a major drawback to the effective use of LCC analysis.
- This hurdle can be overcome as LCC analysis is integrated into the three stages described above
- For example, establishing a consistent costing way to record, store and maintain cost data at relevant points in the above stages allows for the efficient use of data in LCC analysis across them.
- This should not involve new processes, but instead the augmentation of existing processes across those stages to ensure the data is being recorded, stored, and maintained for use in LCC analysis:
    - Common database
    - Common bill of quantities
    - Common maintenance schedules
    - Common asset registers.
- Invariably there will be gaps in available data which will require estimation based on professional judgement.

NSW Gov (2018)

- Before a decision is made, maintenance staff should be consulted regarding logistics, training and maintenance delivery. In addition, the person undertaking the LCC should include relevant information in the LCC model.

ANAO (2001)

- Given the often-dispersed roles and responsibilities of many organisations (e.g., local governments) responsibilities for recording the in service costs of an asset should be made clear at the outset.

AIQS (2021)

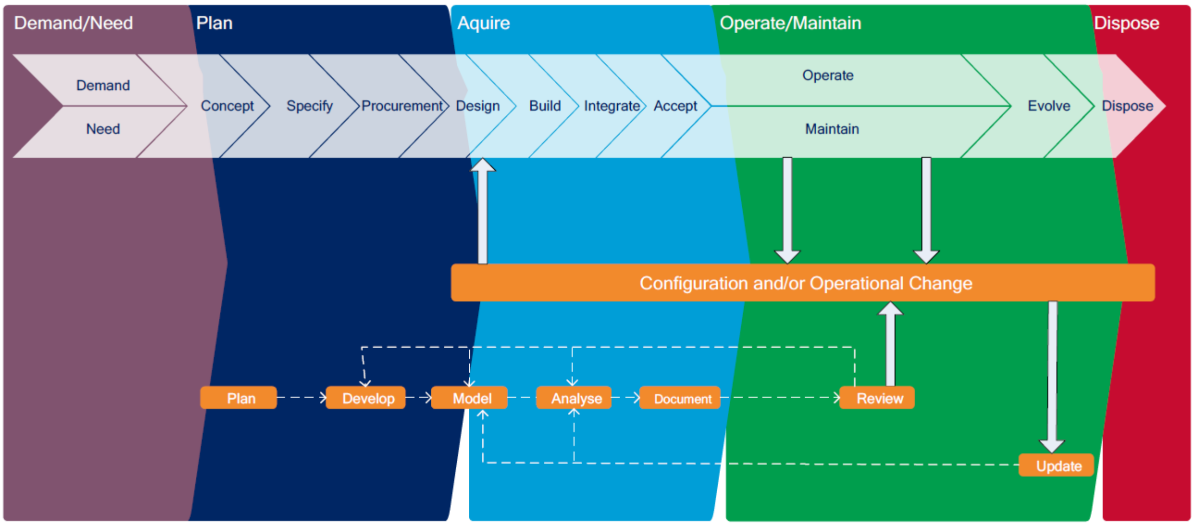
- Successful LCC analysis requires an understanding of:
    - Owner objectives
    - End user requirements
    - Design intent
    - Project scope
    - Life expectancy
    - LCC analysis method
    - Risk assessment
    - Consistent application of established terminology, standards and analysis method.
- For comparison and analysis purposes, all costs should be discounted and dealt with at present values.
- Allowances should be made for inflation, taxation, profit, and risk to deal with future costs in ‘real’ dollars.

A.5 LCC process

A.5.1 Life cycle costing process

NSW Gov (2018)

- In line with AS/NZS 4356:1999, any life cycle cost analysis shall be constructed in a structured and well-documented manner using the following steps:
    - Development of a life cycle cost analysis plan
    - Development or selection of a life cycle cost model
    - Analysis of the model
    - Analysis of LCC documentation
    - Review of LCC results
    - Update of the life cycle cost analysis.
- The above may be performed in an iterative manner if any stage indicates a need to revisit or modify work undertaken in a previous stage.
- Assumptions made at each step shall be documented to facilitate such iterations and to aid in interpreting the results of the analysis.



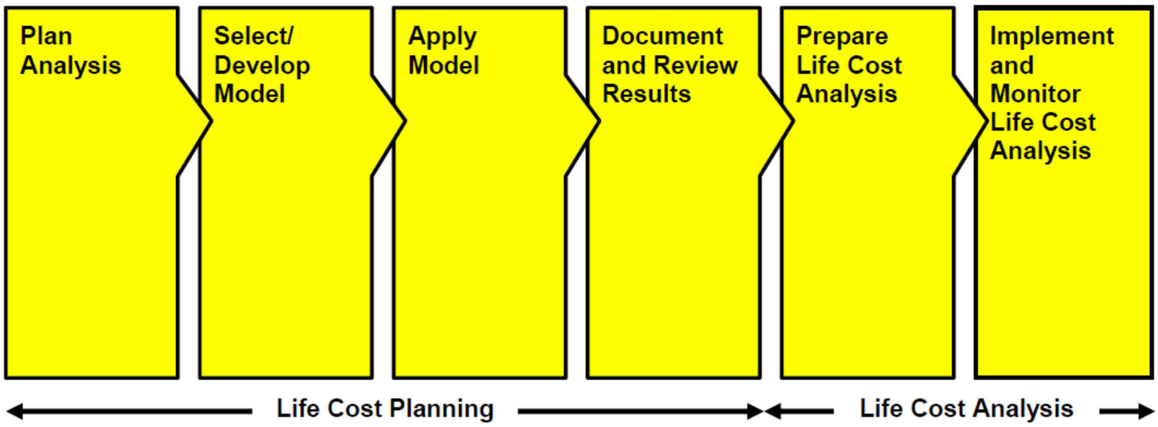
ANAO (2001)

- LCC analysis should begin by developing a plan that addresses the following:
    - Define the objectives
    - Identify the cost drivers and establish their parameters
    - Apply the formula and choose the appropriate discount rate
    - Analyse the rules
    - Record the results.

NSW Treasury (2004)

- Life cycle cost planning:
    - Stage 1: Plan analysis
    - Stage 2: Select/develop model
    - Stage 3: Apply model
    - Stage 4: Document and review results

- Life cycle cost analysis:
    - Stage 5: Prepare life cycle cost analysis
    - Stage 6: Implement and monitor life cycle cost analysis
- As shown in the figure below, the first 4 stages comprise the life cycle cost planning phase while the last 2 stages comprise the life cycle cost analysis phase.



- All stages must be performed iteratively and as needed.
- Assumptions made at each stage should be rigorously documented to facilitate such iterations and to aid in interpretation of the results of the analysis.
- LCC analysis is a multi-disciplinary activity.
- An analyst should be familiar with the philosophy underlying LCC (e.g., cost elements, sources of data, financial principles including time value of money and discounting) and should have a clear understanding of the methods of assessing the uncertainties associated with cost estimation (e.g., sensitivity analysis and risk assessment).

Plan analysis

- Define the analysis objectives in terms of outputs required to assist management decisions.
- Typically these are:
    - Determination of the LCC for an asset to assist planning, contracting, budgeting or similar needs
    - Evaluation of the impact of alternative courses of action on the LCC of an asset (such as design approaches, asset acquisition, maintenance scenarios or alternative technologies)
    - Identification of cost elements which act as cost driver for the LCC of an asset in order to focus design, development, acquisition, maintenance etc.
- Delineate scope of analysis in terms of assets, time period (life cycle phases), the use environment and the operation and maintenance scenario to be employed.
- Identify alternative courses of action to be evaluated. The list of proposed alternatives may be refined as new options are identified or as existing options are found to violate the problem constraints.
- Provide an estimate of resources require and a reporting schedule for the analysis to ensure that the LCC results will be available to support the decision making processes for which they are required.
- The plan should be documented at the beginning of the life cycle costing process to provide a focus for the rest of the work. Intended users of the analysis results should review the plan to ensure their needs have been correctly interpreted and clearly addressed.

Select/develop model

- Stage 2 is the selection or development of an LCC model that will achieve the objectives of the analysis.
- The model should do the following:
    - Create or adopt a cost breakdown structure (CBS) that identifies all relevant cost categories in all appropriate life cycle stages. Cost categories should continue to be broken down until a cost can be readily estimated for each individual cost element. Where available, an existing cost breakdown structure may provide a useful starting point for the development of the LCC breakdown structure.
    - Identify those cost elements that will not have a significant impact on the overall LCC of the assets under consideration or those that will not vary between alternatives. These elements may be eliminated from further consideration.
    - Select a method (or methods) for estimating the costs associated with each cost element to be included in the model.
    - Determine the data required to develop these estimates, and identify data sources.
    - Identify any uncertainties likely to be associated with the estimation of each cost element.
    - Integrate the individual cost elements into a unified LCC model, which will provide the LCC outputs required to meet the analysis objectives.
    - Review the LCC model to ensure it is adequate to address the objectives of the analysis.
    - The LCC model including all assumptions should be documented to guide and support the subsequent phases of the analysis process.

Apply LCC model

- Application of the LCC model involves the following steps:
    - Obtain data and develop cost estimates and their timing for all the basic cost elements in the LCC model.
    - Validate the LCC model with available historical data, if possible.
    - Obtain the LCC model results from each relevant combination of operating and support scenarios defined in the analysis plan.
    - Identify cost drivers by examining LCC model inputs and outputs to determine the cost elements that have the most significant impact on the LCC of the assets.
    - Quantify any differences (in performance, availability or other constraints) among alternatives being analysed, unless these differences are directly reflected in the LCC model outputs.
    - Categorise and summarise LCC model outputs according to any logical groupings, which may be relevant to users of the analysis (e.g., fixed or variable costs, recurring or non-recurring costs, acquisition or ownership costs, direct or indirect costs).
    - Conduct sensitivity analyses to example the impact of variations to assumptions and cost element uncertainties on the LCC model results. Particular attention should be focussed on cost drivers, assumptions related to asset usage and different discount rates.
    - Review LCC outputs against the objectives defined in the analysis plan to ensure all have been achieved and that sufficient information has been provided to support the required decision. If the objectives have not been achieved, additional evaluations and modifications to the LCC model may be required.
    - The LCC analysis (including all assumptions) should be documented to ensure that the results can be verified and readily replicated by another analyst if required.

Document and review results

- The results of the LCC analysis should be documented to allow users to clearly understand both the outcomes and the implications of the analysis with the limitations and uncertainties associated with the results. The report should contain the following:
    - Executive summary: a brief synopsis of the objectives, results, conclusions and recommendations of the analysis

    - Purpose and scope: a statement of the analysis objective, asset description including a definition of intended asset use environment, operating and support scenarios, assumptions, constraints and alternative courses of action considered
    - LCC model description: a summary of the LCC model, including relevant assumptions, the LCC cost breakdown structure (CBS) and cost elements along with the methods of estimation and integration
    - LCC model application: A presentation of the LCC model results including the identification of cost drivers, the results of sensitivity analysis and the output from any other related analyses
    - Discussion: Discussion and interpretation of the results including identification of uncertainties or other issues which will guide decision makers and users in understanding and using the results.
    - Conclusions and recommendations: a presentation of conclusions related to the objectives of the analysis and a list of recommendations along with identification of any need for further work or revision of the analysis.
- A formal review of the analysis may be required to confirm the correctness and integrity of the results, conclusions and recommendations presented in the report. If such a requirement exists, someone other than the original analysts should conduct the review (to ensure objectivity). The following elements should be addressed in the review:
    - The objectives and scope of the analysis to ensure that they have been appropriately stated and interpreted
    - The model (including cost element definitions and assumptions) to ensure that it is adequate for the purpose of the analysis
    - The model evaluation to ensure that the inputs have been accurately established, the model has been used correctly, the results (including those of sensitivity analysis) have been adequately evaluated and discussed and that the objectives of the analysis have been achieved
    - All assumptions made during the analysis process to ensure that they are reasonable and that they have been adequately documented.

Prepare life cost analysis

- The LCC analysis is essentially a tool, which can be used to control and manage the ongoing costs of an asset or part thereof.
- It is based on the LCC model developed and applied during the life cycle cost planning phase with one important difference: it uses data on nominal costs.
- The preparation of the LCC analysis involves review and development of the LCC model as a real-time cost control mechanism. This will require changing the costing basis from discounted to nominal costs. Estimates of capital costs will be replaced by the actual prices paid. Changes may also be required to the cost breakdown structure and cost elements to reflect the asset components to be monitored and the level of detail required.
- Targets are set for the operating costs and their frequency of occurrence based initially on the estimates used in the life cycle costing planning phase.
- These targets may change with time as more accurate data is obtained, either from the actual asset operating costs or from benchmarking with other similar assets.

Implement and monitor life cycle cost analysis

- Implementation of the life cycle cost analysis involves the continuous monitoring of the actual performance of an asset during its operation and maintenance to identify areas in which cost savings may be made and to provide feedback for future life cycle cost planning activities.
- For example, it may be better to replace an expensive building component with a more efficient solution prior to the end of its useful life than to continue with a poor initial decision.

AIQS (2021)

Define objectives

- Context or purpose as determined by interested parties or stakeholder objectives
- Identify the required function to be delivered (what is the intended purpose of the asset)
- Define expected outputs and outcomes from analysis
- Ensures scope of analysis is appropriate and data is collected at required level of detail
- Effort should reflect complexity and risk of the asset or decision being analysed
- Recommended steps for defining the objectives are as follows

1. Define objectives of analysis in terms of outputs that are required to support decision making. Typical objectives include:
    a. Estimate life cycle cost to support planning and acquisition (e.g., budgeting and requests for quotation)
    b. Evaluate the impact of different options for assets and how they're designed and managed on life cycle costs
    c. Identify cost drivers to help focus the above.
2. Delineate the scope of the analysis in terms of:
    a. The asset options
    b. The time period (life cycle phases) being
    c. The design, location, and operation and maintenance scenario.
3. Identify any assumptions and limitations that constrain the range of acceptable options to be evaluated (e.g., minimum performance or availability requirements or maximum costs).
4. Identify alternative courses of action to be evaluated (if this forms part of the analysis objective). In some cases it may be a valid option to continue with the existing situation. The list of proposed alternatives may be refined as new options are identified:
    a. Documenting alternative acquisition and operational options.
5. Provide an estimate of resources required and a reporting schedule for the analysis, to ensure LCC analysis results will be available to support the decision making processes for which they are required.

Identify cost drivers

- A key requirement for a successful LCC is availability of information on significant cost drivers influencing the life cycle cost of the alternative courses of action to be analysed.
- This information may come from designers or manufacturers.
- For example, for plant and equipment, suppliers should be asked to provide estimates of:
    - Initial capital costs
    - Useful or service life
    - Energy consumption
    - Maintenance costs per year
    - Operating resources per year
    - Frequency, nature and costs of capital upgrades needed over the life of the asset
    - Cost of disposing of the asset or its components.
- The level of detail sought should reflect the significance of the acquisition and the relevance of the data to the life cycle model.
- AIQS (2021)
    - The future life expectancy of components is highly linked to the life expectancy of the overall asset.
    - Determining the appropriate period of analysis is therefore part of the analysis and decision making process.

Develop model

NSW Treasury (2004)

- Before selecting a model, the purpose of the analysis and the information it requires should be identified. The model should also be reviewed with respect to the applicability of all cost factors, empirical relationships, constants, elements and variables.

NSW Gov (2018)

- AS/NZS 4356:1999 proposes that in order for the model to be realistic, it shall:
    - Represent the characteristics of the asset being analysed including its intended use, environment, maintenance concept, operating and maintenance support scenarios, and any constraints or limitations
    - Be comprehensive enough to include and highlight all factors relevant to LCC
    - Be simple enough to be easily understood and allow for its timely use in decision making and future updates and modifications
    - Be designed in such a way as to allow for the independent evaluation of specific elements of the LCC.

ANAO (2001)

- The key data to use in all life cycle models can be grouped into five main areas:
    - Capital cost
    - Life-time operating costs
    - Life-time maintenance costs
    - Life-time asset loses
    - Asset disposal cost.
- The LCC model used to estimate the above may be a simple spreadsheet or computer model.
- In every case, important to use consistent model for evaluation of alternatives:
    - Developing a consistent cost model for each option.

AIQS (2021)

- Consistent application of standards and calculation methodology.
- Use of different models for each alternative can make meaningful comparisons very difficult.
- Most models generate a cash flow scenario based on current costs and then adjust these for the impact of cost escalation (including inflation) and a discount factor.
- The application of cost escalation to the analysis is particularly relevant where:
    - The costs of the various elements forming the asset in each scenario are likely to be subject to widely different cost escalation over time
    - The decision is potentially influenced by the expected cash requirement over time.
- Present day costs are adjusted for cost escalation are known as “nominal costs”.
- The choice of a discount factor can cause contention among decision makers using the LCC analysis. The value chosen needs to reflect the policy of the organisation and the nature of the asset.

NSW Gov (2018)

- Depending on the purpose of the analysis, different ways of expressing the cost may be appropriate, i.e., real cost, nominal cost, and discount cost.

ANAO (2001)

- Life cycle costing can be as simple as a table of expected annual costs or it can be as complex as a computer model that allows multiple life cycle cost scenarios to be iterated and evaluated.

- Calculation of life cycle costs can be assisted by cost models… how costs change based on different assumptions.
- Those computer models allow multiple scenarios to be explored without adding to the time and effort for the LCCA.
- They allow the person doing the analysis to focus more on the implications of the analysis than the process of doing the analysis.
- The complexity of the LCC should reflect the complexity and risk of owning the asset being considered.
- Risks to consider include:
    - The ability of the organisation to predict the future costs of the asset
    - The likely significance of the predicted costs to the organisation in the future.

AIQS (2021)

- The level of detail and required accuracy for a LCC analysis should be determined by the project objectives, scope, status and available data.

A.5.2 LCC model Inputs

1. Life expectancy

- AIQS (2021)
    - Service life or useful life of the components and the asset when all objectives, inputs and variables have been considered.
    - 'Service Life' of a constructed asset or facility has generally been considered as having the same meaning as economic, design, useful or effective life.
    - The period of time after practical completion that a constructed asset or facility, or its elements and component parts, meet(s) or exceed(s) the performance requirements.
    - There will invariably be the need to appl a degree of professional judgement on the inputs and outputs of a LCC analysis.
    - For example, life expectancies published by designers and manufacturers may reflect contractual requirements or warranty arrangements rather an evidence-based understanding.
    - Even when expectancies are based in evidence, they likely reflect certain conditions that aren't relevant to the LCC analysis (e.g., location, start condition, operation and maintenance regime).
    - Condition-based life expectancy is empirical and the measure most commonly used in LCC models. Of course, the condition of all assets deteriorates over time, but accelerated deterioration may result due to external factors including environmental conditions and a lack of maintenance.
    - The use of life expectancies based on published data or physical condition provides a basis only.
    - Always consider the asset and the things that may influence life expectancy.

2. Cost elements

NSW Treasury (2004)

- The method used to estimate cost elements in LCC calculations will depend on the amount of information needed to:
    - Establish asset use patterns and operational characteristics and hence expected asset life
    - Understand the technology employed in the asset.

AIQS (2021)

- Design, construction and operational inputs should be reflected progressively through the life cycle of the asset
- Costs associated with components

ANAO (2001)

- Three criteria for cost elements:
    - The element must be a clearly defined activity that generates costs. As far as possible, elements should be independent.
    - The timeline for the element's cost must be known. The significance of a cost generally depends on its position in time within the life of the asset.
    - The relationship between the resources used by the element and the resulting cost must be known.
- AS/NZS 4356 recommends a three-dimensional matrix approach systematically identifying all relevant cost elements. It recognises the above.
- The choice of cost elements for a particular asset should also reflect the complexity of the asset and its key cost drivers.
- All LCC analyses should include contingency allowances for risk in addition to capital cost allowances for design, construction, and operational risks.

3. Cost data

AIQS (2021)

- The use of insufficient or inappropriate data can lead to poor LCC outcomes.
- Databases that collect cost data in a consistent way that support LCC are needed.

NSW Treasury (2004)

- Estimating the life cycle cost requires breakdown of the asset into its constituent cost elements over time.
- The level of which it is broken down will depend on the purpose and scope of the LCC analysis and requires identification of:
    - Significant cost generating activities
    - The time in the life cycle when the activities are to be performed
    - Relevant resource cost categories such as labour, materials, fuel/energy, overheads, transport/travel, and more.
- To support a life cycle costing process capable of supporting decision making, the cost information should be collected and reported in a manner consistent with the defined LCC breakdown structure.
- Sources of cost data:
    - By definition, detailed cost data will be limited in the early stages of the asset life, particularly during design/acquisition stages.
    - Cost data during these early stages will need to be based on the cost performance of similar asset components currently in operation.
    - Where new technology is being employed, data can only be based on estimated unit cost parameters such as $/construction unit, construction unit/labour hours, specified or suggested by the technology.
    - More information will become available during use of the asset, enabling more complete and descriptive costs to be defined.
- Depending on the scope of the analysis, it will be important to obtain cost inputs from individuals who are familiar with each phase of the life cycle. This may include designers, suppliers, construction contractors, maintenance staff and others.

NSW Gov (2018)

- LCC is part of the criteria to be considered when evaluating system options.
- All feasible options require a life cycle cost to be developed.
- In order to estimate the life cycle cost, it is necessary to break down the asset costs into separate cost elements.
- The estimation of cost data may vary depending on when the LCCA is being undertaken over the life cycle of an asset.
- During the early planning and conceptual design stages, where data is limited, cost data may need to adopt different estimation techniques.

Engineering cost method

NSW Gov (2018)

- Engineering cost method: involves direct estimation of a particular cost element by examining the project component by component. It use standard established or known costs.

NSW Treasury (2004)

- Used where there is detailed and accurate cost data for the assets to be analysed. It involves the direction estimation of a particular cost element by examining the asset component by component.
- Uses standard established cost factors (e.g., from firms or manufacturers) to develop the cost of each element and its relationship to other elements (known as cost element relationships or CER).

Analogous cost method

NSW Gov (2018)

- Analogous cost method: involves cost estimation based on experience with similar projects or technology. It uses historical data, updated to reflect cost escalation and effect of technology advances.

NSW Treasury (2004)

- Provides the same level of detail as engineering cost method but draws on historical data from components of other assets having analogous size, technology, use patterns and operational characteristics.

Parametric cost method

NSW Gov (2018)

- Parametric cost method: uses significant parameters and variables to develop cost estimating relationships which are usually in the form of equations. A parameter may be a price (e.g., cost per hour) or an empirically derived ratio.

NSW Treasury (2004)

- Employed where actual or historical detailed asset component data is limited to known parameters. This available data from existing cost analyses is used to develop a mathematical regression or progression formula that can be solved for the cost estimate required.

4. Cost drivers

AIQS (2021)

- A cost driver is an aspect of the asset that has a direct, significant impact on the scale of costs over its life cycle (e.g., for a building, its design, location and size and surrounding landscape and infrastructure).

5. Discount rate

AIQS (2021)

- The use of higher discount rates can lead to the selection of low capital cost and high operational cost alternatives, due to future costs being smaller.
- This can be partly addressed by the use of sensitivity analysis.

NSW Treasury (2004)

- Since the costs for different asset options occur at different times over their life cycle, they can only be compared by reducing the costs to a common base date.
- This is achieved through the well-known process of discounting that reflects the net changes in the real value of an asset cost as a result of:
    - Decreases in value due to inflation
    - Increases in value due to the (potential) interest earned if the money expended on the asset was otherwise invested.
- The discounting of costs takes account of three elements:
    - The interest rate available from long-term investment in bank or government bonds
    - The interest rate that business would expect as a return from risk
    - The inflation rate that would affect the purchasing power of the currency.
- The real discount rate makes allowance for A and B.
- The nominal discount rate makes allowance for A, B and C.
- Discounting does not incorporate changes due to price movements as a result of changes in efficiency, technology, etc. since these are in essence real changes in value.
- The discount rate reflects the net changes in real value due to the compounding effect of interest (potentially) earned on money and the discounting effects of inflation as expressed in the following formula.
- The Discount Rate reflects the real rate of interest at which money is borrowed or lent i.e. the absolute (or nominal) interest rate at which money is borrowed or lent discounted for the effects of inflation.
- Consequently, the terms discount rate and real interest rate are synonymous.

6. Nominal, real and discounted costs

NSW Treasury (2004)

- For the purposes of discounting, there are three relevant expressions of asset component costs. These are:
    - Nominal Cost: the expected price that will be paid when a cost is due to be paid (i.e. including inflation and price movements due to changes in efficiency, technology, etc.)
    - Real Cost: the cost expressed in values of the base date excluding inflation but including price movements due to changes in efficiency, technology, etc.
    - Discounted Cost: the Real Cost discounted by the Real Discount Rate which is equivalent to the Nominal Cost discounted by the Nominal Interest (or Discount) Rate.
- The Discounted Cost is thus often referred to as the Net (or Discounted) Present Value.

7. Span of analysis

ANAO (2001)

- Period of analysis to achieve and maintain desired function, performance, etc.
- Generally, the longer the period involved in the analysis, the more difficult it is to reliably estimate future costs.
- It is often unnecessary, at the outset, to estimate costs beyond 15–20 years.
- Most asset management plans only estimated costs over 10–20 years to inform long-term financial plans (IPWEA, 2015).
- Even for assets with very long lives, the process of discounting future costs means that costs beyond 20 years generally have only a marginal impact on the LCC model.

AIQS (2021)

- The use of shorter or longer life cycles can distort the outcomes to the benefit of one alternative over another.
- This can be partly addressed by the use of sensitivity analysis.

A.5.3 LCC model outputs

1. Life cycle cost

ANAO (2001) & Government of Western Australia (2005) & NSW Gov (2018)

- The life cycle cost (LCC) of an asset can be calculated using the following formula:
  - LCC =
    - Acquisition cost +
    - Lifetime operating costs +
    - Lifetime maintenance costs +
    - Disposal cost -
    - Residual value.
- While this formula is simple, estimating its terms difficult.
- This is particularly the case for future costs like operation and maintenance and adaptation and renewal costs which are subject to a level of uncertainty arising from several factors:
  - The type and frequency of these activities and their costs
  - The impact of inflation on individual and aggregate costs
  - The predicted useful life of the asset.

2. Present value

AIQS (2021)

- The basic principle of LCC analysis is the ‘time value of money’ – a dollar today is worth more than a dollar in the future, due to its earning potential if invested in the interim.

ANAO (2001)

- Future costs are regarded as less significant because they have the potential to be funded by the effective use of existing funds over the intervening period.
- For example, if a $100 purchase is to be made today, it is necessary to have $100 available now.
- However, if the purchase can occur in three years’ time for $100, it would be possible to raise the $100 by investing $75.10 at an interest rate of 10% for three years.
- If the funds can be used in some other way by the organisation, it may be able to generate more than 10% per year.

- In a similar way, the value of a payment to be received at a future time is regarded as less than the value of receiving it now.
- In order to quantify the time impact on future costs, these cash flows are converted to an equivalent present value. This conversion is based on an estimated discount rate (r) and uses the following formula:
    - o PV = FV/(1+r)^n
- Where:
    - o FV = the amount to be spent or received at a point in the future
    - o n = the number of intervals between the present and the future transaction (e.g., years)
    - o r = the discount rate applicable to the chosen intervals.
- For example, an expense of $100 in three years' time with a discount rate of 10% would have a present value (PV) of:
    - o PV = 100/(1+0.1)^3
    - o = 100/1.331
    - o = $75.10.

Government of Western Australia (2005)

- A key concept of life cycle cost analysis is time value of money.
- The challenge in determining the best option from a cost perspective is fairly evaluating them.
- Often decision makers will compare capital and operational costs that are expended at different times.
- To evaluate these costs fairly, they must be expressed in today's dollar values.
- The time value of money is "A concept that acknowledges that money changes value over a period of time; that a sum of money today is worth more than the same sum of money at a future date, because of the fact that the money received now can be invested to earn interest".

3. Net present value

ANAO (2001)

- The net present value (NPV) is the difference between the present value of future revenue and the present value of future costs for an activity over a given period.
- NPV is often a specific function on calculators and in Microsoft Excel.
- The difficulty in calculating NPV arises in choosing an appropriate discount rate.
- The discount rate is usually chosen to reflect the risk-adjusted rate of return on the asset to justify the long-term retention of the asset.
- One option is to use a rate equivalent to the prevailing basic low-risk interest rate, with a small risk premium for low-risk assets.
- However, an organisation that is expected to achieve a better return on its funds than this basic rate would of course choose a higher rate.
- See Chapter 5 Setting discount rates in the Department of Finance publication Handbook of Cost Benefit Analysis. (AGPS, 1991). The Department of Finance and Administration can provide agencies with advice on an appropriate discount rate for significant purchases.

AIQS (2021)

- The sum of initial costs and annual expenditure minus the interest earned had the sum been invested between the base date and future date of payments.
- Future costs are recalculated to an annual impact brought back to the common base date.

A.5.4 Analyse results

ANAO (2001)

- LCC process is built on several assumptions about current and future cash flows and on a range of parameters such as cost escalation factors and the discount rate.
- Each element has a limited accuracy and potentially different impact on the outcome of the analysis.
- Therefore important to explore impacts of changes in these values on the overall results
- This is known as “sensitivity analysis”.
- Sensitivity analysis can be a manual process for simple life cycle costing models or it can be automated in more complex models.
- Either way, it involves repeating the analysis with a variety of alternative values for the above.
- The values are chosen to reflect the level of uncertainty for the data.
- For example, if the cost of annual maintenance is estimated at $125,000 but could range from $100,000 to $150,000, it would be appropriate to investigate the effects of the overall analysis using these three values.
- Analysing the results in the context of the organisation’s business model.

AIQS (2021)

- Sensitivity analysis will assist avoiding unrealistic expectations of the accuracy of LCC analysis.
- It should apply to key variables including the period of analysis, life expectancies, service level agreements, discount rates, etc.
- Sensitivity analysis tests the range uncertainty and may give rise to the prioritisation of alternatives.
- Sensitivity analysis can be applied to a range of key LCC variables.
- Always run a range of assumptions for key LCC variables in isolation and combination allowing best-case and worst-case scenario.

NSW Gov (2018)

- In order to effectively manage risks, the Standard recommends sensitivity analyses be performed and results assessed in detail. The degree of verification of the analysis should correspond with the value and/or risk of the decision.

A.5.5 Reporting

ANAO (2001)

- The value of LCC is increased by presenting results in a clear and consistent format, supported by a summary of significant assumptions that underpin the model.
- Listing the cost drivers and assumptions in a comparative table format is the most appropriate method for presenting and summarising the analysis.
- The table can then be followed by a list of key supporting arguments for the selection option.

AIQS (2021)

- The LCC analysis should document the approach, outcomes and implications of any evaluation with any limitations and assumptions.
- This may extend to qualitative risk analysis for the uncertainties of the analysis.
- LCC analysis report should include:
    - Executive summary: a brief synopsis of the objectives, results, conclusions and recommendations of the analysis

    - Purpose and scope: a statement of the objectives, asset, life cycle stages and what's involved in them including associated costs, assumptions, and alternatives considered
    - LCC method: a description of the LCC method including cost drivers, cost elements analysed, and sensitivity analysis applied, assumptions, exclusions
    - LCC analysis: results of the LCC analysis including the LCC and cost elements
    - Conclusions and recommendations: conclusions related to the objectives of the analysis as well as a list of recommendations along with the need for further work or revision/adaptation of the analysis in the future.

Government of Western Australia (2005)

- The order of sections are:
    - Certification
    - Executive summary
    - Project scope
    - Life cycle cost model
    - Life cycle cost analysis
        - Component 1
        - Component 2
    - Appendix.
- Certification (p. 13 for example)
    - First section is Certificate of Responsibility. The report must be certified by:
        - The person who prepared it
        - The independent reviewer.
- Executive summary
    - Brief synopsis of the purpose of the report, summary of important findings, description of assumptions and limitations, and recommendations based on lowest life cycle cost
    - A summary of results presenting each alternative evaluated, including doing nothing if appropriate
- Project scope
    - Project summary including the assets and alternatives analysed and objectives and scope of the analysis
    - Organisation contact information
    - Professional who put together the LCC report contact information
    - Assumptions form documenting and justifying assumptions including providing references
- Life cycle cost model
    - Analysis of each option must consider all life cycle stages and the costs of activities therein
    - Cost data provided and developed for the options to be analysis are entered under the individual "Component Cost Option" sheets
    - The consolidated LCCA model is a protected work sheet that serves to reflect the consolidation of ach of the component costs options sheets
- Life cycle cost analysis
    - Results of analysis
- Appendix
    - The report appendix is to include supporting information (e.g., sketches, calculations, and other pertinent information to support the recommendations made)

NSW Gov (2018)

- The person undertaking the LCC should provide assurance it has been executed to its intended use, that options have been evaluated adequately and provide supporting documentation.

- Plans should be developed and implemented to validate the LCC in the evaluation of options for decision making.
- Detailed records of the LCC and associated analysis shall be maintained. Records shall comprise:
    - Details of each of the life cycle cost analysis steps
    - Documents substantiating and providing evidence of LCC analysis
    - Assumptions made (and documented), including uncertainty and risks associated with the established model. This is to ensure the model has been appropriately established, used appropriately, with results (including those from sensitivity analysis) have been adequately evaluated and discussed and the objectives of the analysis have been achieved.

A.5.6 Review

AIQS (2021)

- Given the significance of this process, a formal peer review may be required to confirm the integrity of the analysis and results, conclusions and recommendations presented in the report.

Government of Western Australia (2005)

- LCCA reports are to be standalone documents containing all support documentation and be capable of independent review.

A.6 LCC considerations

AIQS (2021)

- LCC analysis can be complex, time-consuming and often bespoke for addressing the number of variables involved and a large amount of data to aggregate through the process.
- The larger and more complex an asset, the more difficult it is to consider or calculate all the possible options and trade-offs, and the cost effectiveness of each design decision.
- However, experience has shown life cycle data to be notoriously scant.
- Only part of the information needed to support decisions aligned to ESG or ecological and financial sustainability.
- It also represents only 1 input into an evaluation process that should consider the environmental and social benefits and costs associated with options.

A.7 Literature review key findings

Across all documents:

- there is general consistency in the guidance they provide and the general process for LCC
- this provides a solid basis for how to develop and apply a LCC tool for WSUD assets that complies with industry accepted guidelines and standards for LCC in Australia
- the tool and its components should follow a LCCA process adapted from these guidelines and standards for WSUD assets
- this general process needs to be adapted for WSUD assets as it is commonly applied to new commercial products.

Appendix B – WSUD guidelines and drawings

Best practice guidelines, standard drawings and similar documents for the focal assets were collected from around Australia and reviewed to attempt to identify a consistent basis for the LCC of these assets in terms of their naming conventions, design components and life cycle activities.

We drew on the following to collect documents:

- A literature review of WSUD guidelines, standard drawings, and similar documents undertaken by members of the Project Team for Blacktown City Council in 2021 and Water by Design in 2022
- The Project Team's knowledge of industry developments including their experience co-authoring recently published guidelines (e.g., Water by Design's Guidelines for the construction and establishment of bioretention systems and constructed wetlands)
- PSG member websites and meetings.

We collected documents that met the following criteria:

- They represented best practice based on the Project Team's judgement.
- There were authored by an authoritative source (e.g., an industry association or group).
- They were published in the past 15 years.
- They were accepted and used by stakeholders in SA, VIC or WA.

Best practice documents published by authoritative sources outside of SA, VIC, or WA were also included but viewed as less applicable for PSG members (e.g., guidelines from Water by Design in QLD).

B.1 WSUD guidelines

Table 1 presents the WSUD guidelines, fact sheets and instruction sheets collated and reviewed to understand their naming conventions and life cycle activities.

Table B.1

WSUD guidelines, fact sheets and instruction sheets reviewed

Author	Title	Type	Year	Geographic scope	Asset type
Melbourne Water	Raingarden design for Melbourne's west	Fact sheet	Not dated	Victoria	Biofilter
New WAter Ways	Water sensitive urban design Pervious paving	Fact sheet	June 2011	Western Australia	Permeable paving
New WAter Ways	Water sensitive urban design Biofilters	Fact sheet	July 2016	Western Australia	Biofilter
New WAter Ways	Introducing water sensitive urban design Tree pits	Fact sheet	Not dated	Western Australia	Passively watered solutions
New WAter Ways	Introducing water sensitive urban design Soakwells	Fact sheet	Not dated	Western Australia	Passively watered solutions
New WAter Ways	Water sensitive urban design Infiltration basins and trenches	Fact sheet	June 2011	Western Australia	Passively watered solutions
Government of Western Australia	Stormwater management manual for Western Australia	Guideline	April 2005, updated May 2022	Western Australia	All
Monash University	Vegetation guidelines for stormwater biofilters in the south-west of Western Australia	Guideline	Nov 2014	Western Australia	Biofilter
Water Sensitive SA	South Australia – MUSIC Guidelines	Guideline	Feb 2021	South Australia	All
Water Sensitive SA	South Australia – WSSA – A guide to raingarden plant species selection and placement	Fact Sheet	2016	South Australia	Biofilter

Author	Title	Type	Year	Geographic scope	Asset type
Water Sensitive SA	South Australia - Technical manual	Guideline	2010	South Australia	All
Cooperative Research Centre for Water Sensitive Cities	Adoption Guidelines for Stormwater Biofiltration Systems	Guideline	Oct 2015	Australia-wide	Biofilter
Cooperative Research Centre for Water Sensitive Cities	Designing for a cool city - Guidelines for passively irrigated landscapes	Guideline	April 2020	Australia-wide	Passively watered solutions
Melbourne Water	Design, Construction & Maintenance of WSUD	Guideline	January 2011	Victoria	All
Melbourne Water	Water Sensitive Urban Design Guidelines South Eastern Councils	Guideline	April 2013	Victoria	All
Melbourne Water	WSUD maintenance guidelines A guide for asset managers	Guideline	May 2013	Victoria	All
Melbourne Water	WSUD Audit Guidelines	Guideline	June 2017	Victoria	All
Melbourne Water	Biofiltration systems in Development Services Schemes	Guideline	September 2020	Victoria	All
Water by Design	Bioretention technical design guidelines	Guideline	October 2014	Queensland	Biofilter
Water by Design	Guideline for the construction and establishment of bioretention systems	Guideline	September 2022	Queensland	Biofilter

Author	Title	Type	Year	Geographic scope	Asset type
	and constructed wetlands				
Melbourne Water	Building an infiltration raingarden	Instruction sheet	December 2013	Victoria	Biofilter
Melbourne Water	Building an inground raingarden	Instruction sheet	December 2013	Victoria	Biofilter
Melbourne Water	Building a planter box raingarden	Instruction sheet	December 2013	Victoria	Biofilter
Melbourne Water	Building a vegetable raingarden	Instruction sheet	November 2013	Victoria	Biofilter
Melbourne Water	INSTRUCTION SHEET Porous paving	Instruction sheet	October 2012	Victoria	Permeable paving
Clearwater	Raingarden design principles Building raingardens in our streetscapes to treat stormwater	Instruction sheet	May 2012	Victoria	Biofilter
Clearwater	Tree pit design principles	Instruction sheet	February 2014	Victoria	Passively watered solutions
Healthy Land & Water	Building a raingarden – A step-by-step guide	Instruction sheet	Not dated	Queensland	Biofilter

B.2 WSUD typical drawings

Table B.2 outlines the concept and detailed design drawings on the focal WSUD assets, reviewed to understand their common attributes and terminology.

Table B.2

Design drawings of focal WSUD assets

Author	Drawing #	Drawing name	Year	Type	Geographic scope	Asset type
Water Sensitive South Australia	4	Infiltration trench	2020	Concept drawings	SA	Passively watered solutions
Water Sensitive South Australia	5	Infiltration pit	2020	Concept drawings	SA	Passively watered solutions
Water Sensitive South Australia	6	Permeable pavement	2020	Concept drawings	SA	Permeable paving
Water Sensitive South Australia	8	Swale	2020	Concept drawings	SA	Passively watered solutions
Water Sensitive South Australia	9	Raingarden	2020	Concept drawings	SA	Biofilter
Merri-bek City Council	C120.01	Typical Raingarden Layout	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.02	Raingarden Inlet Options	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.03	Raingarden Outlet Options	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.04	Raingarden Plants	2022	Detailed	City of Merri-bek	Biofilter

Author	Drawing #	Drawing name	Year	Type	Geographic scope	Asset type
Merri-bek City Council	C120.05	Raingarden Soil and Layers	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.06	Raingarden Edge Treatment and Fencing	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.07	Raingarden Configurations	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.08	Raingarden Tree Pits	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.09	Permeable Paving	2022	Detailed	City of Merri-bek	Permeable paving
Merri-bek City Council	C120.10	Planter Box	2022	Detailed	City of Merri-bek	Biofilter
Merri-bek City Council	C120.11	Passive Irrigation in Nature strips Configuration	2022	Detailed	City of Merri-bek	Passively watered solutions
Merri-bek City Council	C120.12	Passive Irrigation in Natures trips Configuration	2022	Detailed	City of Merri-bek	Passively watered solutions
IPWEAQ	DS-071	BIORETENTION DRAINAGE PROFILE - TYPE 1 SATURATED ZONE - CONSTRAINED	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-072	BIORETENTION DRAINAGE PROFILE - TYPE 2 SEALED	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-073	BIORETENTION DRAINAGE PROFILE - TYPE 3 CONVENTIONAL	2015	Detailed	QLD	Biofilter

Author	Drawing #	Drawing name	Year	Type	Geographic scope	Asset type
IPWEAQ	DS-074	BIORETENTION DRAINAGE PROFILE - TYPE 4 PIPELESS	2018	Detailed	QLD	Biofilter
IPWEAQ	DS-075	LARGE BIORETENTION SEDIMENT FOREBAY	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-076	BIORETENTION WEIR	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-077	BIORETENTION STREET TREE	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-070	BIORETENTION DRAINAGE PROFILE - TYPE 1 SATURATED ZONE - UNCONSTRAINED	2015	Detailed	QLD	Biofilter
IPWEAQ	DS-078	BIORETENTION STANDARD NOTES	2015	Detailed	QLD	Biofilter
IPWEAQ	HW-01	BIORETENTION TREE PIT	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-02	EXAMPLE STREETSCAPE BIORETENTION	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-03	EXAMPLE BIORETENTION BASIN	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-04	BIORETENTION - TYPICAL SECTIONS	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-05	BIORETENTION - DRAINAGE PROFILES	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-06	BIORETENTION - DRAINAGE PROFILES	2014	Detailed	QLD	Biofilter

Author	Drawing #	Drawing name	Year	Type	Geographic scope	Asset type
IPWEAQ	HW-07	FLOW SPREADING SWALE AND WEIR	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-08	LARGE BIORETENTION SEDIMENT FOREBAY	2014	Detailed	QLD	Biofilter
IPWEAQ	HW-17-2	WSUD STANDARD NOTES - SHEET 2 OF 2 - BIORETENTION SYSTEM SPECIFICATIONS	2014	Detailed	QLD	Biofilter

B.3 Review findings

There are many guidelines, fact sheets and design drawings available for the focal assets which are often specific to a local government or regional area. Documents use slightly different language for the focal assets and their components; however, some terms are used interchangeably across the country (e.g., biofilter and bioretention system, permeable and porous paving, sediment forebay and sedimentation forebay) as demonstrated in Table 3.

Documents provide slightly different guidance for the design and life cycle activities of the focal assets (e.g., construction and maintenance). This is largely owing to a lack of national standardisation, specific areas embracing specific language (e.g., biofilter vs. bioretention system), and the need for guidance that responds to the specific conditions, constraints and policy and other requirements in local government and regional areas. Consequently, a consistent basis for the LCC of the focal assets cannot be readily identified from the literature.

Table 3

WSUD guideline assets and terminology

WA (2022)	SA (WSUD Guidelines)	SA (Other guidelines)	Victoria	Queensland
Biofilter Raingarden Bioretention system	Bioretention system Bioretention swale	Raingarden Biofiltration Bioretention asset Bioretention swale	Biofiltration Raingarden aka Biofilter Bioretention Bio-infiltration	Biofiltration system aka Biofilter Bioretention system Bioretention pod Raingarden
Tree pit	-	-	Passively irrigated street trees Bioretention tree pits	Passively irrigated street tree Self-watered street tree
Pervious pavement	Pervious pavement	Permeable pavement Porous pavement		
		Rooftop garden		
Rainwater storage system	Rainwater tank	Rainwater tank Retention tank		
Infiltration basin Infiltration trench Soakwell	Infiltration trench	Infiltration trench Infiltration pit		Infiltration measures Sand filters
Swales and buffer strip	Buffer strip	Swale Buffer Grass buffer	Vegetated swale	Swale
Dry/ephemeral detention area		Detention	Detention basin	
		Pond Lake		
		Sediment pond	Sediment pond Sediment basin	Sediment basin
Constructed wetland	Constructed wetland	Wetland	Wetland Constructed wetland	Constructed wetland
Living stream				Natural channel design Naturalisation
Litter and sediment management Gross pollutant trap (GPT) Trash rack	Gross pollutant trap	Gross pollutant trap	Gross pollutant trap	Gross pollutant trap Litter trap

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