Estimating life cycle costs of stormwater treatment measures *

AC Taylor † and TD Fletcher
Institute for Sustainable Water Resources,
Department of Civil Engineering, Monash University, Victoria

SUMMARY: *Increasingly, Australian stormwater managers are making more holistic decisions about proposed urban stormwater treatment measures by considering the financial, social and ecological costs, and benefits of alternative options.*

An essential input into such decision-making processes is a sound understanding of the measure's cost over its life cycle. To assist stormwater managers to quickly estimate indicative life cycle costs of common types of stormwater treatment measures, a new life cycle costing module has been developed as part of the continuing development of the Model for Urban Stormwater Improvement Conceptualisation (MUSIC). MUSIC is a pollutant export computer model that is used by stormwater managers during the conceptual design stage of projects. The life cycle costing module allows users to enter size-related details of the treatment measure (eg. the area of a stormwater pond) to estimate the approximate life cycle cost of the treatment measure, as well as "cost elements" that make up this cost (eg. typical annual maintenance cost, decommissioning cost, etc.).

A key feature of this new tool is the ability to generate a predicted range (eg. mean, along with upper and lower bounds) for each cost element in the measure's life cycle. The use of upper and lower bounds aims to promote awareness among users of the high variability typically associated with such costs. It is hoped that this will lead to more informed and cautious use of cost estimates, as well as a stronger commitment to the gathering of high-quality data sets that are needed to progressively reduce the degree of uncertainty currently associated with these cost estimates.

This paper explains how the life cycle costing module was created, provides details of the algorithms currently used in the module to estimate costs from sizing information, highlights its strengths and weaknesses, provides a worked example, and outlines a cooperative plan to further improve the ability of Australian stormwater managers to estimate the approximate cost of proposed stormwater treatment measures.

1 INTRODUCTION

The focus on stormwater as a cause of waterway degradation in urban areas has led to the increased use of infrastructure to improve the management of stormwater quality and quantity in Australia. For example, a survey by the Cooperative Research Centre (CRC) for Catchment Hydrology (Taylor & Wong, 2002) involving 25 stormwater managers from across Australia found that the majority of respondents to the survey reported an increasing trend in use for many structural stormwater treatment measures.

* Paper W25/742 submitted 9/08/05; accepted for publication after review and revision 21/04/06.

† Corresponding author André Taylor can be contacted at andretaylor@iprimus.com.au.

In part, this infrastructure is being built as the philosophy of water sensitive urban design is being adopted. Water sensitive urban design involves using non-structural and structural stormwater management measures at the planning and design stage of developments to minimise their impact on the water cycle (Lloyd et al, 2002). This paper deals specifically with the stormwater management aspects of WSUD.

In Australia, WSUD has strong support in principle, but concerns have been raised over its relatively slow adoption rate (Taylor & Weber, 2004). Studies that have surveyed stakeholders to identify possible impediments to WSUD have found that inadequate information on the cost of treatment measures is one of the most significant impediments (Lloyd et al, 2002; Colmar Brunton, 2005; Wong, 2001). Specifically, stakeholders making decisions on the use of stormwater management measures to improve waterway health need practical tools to estimate life cycle costs at the conceptual design stage of a development or stormwater management plan. It is at this stage that the relative cost-effectiveness of alternative stormwater management measures needs to be quickly assessed.

To complicate matters, not all stakeholders are equally concerned about the same cost elements of stormwater treatment measures. For example, a developer funding the design and construction of a large residential estate is likely to be primarily concerned with the initial capital costs associated with stormwater treatment measures, while the local authority that may have to maintain these measures in the long term may be more concerned about "typical annual maintenance costs" (ie. routine maintenance costs), infrequent "renewal and adaptation costs" (eg. corrective maintenance costs), "decommissioning costs" and the "life cycle costs". Consequently, a useful cost estimation tool should be able to provide estimates for all significant cost elements that occur over the asset's life span, as well as combine these elements to calculate an overall "life cycle cost" (equivalent to a net present value). Fortunately, well established frameworks for doing this already exist, such as the Australian Standard (AS/NZS 4536) for life cycle costing (Standards Australia, 1999).

In response to a request from water management agencies in Melbourne and Brisbane, the CRC commissioned a project to develop a simple life cycle costing model that could be used for stormwater management measures that aim to improve waterway health. This paper explains the methodology that was used to create this new tool and its key features.

2 BACKGROUND RESEARCH

A review of published work in this area found useful examples of how to undertake life cycle costing and some limited modelling tools. For example, Rozis & Rahman (2002) provided a good example of how to calculate life cycle costs for stormwater treatment measures to enable comparison to be made between traditional and water sensitive designs. Several studies (eg. Lloyd et al, 2002; Weigand et al, 1986; Lloyd & Wong, 2003) used regression analysis to relate aspects of a stormwater treatment measure's size (eg. storage volume) with cost elements (eg. construction cost) to derive equations that could be used to generate a predicted cost if the size of the measure is known. Some simple, software-based models were identified that used characteristics of the catchment to derive likely costs associated with different types of structural treatment measures (eg. Choi & Engel's *Cost Analysis System for Urban Storm Water BMPs* (2003) using methodology from US EPA (1999)). Finally, some more sophisticated pollutant export models for modelling the effect of urban stormwater treatment measures were found that contain simple cost-estimation tools that are reliant on the user entering estimates for cost elements (eg. XP-AQUALM, as described in the *Australian Runoff Quality Guidelines* (Institution of Engineers Australia, 2003)).

The findings of this review supported the views of Fletcher et al (2001), who concluded that compared to research into the pollutant removal performance of stormwater treatment measures, little research on the costing of such measures has been undertaken. The review also concluded that available tools for estimating the life cycle costs of stormwater management measures did not fully satisfy the needs of Australian stormwater managers in four key areas.

First, attempts to relate the size of stormwater treatment measures to their cost elements (when built in Australia) draws on a relatively small, low quality data set for most types of treatment measures. For example, costing data have been used to generate equations relating size and cost when important characteristics of the data were unknown. Such characteristics include: whether the costing data included government taxes; the date of expenditure (so adjustments can be made for inflation); whether costing data included project and/or contract management expenses; whether costs were actually incurred or estimated; and whether costs included expenses associated with acquiring land.

Second, attempts to relate the size of stormwater treatment measures to their cost elements commonly focus on "construction" and "typical annual maintenance" costs, but often fail to address other costs in the asset's life cycle (eg. design costs, corrective maintenance costs, decommissioning costs, etc.).

Third, where equations or simple models have been developed to predict cost elements of stormwater treatment measures given information about their size, the resulting estimates generally do not include a description of the degree of uncertainty associated with the estimate. This is suggested as a significant shortcoming, particularly given the highly variable nature of these costs has been recognised for some time (eg. Weigand et al, 1986).

Finally, stormwater quality managers in Australia have not had ready access to a comprehensive suite of costing information with supporting modelling tools to help generate cost estimates and undertake life cycle costing. Nor have they had access to tailored guidelines that explain how to do a comprehensive life cycle cost analysis for stormwater treatment measures. In the absence of such guidance, inconsistent approaches have been used. The lack of such guidance has also resulted in confusion concerning significantly different terms such as "life cycle assessment" and "life cycle costing", leading to miscommunication between stakeholders.

Note that this paper and the model it describes adopts the definition of life cycle costing from AS/NZS 4536 (Standards Australia, 1999), namely "the process of assessing the cost of a product over its life cycle or portion thereof" (pp. 6). Life cycle costing is similar to calculating a net present value, where all cost elements of a product/asset are identified and added, while allowing for the time-value of money. The final life cycle cost (LCC) figure from the life cycle costing model described here is a single dollar figure (eg. "the LCC of the wetland is A$1,000,000 in 2006, using all default values in version 3 of the MUSIC software"), that relates to the direct costs of the asset, but does not include externalities (eg. added value to adjacent properties) or the cost of the land occupied by the asset.

In contrast to the definition of life cycle costing, life cycle assessment is defined in AS/NZS ISO 14040 (Standards Australia, 1998) as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system through its life cycle" (pp. 2). For an example of a life cycle assessment in the water industry, see Peters & Lundie (2002).

3 DEVELOPMENT OF A LIFE CYCLE COSTING MODEL

3.1 A new tool for Australian stormwater managers

In response to the identification of industry needs and the shortcomings of existing tools, the CRC developed a life cycle costing module in version 3 of its MUSIC model (Model for Urban Stormwater Improvement Conceptualisation (Lloyd & Wong, 2003; Fletcher et al, 2001)).

MUSIC is a decision support system that assists users to plan and evaluate conceptual designs of stormwater treatment measures to meet quantitative objectives for water quality and quantity, derive approximate sizes of structural stormwater treatment measures, and estimate pollutant load reductions associated with specific treatment measures (Wong, 2001; Lloyd & Wong, 2003; Institution of Engineers Australia, 2003; Fletcher et al, 2001). MUSIC has been designed to simulate stormwater treatment measures in urban catchments from 0.01 to 100 km^2 in size, using modelling time steps ranging from 6 minutes to 24 hours to match the spatial scale. Version 3 of MUSIC can simulate the operation of buffer strips, vegetated swales, constructed wetlands, bioretention and infiltration systems, ponds, rainwater tanks, gross pollutant traps, sediment basins, and also has a generic treatment note that enables the user to define flow and water quality performance. For more details on MUSIC, see Fletcher et al (2001) or www.toolkit.net.au.

3.2 Methodology

3.2.1 Data collection

Stormwater management authorities from across Australia were contacted to participate in a survey that gathered information on the physical properties (eg. size) and actual costs associated with recently constructed stormwater treatment measures. Size was known to be an important predictor of costs, based on previous studies (eg. Lloyd & Wong, 2002).

Preliminary discussions with key stakeholders in the stormwater management industry prior to launching the survey indicated that gathering costing information would be difficult for four reasons. First, there was a general reluctance of many local government authorities to participate in stormwater-related surveys. Second, there was a common tendency for relevant record-keeping to be poor (eg. itemised costings), largely because the construction of stormwater treatment measures had only occurred in recent years in most areas, meaning that established protocols for the collection and management of such data were rare. Third, organisational fragmentation was common in Australian stormwater management agencies, making acquisition of all costs difficult for a given asset. And finally, there was a lack of experience with post-construction costs, particularly for newly constructed vegetated treatment measures.

To address these concerns, a draft survey instrument was reviewed by several industry-based stormwater managers to ensure it could be understood and completed without an unreasonable burden on survey recipients. This survey was also circulated to several researchers who had done preliminary research on costing to ensure that its content was sound.

Sixty-eight stormwater managers were asked to participate in the survey. Of these, 67 initially agreed to participate (ie. 99%). Forty-six eventually submitted a completed survey and/or useful data in another form (ie. a 69% response rate). These survey respondents represented stormwater managers from all six Australian states, including major cities and regional areas.

In general, survey respondents completed the survey well. An area of the survey that revealed a great deal of uncertainty, however, involved the frequency and cost of maintenance associated with vegetated measures and infiltration systems. It was apparent that very few of the surveyed stormwater management agencies had undertaken infrequent maintenance work such as replacing a wetland's macrophyte zone or a bioretention system's filtration media. Data relating to the frequency of such events and the likely cost were typically only educated estimates, given the recent application of these technologies.

3.2.2 Data analysis

The authors assigned a "data quality score" (out of 10) for each dataset that was gathered. This score was based on knowledge of the supplying organisation, whether the data related to actual expenditure or only estimates, and whether the data were internally consistent within the survey form. In addition, a score (out of 10) was assigned for the degree to which the stormwater treatment measure represented current "best practice" (based on available guidelines, such as Institution of Engineers Australia (2003)).

While both scores were quite subjective (ie. based on expert opinion that used limited data), they helped to identify poor data sets that could justifiably be removed from the analysis to reduce the overall level of uncertainty associated with the numerical size-cost relationships for each type of treatment measure. For example, during the data interrogation stage it was possible to examine the quality of size-cost relationships for all data sets, only those that scored above 8/10 on both measures, etc. This capability resulted in a refined dataset with enhanced explanatory power.

Terminology from the Australian Standard for life cycle costing (Standards Australia, 1999) was used as a guide to break down the total cost of a treatment measure into "cost elements". The cost elements used during the project were:

- total acquisition cost (ie. capital cost). This is the cost associated with the identification and definition of the need for the stormwater management measure, conceptual design, preliminary design and construction/purchase costs. It also includes overheads (eg. project/contract management costs), but does not include tax, the land acquisition costs or opportunity costs.
- typical annual maintenance cost (sometimes known as the routine maintenance cost).
- renewal and adaptation cost. This type of cost may occur infrequently (eg. replacing infiltration media) and may also involve modification to the design of the stormwater treatment measure (eg. installing a new maintenance access track).
- decommissioning cost. This is the cost of fully reinstating the site at the end of the measure's life cycle. It is acknowledged that this cost element may not be applicable to some treatment measures, so MUSIC users may choose not to include it in their life cycle costing analysis.

Note that all "raw" costing data was adjusted to a common base date (using an annual inflation rate of 2%) prior to analysis.

Two forms of analysis were undertaken on the data. First, regression analysis was undertaken to relate the size of specific types of stormwater treatment measures to their total acquisition cost and typical annual maintenance cost. Second, statistical analysis was undertaken to generate estimates for renewal and adaptation costs (and the period that these costs would typically reoccur), decommissioning costs, and the life-cycle (or lifespan) of each type of common stormwater treatment measure.

3.2.2.1 Regression analysis

Initial analysis of plots of treatment size versus cost elements showed some clear outliers in the dataset, which, upon investigation, were excluded to ensure only treatments of consistent type were included. For example, greenfield (ie. previously undeveloped) constructed wetland data were included, while wetlands that had been retrofitted in established urban areas were excluded due to their highly variable construction costs (eg. costs associated with relocation of existing services, etc.). In addition, poor quality data sets were excluded, based on the previously-described "best practice" and "data quality" scores.

Some gaps in the data set were interpolated. For example, some agencies supplied high quality data for the "construction cost" of an asset, but not the required "total acquisition cost". Average ratios were developed from all complete data sets to help fill these gaps.

For each possible relationship between a treatment measure's size and major cost elements (ie. total acquisition cost and typical annual maintenance cost), non-linear regression curves (using the SPSS software – version 11.5.0) were fitted, with the best fit chosen based on its coefficient of determination (R^2) and significance (p-value). Only regressions with a significance (p) < 0.05 were accepted. Consistency with the assumption of normality was also tested using the Kolmogorov-Smirnov test (with rejection at $p < 0.05$). The resulting regression equations were then transformed into a linear form, to allow prediction intervals to be calculated that could be used to generate upper and lower cost estimates.

For each common type of treatment measure, the regression equation, as well as the ± 1 standard error prediction interval (ie. the band within which 68% of individual data points will fall) equations were calculated using equation 1, to form a predicted relationship along with lower and upper bounds.

Standard error (prediction) =

$$\sqrt{s^2_{residual} \cdot \left(1 + \frac{1}{n} + \left(\frac{(X_i - \overline{X})^2}{\sum x^2}\right)\right)} \qquad (1)$$

where:

n = number of data points in the regression

X_i = X value of interest (ie. a size-related variable, such as the area of the treatment zone for a constructed wetland)

$s^2_{residual}$ = variance of the residual

$\overline{X}$ = mean of X from the regression

$\sum x^2$ = regression sum of squares.

3.2.2.2 Estimates of remaining cost elements and costing parameters

The statistical analysis to generate estimates for typical renewal and adaptation costs (and the typical period that these infrequent costs are occurred), decommissioning costs, and life cycle (or lifespan) for each type of stormwater treatment measure involved the following protocol.

First, median values from the dataset were used to estimate typical values for renewal and adaptation costs (RC), the renewal period (RP), decommissioning costs (DC) and life cycles (LC). The RP and LC values were in years, while RC and DC values were expressed as a percentage of the asset's total acquisition cost.

Where the sample size (n) of the interrogated data set was > 5, the RC, DC and LC data were transformed to satisfy assumptions of normality (ie. $\log_{10}$ transformation was used with normality accepted where $p > 0.05$ for the Kolmogorov-Smirnov test) and 68% confidence intervals (ie. ±1 standard deviation) were generated to provide an upper and lower bound on the estimate. For smaller data sets ($n \leq 5$), the 16th and 84th percentiles were used for the lower and upper bounds, respectively, as there were inadequate data from which to reliably estimate the standard deviation.

For several types of treatment measure (ie. sediment basins and ponds, constructed wetlands, bioretention systems and vegetated swales, and infiltration systems), the final expected estimate of their life cycle (in years) was derived using judgment rather than from analysing the estimates of survey respondents (which were often absent, or identified as guesses only). For example, it could be argued that constructed wetlands have an infinite life cycle if typical annual maintenance is undertaken, and "resetting" of the macrophyte zone occurs say every 20 years (as part of the renewal and adaptation cost). But to calculate a "life cycle cost" using the methodology in the Australian Standard for life cycle costing (Standards Australia, 1999), the length of the life cycle must be finite. Consequently it can be set at a figure of say 50 years, where the effect of discounting future costs makes costs incurred this far after construction insignificant in the calculation of the "life cycle cost" (assuming the real discount rate does not drop significantly below 5.5% per annum – the default value for MUSIC version 3 in 2006).

3.2.3 *Software development*

A life cycle costing module was incorporated into version 3 of the MUSIC software. This module uses methodology defined in the Australian Standard (Standard Australia, 1999) for life cycle costing to calculate a life cycle cost. Note that the "life cycle cost" of an asset derived from MUSIC is the sum of all discounted real costs over the entire life-span of the asset (where real costs are those that are not adjusted for inflation and are discounted using a real discount rate. For more information see Standard Australia (1999), MUSIC Development Team (2005) and Taylor (2003).

3.3 Results

This section provides an overview of how users operate the life cycle costing module in MUSIC, provides one full set of cost-related algorithms and estimates that are used in the module, and provides a worked example with outputs from the model.

3.3.1 *The steps to generate a life cycle cost estimate*

Users of MUSIC's life cycle costing module firstly establish their stormwater treatment train and set the parameters of their catchment, simulated rainfall and each stormwater treatment node (including sizing parameters that drive the costing algorithms). After running the model, users then open the life cycle costing module for each treatment node (eg. a swale) and estimate the cost of each "cost element" by choosing the expected, upper, lower or user-defined estimate in MUSIC. Users also need to choose an appropriate life cycle (or span) for the asset, renewal period (ie. the period between each episode of infrequent renewal and adaptation costs), real discount rate and annual inflation rate. Once this is done, the module calculates the estimated life cycle cost of the asset and the equivalent annual payment (ie. the life cycle cost divided by the number of years in the life cycle). Result screens in MUSIC also highlight the temporal distribution of costs, the relative distribution of each cost elements and the sensitivity of the life cycle cost to the real discount rate. Examples of these screens are presented with the worked example in section 3.3.3.

MUSIC can also generate life cycle cost estimates for entire treatment trains. Users must, however, firstly specify a "span of analysis". This is the number of years over which all discounted real costs will be added. For example, a treatment train may include a release net gross pollutant trap with a life cycle of 10 years and a constructed wetland with a 50 year life cycle. If the span of analysis is set for 50 years, the treatment train's life cycle cost will include all costs

Table 1: Costing relationships for constructed wetlands in MUSIC (modified from MUSIC Development Team (2005)).

Element of the life cycle costing model	**Default option for estimation in MUSIC**	**Alternative(s)**	**Notes**
Life cycle	50 years (expert judgement)	30 years (from collected survey data, n = 15).	One could convincingly argue the life cycle is infinite for well-maintained and "reset" wetlands, but the life cycle must be a finite number to calculate a life cycle cost. Fifty years is suggested as a conservative figure, as the effect of discounting usually reduces the influence of costs typically incurred after 30-40 years on the life cycle cost to negligble amounts. Expected, upper and lower estimates in MUSIC are based on expert judgement.
Total acquisition cost (TAC)	TAC (\$2004) = 1911 x $(A)^{0.6435}$ $R^2 = 0.80$; $p < 0.01$; $n = 21$ where: A = surface area of treatment zone in m^2	No alternative size / cost relationships in MUSIC. For literature values, see Taylor (2000b) – included in Appendix H of the *MUSIC User Manual* (MUSIC Development Team, 2005).	Upper and lower estimates derived using a 68% prediction interval for the regression. To convert an estimated total construction (TC) cost to TAC for greenfield wetlands: TC ≈ 92% of TAC (based on the CRC data set). "Treatment zone" refers to the inlet zone/ pond and macrophyte/ storage zone.
Typical annual maintenance (TAM) cost	TAM (\$2004) = 6.831 x $(A)^{0.8634}$ $R^2 = 0.76$; $p < 0.01$; $n = 18$ where: A = surface area of treatment zone in m^2	As above.	Upper and lower estimates derived using a 68% prediction interval for the regression.
Annualised renewal and adaptation cost (RC)	RC (\$2004) = 0.52% of TAC p.a. $n = 4$	As above.	Upper and lower estimates derived using a 84^{th} and 16^{th} percentile, respectively.
Renewal period	20 years $n = 4$	As above.	Period estimated after reviewing the CRC data set. There is great uncertainty surrounding this period (and the associated RC), given the lack of experience in "resetting" the macrophyte zone of constructed wetlands in Australia. Range of data = 10-50 years (10-20 is the most common range). Note that Fletcher et al (2005) suggested 20-50 years.

Decommissioning cost (DC)	DC ($2004) = 42% of TAC n = 4	No alternative size/cost relationships in MUSIC.	Upper and lower estimates derived using a 84th and 16th percentile, respectively.
General caveats/ notes for this type of device	• *For the purposes of costing a "wetland", the treatment device is assumed to include an inlet zone sediment basin/pond and macrophyte zone, but no gross pollutant trap pretreatment device.* • *Retrofitted wetlands were excluded from the data set that was used to generate these relationships, due to limited data and unusually high total acquisition costs. It is suggested that additional costs associated with retrofitted wetlands (eg. relocating underground services) be manually added to the estimates of relevant cost elements that are generated by MUSIC.* • *Final results from the life cycle costing analysis should only be reported to two significant figures.*		

associated with the original wetland and release net, as well as four replacement release nets.

All of the default algorithms and estimates used in the MUSIC life cycle costing module are too numerous to list here, but are publicly available via the life cycle costing chapter (7) of the User Manual (MUSIC Development Team, 2005) that can be downloaded at the Catchment Modelling Toolkit: www.toolkit.net.au. The manual also includes an appendix that summarises costing information from the literature that can be used as alternatives to the algorithms in MUSIC. This information is also freely available as a separate PDF file from the Catchment Modelling Toolkit (see Taylor, 2005b).

3.3.2 A set of the costing algorithms and estimates used in the life cycle costing module

Table 1 is an example of one set of cost-related relationships that are used in the MUSIC life-cycle costing module (for greenfield constructed wetlands). Similar sets are available in the User Manual for vegetated swales, buffer strips, bioretention systems, ponds, sediment basins, infiltration systems, rainwater tanks and gross pollutant traps (including a "generic" type, in-ground gross pollutant traps, open gross pollutant traps, trash racks and litter baskets, release nets, and side entry pit traps).

While the regression equations carry four significant figures in table 1 and the User Manual (MUSIC Development Team, 2005), users of the life cycle costing module in MUSIC are strongly encouraged during training to round-off the final results of their analysis to two significant figures.

Figures 1 and 2 show the CRC's costing data set for greenfield constructed wetlands from around Australia (for total acquisition costs and typical annual maintenance costs, respectively), along with the calculated regressions that relate each cost element to the size of the wetland, and the 68% (or ± 1 standard error) prediction interval that is used in the MUSIC life cycle costing module to generate upper and lower estimates for these cost elements.

3.3.3 A worked example of life cycle costing involving a greenfield constructed wetland

Consider the following worked example to estimate the life-cycle cost of a greenfield constructed wetland using the costing module in MUSIC (version 3.01).

After running the MUSIC model, the user begins to generate estimates for each "cost element" of the wetland. Figure 3 shows the primary costing screen that summarises these estimates (as well as the life cycle and renewal period). The user uses "wizards" (by selecting the dotted button on the right-hand side of each cost element field) to choose from the expected, upper, lower or user-defined estimates. Figure 4 shows these options for the total acquisition cost element. In this case, the algorithm that estimates total acquisition cost is based on the size of the wetland's treatment zone (table 1).

Screens in the MUSIC model like that shown in figure 4 highlight to users the difference between the expected, upper and lower estimates for each cost element. In version 3 of MUSIC, users must manually select an option on these screens. In this way, the model seeks to be transparent about the uncertainty associated with its cost estimates and regularly bring these to the attention of users.

MUSIC users can then generate and inspect four result screens. These are shown in figures 5, 6, 7 and 8. Figure 5 shows the primary results screen, including the estimated life cycle cost (ie. approximately $1.1 million with a base date of 2006), the equivalent annual payment, and the equivalent annual payment per kilogram of trapped pollutants per year.

Figure 6 shows the relative distribution of the wetland's cost elements. This can be useful for assets that are planned to be donated to a local government to maintain. For example, in figure 6, a local government authority, in theory, would need approximately $380,000 in 2006 (ie. the sum of all of the three discounted post-construction cost elements) to be able to fund all of the post-construction costs associated with the wetland for the following 50 years. A local government authority that is reluctant to accept such assets (as developers could have constructed alternative measures on privately-owned land) may require such an upfront payment as a condition of accepting responsibility.

Figure 7 shows how the cost elements occur over time, both as real and discounted real costs. Note that in this example, it was assumed that the wetland would continue indefinitely, so the decommissioning cost in the 50^{th} year was manually set to be equivalent to the typical annual maintenance cost. Note also that real costs are not adjusted for inflation. The real discount rate allows for inflation as well as the time value of money.

Figure 8 shows the sensitivity of the estimated life cycle cost to the choice of the real discount rate. In some circumstances, where several stormwater management scenarios are being assessed, the scenario with the lowest life cycle cost may vary, depending on the choice of discount rate.

4 DISCUSSION

The life cycle costing module in MUSIC has the benefit of being simple to use, consistent with the Australian Standard for life cycle costing, able to be used "manually" (ie. by using user-defined entries for all fields), supported by a detailed User Manual (MUSIC Development Team, 2005) that includes details of all costing algorithms and estimates, supported by a summary of costing information from the literature (Taylor, 2005b), and incorporates algorithms based on the best available data set of actual costing information from around Australia.

The module does, however, have two significant weakness. First, the data on which many of the costing algorithms are based are limited. This reflects the difficulty of obtaining high-quality data sets from stormwater management managers around Australia, particularly for infiltration systems, ponds, sedimentation basins, bioretention systems and

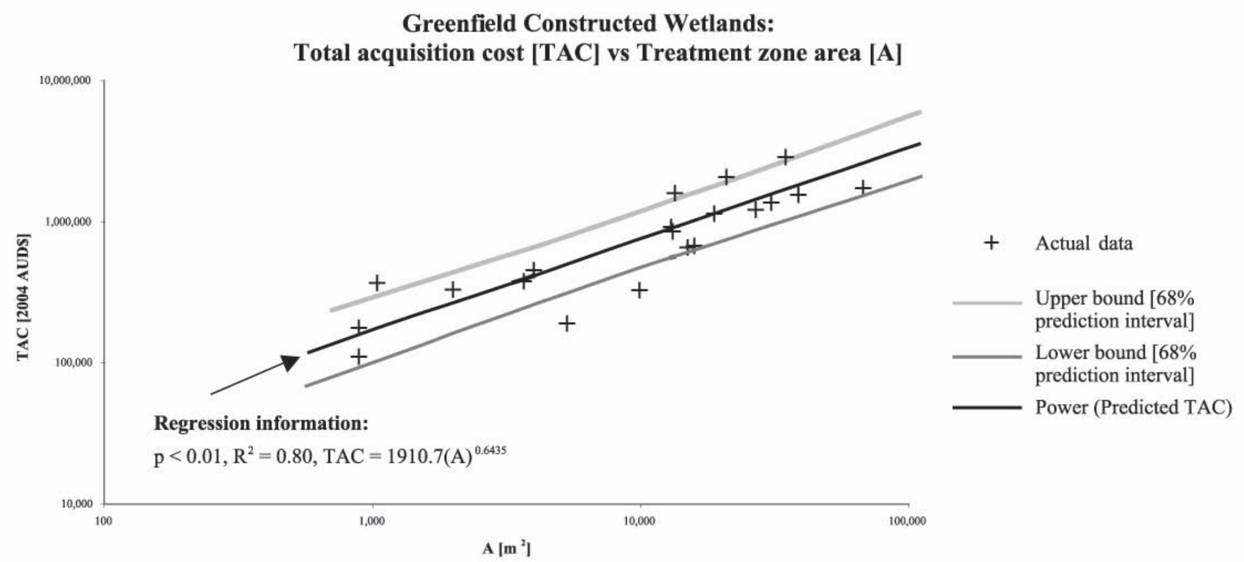

Figure 1: Example of regression analysis: total acquisition costs of greenfield wetlands.

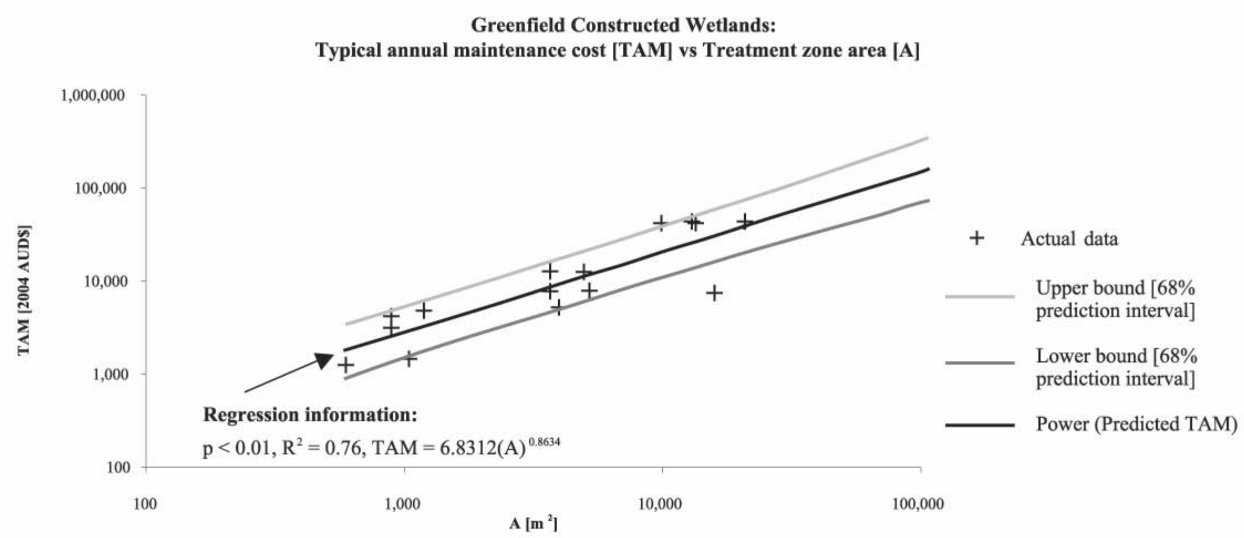

Figure 2: Example of regression analysis: typical annual maintenance costs of greenfield wetlands.

vegetated swales. This problem was identified early in the project and a Data Collection Form (Taylor, 2005a) has been developed to assist Australian stormwater managers collect relevant information in a form that can be used by researchers in the future to improve costing algorithms for use in tools, such as the life cycle costing module in MUSIC. This form is available from the Catchment Modelling Toolkit (www.toolkit.net.au). Opportunities are being taken by researchers who developed the MUSIC life cycle costing model to encourage Australian stormwater managers that have details of the size and cost of current best practice stormwater management measures to collect these details using this form, or in a database that is structured in accordance with this form. Such action is an investment in the future ability of the Australian stormwater management industry to estimate costs associated with proposed measures with greater certainty.

Second, for most costing relationships currently in MUSIC, there is substantial variation in the cost of similarly sized measures (as shown in figures 1 and 2). Accordingly, the regression equations used

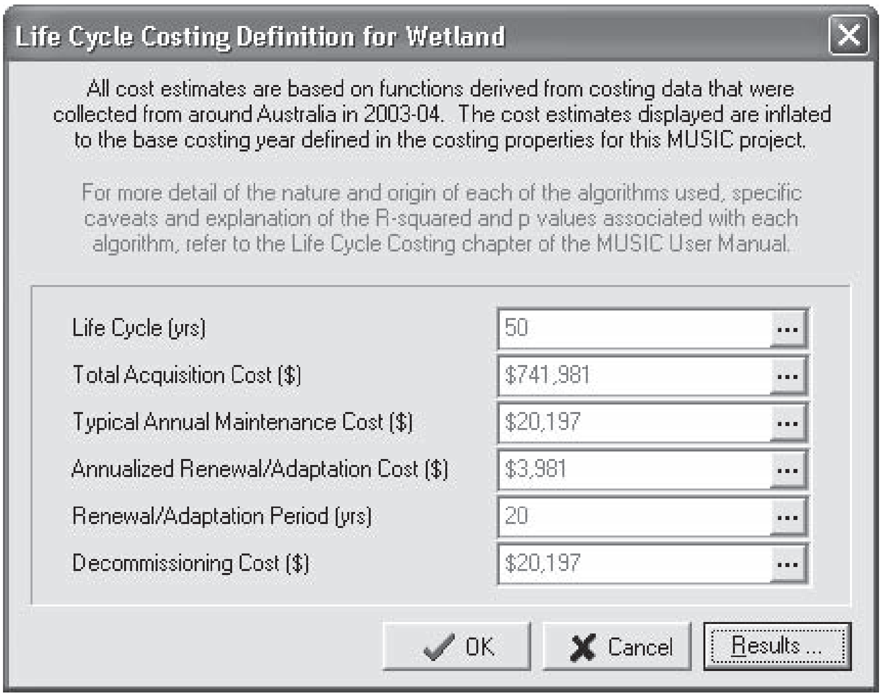

Figure 3: Worked example: the primary costing screen for a constructed wetland.

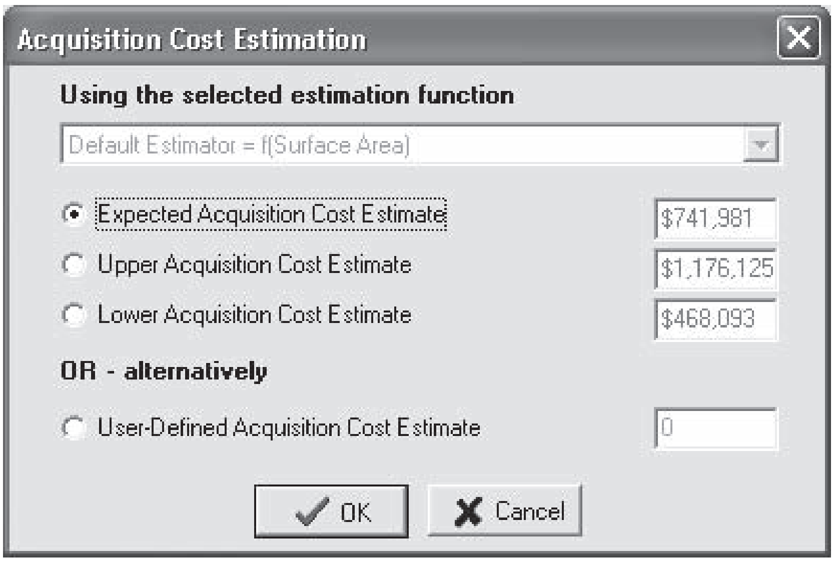

Figure 4: Worked example: the cost estimate options for the wetland's total acquisition cost (note that this screen highlights the significant difference between the expected, upper and lower estimates for this cost element).

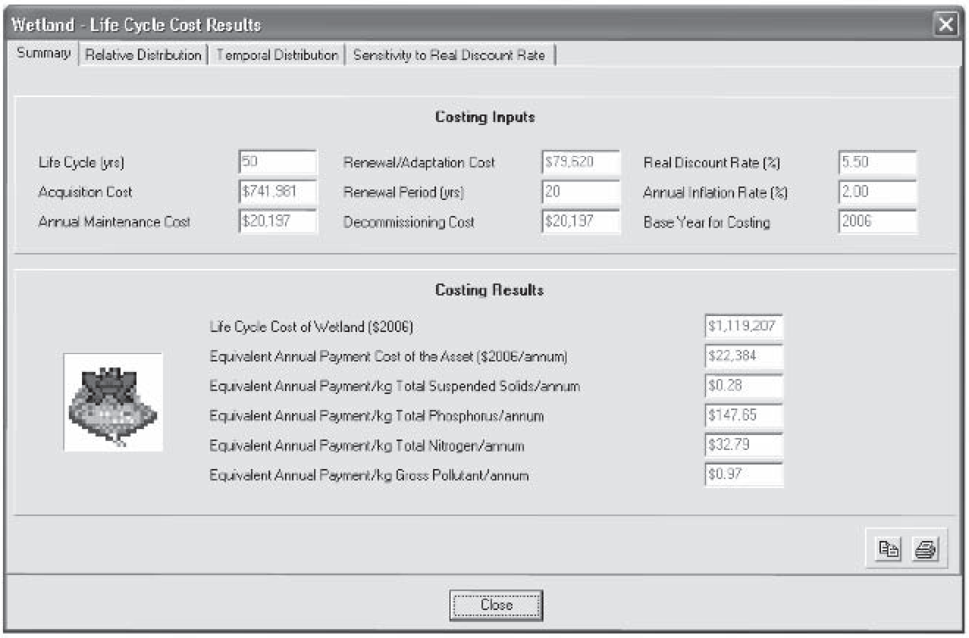

Figure 5: Worked example: the primary costing results screen (note that final results from the life cycle costing analysis should be rounded to two significant figures).

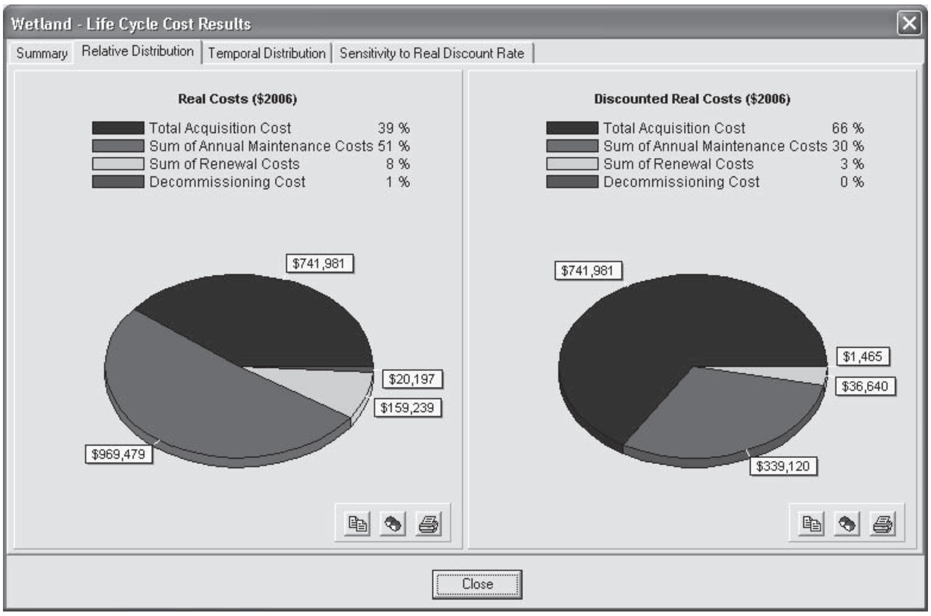

Figure 6: Worked example: the relative distribution of cost elements.

in the life cycle costing module are associated with reasonably wide 68% prediction interval. Reasons for this variation include geographic differences, economies of scale, site-specific factors (eg. existence of bedrock, acid sulphate soils, weed infestations, etc.), the type of maintenance method, the standard of maintenance undertaken, the design of the stormwater management measure, and local costs associated with waste disposal. Such variation underlines the need for cost estimation models to include upper and lower estimates (reflecting the bounds of clearly defined prediction intervals), in addition to expected estimates, to alert users to the levels of uncertainty associated with cost estimates. In addition, it highlights the need for cautious and responsible use of cost estimates developed by such models. It is suggested that the use of such estimates should be restricted to conceptual design and/or planning exercises, where only relative and/or approximate costs are needed. For further analysis, it is recommended that detailed cost estimates, based on design specifications, be obtained.

There will be a need for MUSIC developers to update the costing algorithms in the model as new treatment measures emerge and because costing data has a limited "shelf life". It is suggested that costing algorithms in MUSIC should be revised every five to 10 years, with five years being preferable.

5 CONCLUSIONS

Stormwater managers that are seeking to make more holistic and considered decisions about the pros and cons of alternative treatment measures and/or designs need to be able to predict with a known degree of certainty the likely cost of measures at the conceptual design stage. Historically, the ability of stormwater managers in Australia to quickly generate such estimates has been significantly hampered by a lack of easily accessible information that relates the size of measures to their cost elements and overall life cycle cost. In addition, few tools have been available that enable them to undertake an analysis of the cost of a wide range of stormwater management measures in conjunction with an analysis of their pollutant removal performance.

The new life cycle costing module in the MUSIC model represents a useful tool to help stormwater managers make more informed decisions about cost-effective stormwater treatment. In particular, the model seeks to be transparent about the levels of uncertainty associated with cost predictions, which can be high for some types of stormwater treatment measure. Instead of ignoring uncertainty (and thus hiding it from users), the module allows users to estimate the "expected", "upper" or "lower" cost for all cost elements that collectively make up the asset's life cycle cost. In addition, all "expected" costing

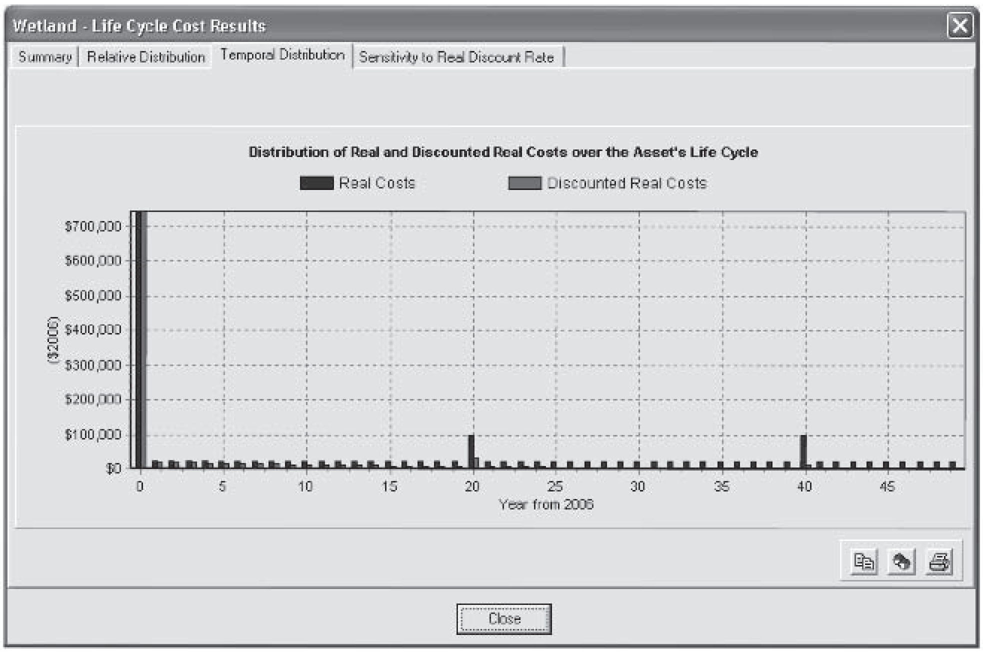

Figure 7: Worked example: the temporal distribution of cost elements.

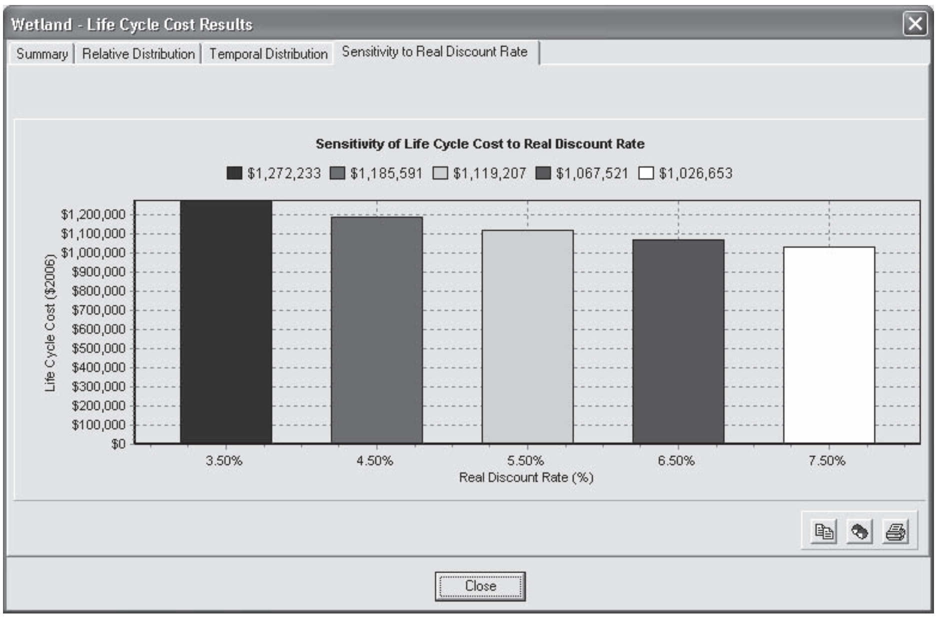

Figure 8: Worked example: the sensitivity of the life cycle cost to the real discount rate.

algorithms and estimates used in the module are publicly available for scrutiny via the User Manual (MUSIC Development Team, 2005) for version 3 of MUSIC (available at www.toolkit.net.au).

The costing data that were collected to generate algorithms in the life cycle costing module, while being the most comprehensive data set in Australia of its type, are still limited for some types of stormwater treatment measure. This project has, however, provided an impetus for improved collection of high-quality costing data in future by developing and circulating a simple costing guideline (Taylor, 2003) and Data Collection Form (Taylor, 2005a) (also available at www.toolkit.net.au) for stormwater managers to use. Gathering such data will help researchers to continually improve the ability of models, such as MUSIC, to estimate costs.

ACKNOWLEDGEMENTS

This paper presents findings of research work funded by the Victorian Environmental Protection Authority (via the Victorian Stormwater Action Program), Melbourne Water and Brisbane City Council.

REFERENCES

Choi, J. & Engel, B. A. (undated), *Cost analysis system for urban stormwater BMPs (CASUB) – a internet based cost estimation system*, http://danpatch.ecn.purdue.edu/~sprawl/LTHIA7/ubmp0/cgi-bin/ubmp0.cgi, accessed November 2003.

Colmar Brunton, 2005, *Water sensitive urban design: Research into the barriers to adoption, opportunities and stakeholder needs in southeast Queensland*, Report for the Moreton Bay Waterways and Catchments Partnership, Brisbane, Queensland.

Fletcher, T. D., Wong, T. H. F., Duncan, H. P., Coleman, J. R. & Jenkins, G. A. 2001, "Managing impacts of urbanisation on receiving waters: A decision-making framework", *Proceedings of the 3rd Australian Stream Management Conference*, Brisbane, Queensland, 27-29 August, pp. 217-223.

Fletcher, T., Duncan, H., Lloyd, S. & Poelsma, P. 2005, *Stormwater flow and quality and the effectiveness of non-proprietary stormwater treatment measures*, Technical report No. 04/8, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria.

Institution of Engineers Australia, 2003, *Draft Australian run-off quality guidelines – proceedings*, Albury, Victoria.

Lloyd, S. D., Wong, T. H. F. & Chesterfield, C. J. 2002, *Water sensitive urban design – a stormwater management perspective*, Technical Report No. 02/10, Cooperative Research Centre for Catchment Hydrology. Melbourne, Victoria.

Lloyd, S. D & Wong, T. H. F. 2003, "Cost-benefit analysis of structural stormwater management strategies", *Proceedings of the 3rd South Pacific Conference on Stormwater and Aquatic Resource Protection*, Auckland, New Zealand, 14-16 May, CD-ROM, 9p.

MUSIC Development Team, 2005, *MUSIC user guide – version 3*, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria, www.toolkit.net.au.

Peters, G. & Lundie S. 2002, "Life-cycle assessment of biosolids processing options", *Journal of Industrial Ecology*, Vol. 5, No. 2, pp. 103-121.

Rozis, N. & Rahman, A. 2002, "A simple method for life cycle cost assessment of water sensitive urban design", *Proceedings of the 9th International Conference on Urban Drainage*, Portland, Oregon, 8-13 September, available at www.pubs.asce.org.

Standards Australia, 1999, *AS/NZS 4536:1999 Life cycle costing – an application guide*, Homebush, New South Wales.

Standards Australia, 1998, *AS/NZS ISO 14040:1998 Environmental management – life cycle assessment – principles and framework*, Homebush, New South Wales.

Taylor, A. 2003, *An introduction to life-cycle costing involving structural stormwater quality management measures*, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria.

Taylor, A. 2005a, *Data collection form – to gather costing information on urban stormwater treatment measures that aim to improve waterway health*, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria, www.toolkit.net.au.

Taylor, A. 2005b, *Structural stormwater quality best management practice cost – size relationship information from the literature (version 3)*, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria, www.toolkit.net.au.

Taylor, A. C. & Weber, T. 2004, "Using effective policy frameworks to drive water sensitive design", *Proceedings of Cities as Catchments – WSUD 2004*, Adelaide, South Australia, 21-25 November, Engineers Australia, pp. 593-603.

Taylor, A. C. & Wong, T. H. F. 2002, *Non-structural stormwater quality best management practices – a survey investigating their use and value*, Technical report No. 02/12, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria.

US Environmental Protection Agency (US EPA), 1999, *Preliminary data summary of urban stormwater best management practices*, Report No.: EPA-821-R-99-012, Washington, DC.

Weigand, C., Schueler, T., Chittenden, W. & Jellick, D. 1986, "Cost of urban run-off quality controls", *Proceedings of the Urban Run-Off Quality – Engineering Foundation Conference*, Henniker, New Hampshire, 23-27 June, pp. 366-380.

Wong, T. H. F. 2001, "A changing paradigm in Australian urban stormwater management – keynote address", *Proceedings of the 2nd South Pacific Stormwater Conference*, Auckland, New Zealand, 27-29 June, available at www.toolkit.net.au.

ANDRÉ TAYLOR

André Taylor is a Research Fellow for Monash University both within the Institute for Sustainable Water Resources and the National Urban Water Governance Program. He also works as a consultant to urban water management agencies across Australia and New Zealand.

André has worked for 15 years in the fields of environmental management, and specifically urban water and waterway management. His has enjoyed the experience of working in five Australian states for consultancies, state governments, local governments and universities. Previous roles have included being team leader for water quality management within Brisbane City Council, the largest local government authority in the southern hemisphere.

While working at Monash University, André led the development of the life-cycle costing module in version 3 of the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) software; managed a project that investigated the use, value and evaluation of non-structural measures for stormwater quality improvement; and managed a project on triple-bottom-line assessment methodologies for proposed projects that aim to improve urban stormwater quality. All of these applied research projects delivered practical tools for the Australian stormwater management industry (eg. computer models, technical reports and guidelines).

TIM FLETCHER

Dr Tim Fletcher is director of the Institute for Sustainable Water Resources at Monash University and a senior lecturer within the Department of Civil Engineering. He was the leader of the Urban Stormwater Quality Program within the Cooperative Research Centre for Catchment Hydrology and one of the creators of MUSIC.

Tim's research focuses on the prediction of stormwater quality (and its uncertainty), treatment performance, aquatic ecosystem responses, and integration within the urban water cycle.

Tim has also held a number of senior roles in the water and waterway management industries, including water resources manager with the Corangamite Catchment Management Authority, senior environmental planner with Melbourne Water, and roles with Central Highlands Water.

He co-chairs the UNESCO International Hydrologic Program project on data for integrated urban water management, and is on the editorial board of the *Urban Water* journal.