THE DEVELOPMENT OF AN ECONOMIC COSTING METHODOLOGY FOR STORMWATER MANAGEMENT WITHIN A SPATIAL DECISION SUPPORT SYSTEM USED TO EVALUATE THE IMPACTS OF URBAN DEVELOPMENT

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ABSTRACT

The key innovation reported in this paper is the development of a catchment scale method for assessing the stormwater management costs associated with urban development. This research extends current international practice which typically operates at the scale of individual stormwater management devices. The method has been developed for incorporation in a catchment-scale spatial decision-support system (SDSS) which being developed by the National Institute of Water and Atmospheric Research (NIWA) and the Cawthron Institute to aid in the evaluation of impacts of urban development on receiving water bodies. The SDSS aims to express indicators of impacts on receiving water body environment values, and will use this system to integrate the measurement of environmental, social, economic and cultural wellbeings. Two key factors which influence economic wellbeing are stormwater management costs and economic benefits to society that arise from stormwater management measures. The economic costing methodology has been developed using a life cycle cost assessment approach. Methods for estimating relevant costs associated with different urban development scenarios within the SDSS are described.

KEYWORDS

Economic wellbeing, life cycle costing, spatial decision-support system

PRESENTER PROFILE

Sue Ira is the Director of Koru Environmental Consultants Limited. She is an environmental scientist with a number of years experience working with the construction and development industry. Prior to starting Koru Environmental, she worked at the Auckland Regional Council and managed the stormwater consents and compliance team.

Sue has extensive experience in catchment management plan development and review, and was the primary developer of the COST_{NZ} Model.

1 INTRODUCTION

There is substantial evidence that expansion of the built environment, as well as modification and use of streams, rivers and estuaries for the disposal of stormwater runoff has contributed to poor water quality and ecological degradation. Examples of these effects are evident in changes to the characteristics of water bodies associated with New Zealand's two largest cities, Auckland and Christchurch (Moores et al., 2011). Given that population growth is likely to result in the continued expansion and intensification of our cities, it can be expected that urban waterbodies will come under increasing pressure, reducing their ability to provide for economic, social and cultural needs of urban communities. Local government has identified that improved outcomes for urban waterbodies are a critical issue in the planning of sustainable cities. Further, a lack of methods and information to demonstrate and quantify the linkages between alternative forms of development and the effects on receiving waterbodies exists. This paper reports progress on one aspect of a Ministry for Science and Innovation funded research programme entitled Urban Planning that Sustains Waterbodies (UPSW), which aims to address these gaps by developing a catchment-scale spatial decision-support system (SDSS). The computer-based SDSS aims to aid the evaluation of the effects of urban development on freshwater and estuarine urban waterbodies in terms of four wellbeings: environmental, cultural, social and economic. This paper describes the development of the economic costing methodology, used to contribute to the overall economic wellbeing indicator. The approach we take is to present the structure of the economic wellbeing indicator, and describe the techniques used to generate the data required for the development of the economic costing.

2 METHODS

The system which this project addresses is limited to the receiving bodies – freshwater and estuarine – of the constituents of urban fresh water run-off. This partial, bounded definition of the system at hand allows a focus on tracking the effects of stressors through freshwater and estuarine ecosystems, and understanding the costs and benefits that are finally expressed as changes in the economic wellbeing associated with the receiving water bodies. Combinations of policy and engineering interventions which target mitigation of the effects of stormwater act through changes to stormwater constituents to modify receiving environments, changing underlying biophysical attributes and potentially ecosystem integrity.

2.1 ECONOMIC WELLBEING

The economic wellbeing (EW) associated with a receiving water body (i) and generated through changes to the current development state by a proposed urban development option (UDO) (j) is expressed as the ratio of benefits (B) to costs (C).

$$EW_{i,j} = \frac{B_{i,j}}{C_{i,j}} \qquad \text{……..} \ (1)$$

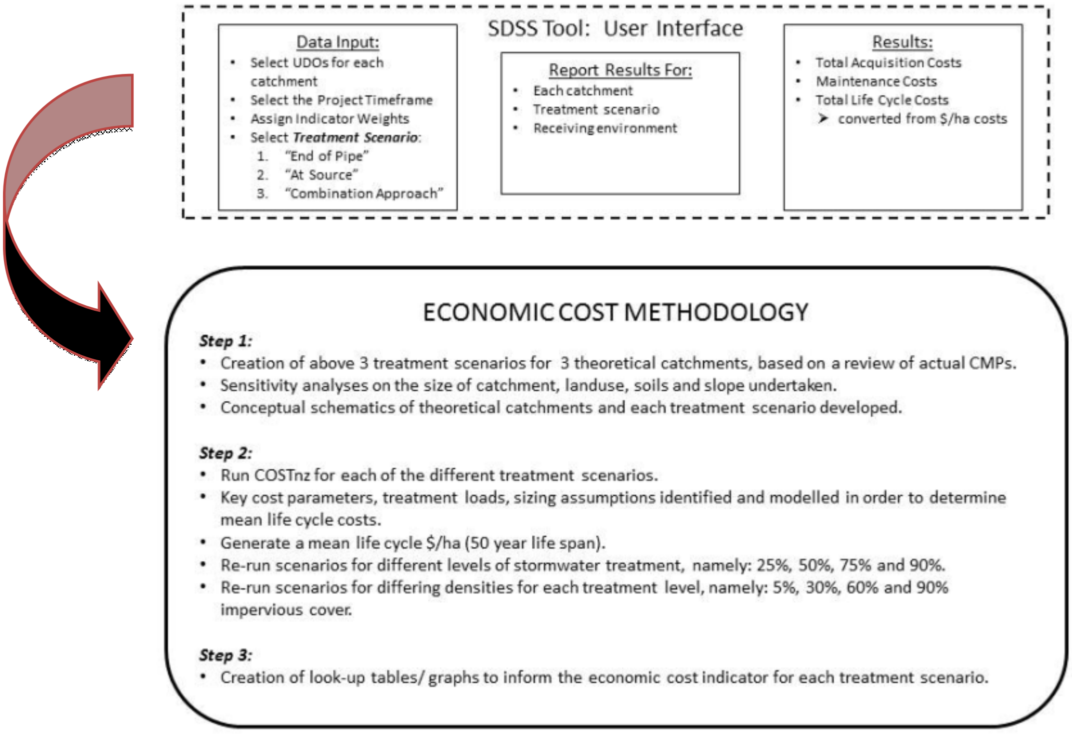
Economic costs and benefits associated with receiving water body (i) and generated through changes to the current development state by a proposed UDO (j) are captured as net benefits arising through ecosystem services derived from water body (i), and are assessed through non market valuation of changes to the characteristics of water body (i) under UDO (j). This paper focuses on the development of a methodology to evaluate economic costs of stormwater management on a catchment or planning level scale. Economic costs which arise from controlling or mitigating effects of urban development on the receiving environment, and that are associated with any UDOs, are able to be simulated within the SDSS tool. These costs are incurred as the result of the construction and maintenance of stormwater devices and riparian management practices. A life cycle costing approach is utilised to quantify the costs of stormwater mitigation.

Development of the methodology and results associated with the assessment of economic benefits is described in Batstone and Sinner (2009) and Ira *et al*. (2012).

2.2 ECONOMIC COSTS

A life cycle costing (LCC) approach has been utilised to quantify the costs of stormwater mitigation. The Australian/New Zealand Standard 4536:1999 defines LCC as the process of assessing the cost of a product over its life cycle or portion thereof. The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage, and maintenance through to disposal. Consideration of revenue is excluded from LCC. A cradle-to-grave time frame is warranted because future costs associated with the use and ownership of an asset are often greater than the initial acquisition cost and may vary significantly between alternative solutions to a given operational need (Australian National Audit Office, 2001).

In New Zealand, a unit-based life cycle costing model, known as COSTnz (Ira *et al*., 2008; Ira *et al*., 2009), has been developed. The proposed process for using COSTnz to create a catchment-scale costing tool ("the costing tool") is illustrated in Figure 1. COSTnz is a site and device specific life cycle costing model. It requires a good understanding of the local site conditions, contaminant inputs and stormwater device design. The model is therefore aimed at a vastly different scale to that envisaged through the UPSW research programme.



Data Input:
- Select UDOs for each catchment
- Select the Project Timeframe
- Assign Indicator Weights
- Select *Treatment Scenario*:
  1. "End of Pipe"
  2. "At Source"
  3. "Combination Approach"

Report Results For:
- Each catchment
- Treatment scenario
- Receiving environment

Results:
- Total Acquisition Costs
- Maintenance Costs
- Total Life Cycle Costs
  - converted from $/ha costs

Step 1:
- Creation of above 3 treatment scenarios for 3 theoretical catchments, based on a review of actual CMPs.
- Sensitivity analyses on the size of catchment, landuse, soils and slope undertaken.
- Conceptual schematics of theoretical catchments and each treatment scenario developed.

Step 2:
- Run COSTnz for each of the different treatment scenarios.
- Key cost parameters, treatment loads, sizing assumptions identified and modelled in order to determine mean life cycle costs.
- Generate a mean life cycle $/ha (50 year life span).
- Re-run scenarios for different levels of stormwater treatment, namely: 25%, 50%, 75% and 90%.
- Re-run scenarios for differing densities for each treatment level, namely: 5%, 30%, 60% and 90% impervious cover.

Step 3:
- Creation of look-up tables/ graphs to inform the economic cost indicator for each treatment scenario.

Figure 1: Proposed process for the creation of a life cycle NZ$/ha cost using COSTnz.

Following a review of stormwater catchment management plans (CMPs) and relevant literature, three stormwater treatment scenarios were created for development of the costing tool. These are shown in Table 1. Various treatment options for each scenario have been created and modelled using COSTnz.

Table 1: Summary of treatment scenarios and modelling options to determine a NZ$/ha life cycle cost for a typical catchment.

	Treatment Scenario	Devices Included	Options
A	End of Pipe	Ponds and Wetlands	*A1:* catchment treatment via 4 wetlands *A2:* catchment treatment via 4 ponds *A3:* catchment treatment via 4 ponds and 4 wetlands
B	At Source	Rain Gardens; Swales, Infiltration Trenches, Sand Filters, Stormfilters	3 model runs for each device using small (1ha), medium (2ha) and large (3ha) sizing in varying combinations to make up a 136ha catchment.
C	Combination	All of the above	Varying combinations of Scenarios A and B for a theoretical 136ha catchment.

2.2.1 END OF PIPE SCENARIOS

Sizing of the wetlands and ponds was based on the sizing provided within three of the reviewed CMPs. The wetland surface area was assumed to equal the water quality volume (WQV) as they were designed with an average depth of 1m. Table 2 summarises the WQV per hectare of impervious area for each catchment.

Table 2: Average WQV per hectare of impervious area for the 3 catchments in Auckland, NZ.

End of Pipe COSTnz Modelling Scenario	
Catchment Name	**Average WQV**
Hobsonville Peninsula	259 m^3
Airport Oaks	323 m^3
Orewa West	304 m^3

The average WQVs were then extrapolated for generalisation over a range of impervious areas using the formula below (equation 2).

$$WQV = CA * IMP * \overline{WQV} \qquad \ldots\ldots \quad (2)$$

Where CA = catchment area for the wetland, IMP = percentage imperviousness in increments of (5%, 30%, 60%, 90%), and $\overline{WQV}$ = average water quality volume determined for each catchment.

The wetlands within the catchments listed in Table 2 were designed to remove either 75% or 30% total suspended solids (TSS) over a long term average basis. Using guidance given in the former Auckland Regional Council's (ARC) stormwater design manual (TP10: ARC, 2003), the wetlands were sized for differing levels of stormwater treatment for each percentage of impervious area (Table 3).

Table 3: Sizing of wetlands for differing treatment efficiencies (adapted from ARC, 2003)

Percentage TSS Removal	Size of the WQV

90% TSS removal	175% of the WQV
75% TSS removal	100% of the WQV
50% TSS removal	25% of the WQV
25% TSS removal	5% of the WQV

Sizing of the stormwater ponds, was based on a similar methodology to that described above, however, an average depth of 2 m was used. The former ARC's contaminant load model (ARC, 2006) was used in order to calculate the total suspended sediment (TSS) load to be treated by each device.

Two hundred and eighty eight COSTnz models were built and run for the "End of Pipe Scenario". The base year for the costing data is 2011 and a discount rate of 3.5% was used. A life span of 50 years was selected for the devices in order to be consistent with the options provided in the UPSW SDSS. The total acquisition costs (TAC) for both the pond and wetland models were calculated using the statistical relationship provided in COSTnz (as outlined in the COSTnz user manual: http://www.costnz.co.nz/index.aspx). Maintenance costs, however, were worked out on a unit cost basis.

2.2.2 AT SOURCE SCENARIOS

Each of the "At Source" devices, namely rain gardens, swales, infiltration trenches and sand filters, were sized individually in general accordance with the former ARC's TP10 parameters (ARC, 2003). The device sizing spreadsheets within the COSTnz model were utilised, and local rainfall data for a catchment within the Upper Waitemata Harbour was obtained from the NIWA HIRDS database (accessed from http://hirds.niwa.co.nz/). One third of the 90th percentile storm was used as the water quality design storm event (27 mm rainfall depth). The theoretical scenarios were run for a 'typical' catchment area of 136ha.

As shown in Table 1 (line B), each "At Source" device was designed for a 1ha, 2ha and 3ha catchment and for incremental increases in impervious area (5%, 30%, 60% and 90%). These sizing scenarios fit well within the catchment area limits of each device, as documented in the former ARC's TP10 (ARC, 2003). As with the design of the ponds and wetlands, the devices were sized to treat 75% TSS removal on a long term average basis. Sizing of devices for the alternative treatment levels (i.e. 25%, 50% and 90% TSS removal) were extrapolated using Table 3.1 in the former ARC's TP10 (as shown in Table 3).

A total of 192 COSTnz models were built and run for the "At Source" scenarios (i.e. 48 per device).

2.2.3 COMBINATION SCENARIOS

The "Combination" treatment scenarios facilitated stormwater mitigation through a mix of "At Source" and "End of Pipe" solutions. The theoretical scenarios were also run for a 'typical' catchment area of 136ha and incremental increases in impervious area. The scenarios run were split according to differing proportions of "At Source" control within the catchment area. This ranged from ⅓ "At Source" and ⅔ "End of Pipe" to ⅔ "At Source" and ⅓ "End of Pipe".

2.2.4 COSTING ASSUMPTIONS

A summary of the costing and discounting assumptions used within the COSTnz model are provided below:

- COSTnz provides a low, mean and high estimate of costs. For all scenarios the low value was used. Council contracts are generally wide-reaching and allow for lower costs to be achieved.
- The base year for the COSTnz model is 2007. As a result, all costs were inflated to 2011 values using a 2.8% inflation rate.
- A life cycle analysis period and life span of 50 years was used for all scenarios.
- A discount rate of 3.5% was used.
- Total Acquisition Costs (TAC) included design, planning, consenting and construction costs of a device. A statistical relationship between the surface of a device and the TAC was used for ponds, wetlands and sand filters. This relationship is documented in Vesely *et al*. (2006). The remaining devices were costed using a unit cost approach.
- Routine and corrective maintenance costs were costed using a unit cost approach.
- A land cost factor was developed to account for land purchase costs, as well as to account for the difference in land prices between greenfield and redevelopment catchments.

3 RESULTS

Costing results for all the treatment scenarios are presented in Figures 2, 3 and 4, and are shown as NZ$ per hectare per year. Both the undiscounted and net present value (NPV) costs were determined, however, only the undiscounted costs are presented in this paper.

With respect to the "End of Pipe" treatment, Figure 2 clearly illustrates that, over the life cycle, wetlands are more expensive than ponds. On closer inspection of the models themselves, the data shows that whilst wetlands may be more expensive to construct (i.e. higher TACs), ponds are more expensive to maintain. The reasons for this are primarily due to the difference in units for the different maintenance activities (i.e. maintenance costs per square metre vs per pond/ wetland) and the high cost associated with weed control in open water ponds.

The differences between costs associated with wetlands and ponds are least marked for 25% TSS removal (both discounted and NPV costs). In all likelihood this is due to the very small size of the devices. These small wetlands fall well below the original range of the wetlands used to create the COSTnz wetland TAC statistical formula. In general, it is likely that the TAC of very small ponds and wetlands is not that dissimilar, but as the wetlands get bigger (along with the level of earthworks and landscaping), so the cost margin difference increases.

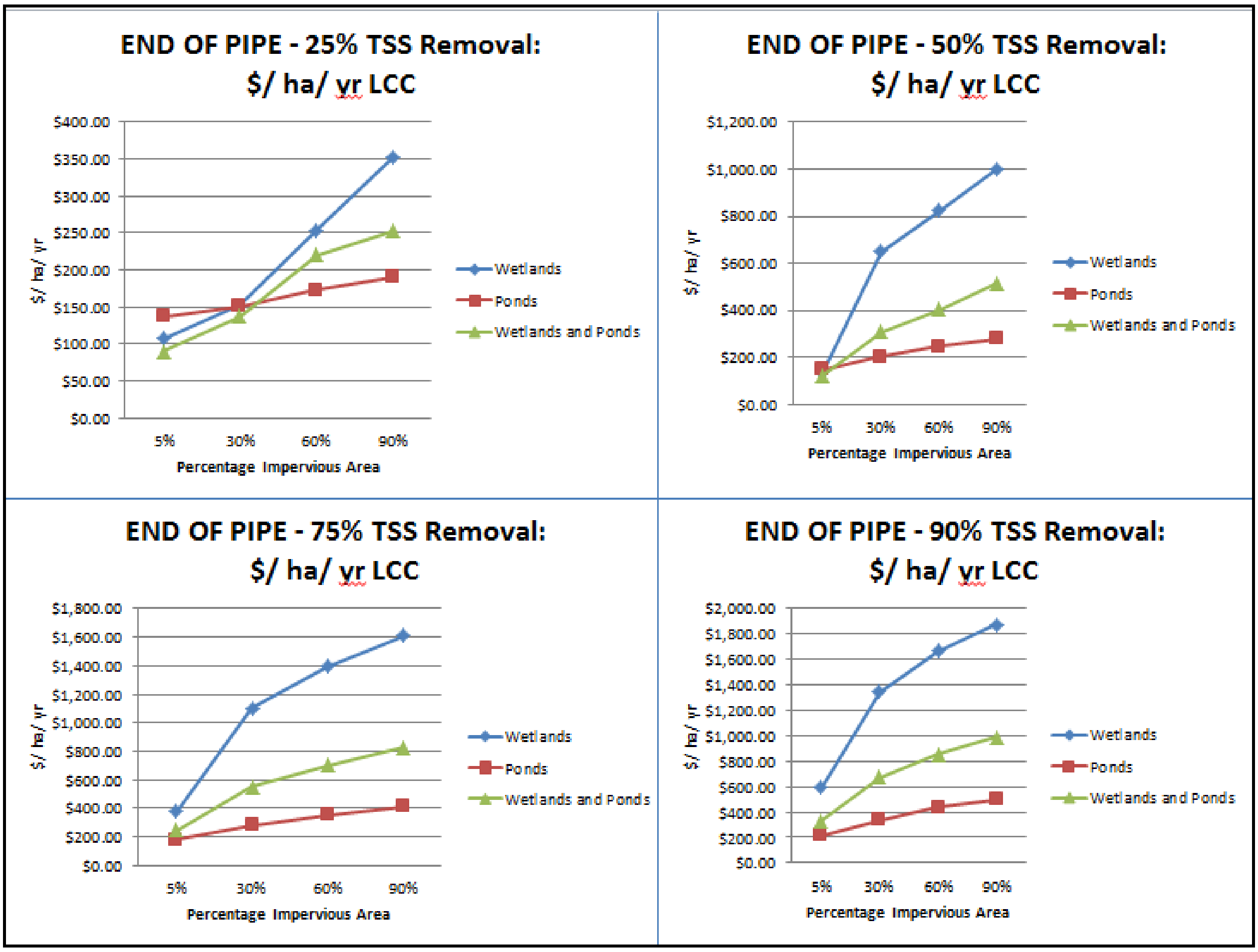


Figure 2: $/ha/yr life cycle costs for "End of Pipe" treatment

Figure 3: $/ha/yr life cycle costs for "At Source" treatment

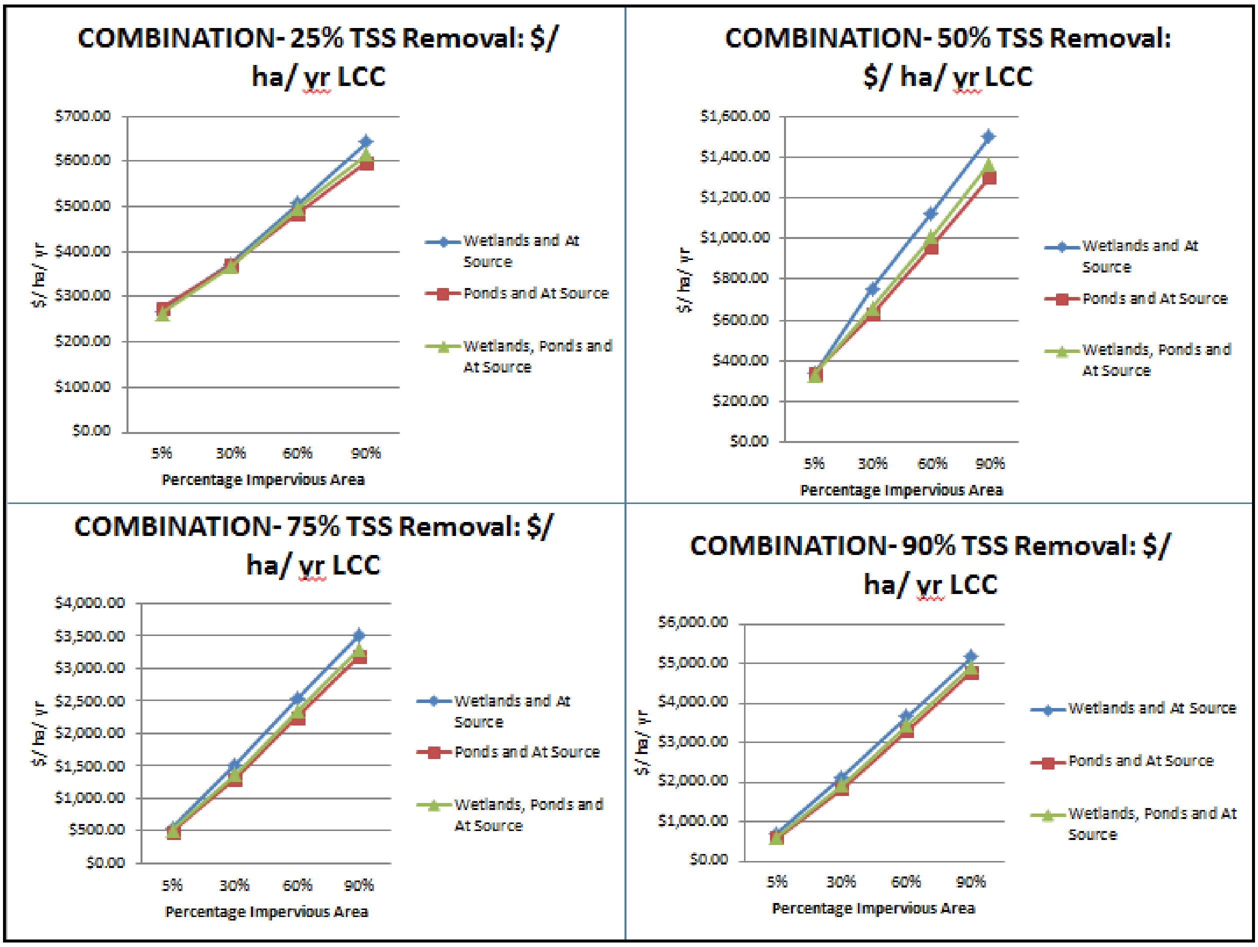


Figure 4: $/ha/yr life cycle costs for "Combination" treatment

When compared with the $/ha/yr costs of the "End of Pipe" scenarios, "At Source" treatment is clearly more expensive. For example, at 60% impervious area and 75% treatment, the $/ha/yr cost for wetlands is approximately $1,400 as opposed to about $5,700 for the at source treatment devices.

Costing results for the "Combination" scenarios are shown in Figure 4. As described in Section 2.2.3, the results were generated using the mean "At Source" results combined, in differing proportions, with the "End of Pipe" results. These different scenarios were then summed and the mean total LCC used to generate $/ha/yr costs shown in the Figure 4.

Figure 4 highlights that there is not a significant difference in cost between the three different scenarios (i.e. "At Source and Wetlands", "At Source and Ponds", and "At Source, Wetlands and Ponds") across the range of treatment levels. More than likely the "At Source" costs temper the difference between the pond and wetland costs.

4 CONCLUSIONS

4.1 SUMMARY AND CONCLUSIONS

Urban development within New Zealand is contributing to the ecological degradation of coastal and freshwater receiving waters and, as a result, to the economic, social and cultural values associated with these water bodies. One of the principal causes of this degradation is the accumulation of stormwater contaminants in receiving environments. There is currently an absence of tools which allow stormwater effects and associated mitigation measures to be assessed in terms of responses in the receiving environment across the four wellbeings. As a result, NIWA and the Cawthron Institute are collaborating in a programme of research designed to create a catchment-scale SDSS to allow alternative urban development and stormwater management scenarios to be assessed in terms of their influence on environmental, social, economic and cultural wellbeing associated with receiving waters.

In order to derive an economic wellbeing indicator, the costs and benefits associated with any given urban development scenario need to be compared. This paper presented the methodology developed to determine economic costs of stormwater management on a catchment or planning level scale. In addition, it has provided the cost results for inclusion in the SDSS tool. A life cycle costing approach to stormwater management has been undertaken.

Whilst internationally life cycle cost models have been previously used to assess costs associated with stormwater devices, the assessment is generally undertaken at a site- or device-specific scale. In New Zealand, the COSTnz model is the only recognised stormwater treatment life cycle costing model and it also operates at the single-site scale. This research is therefore the first of its kind in New Zealand, and has utilised and adapted COSTnz to generate a catchment-wide approach to life cycle costing of stormwater management.

The paper has presented a number of theoretical stormwater management scenarios which were developed. The assumptions for each scenario have been outlined and the costing results presented. The end result has been the development of a series of average $/ha/yr LCC graphs which can be applied to different urban development scenarios in the SDSS. Once the life cycle cost has been determined using this catchment or planning scale approach, it can be compared with the estimated economic benefit in order to determine the SDSS economic wellbeing indicator.

4.2 FURTHER WORK

This research has taken the firsts steps towards building a catchment-based life cycle costing approach to assess the costs of stormwater management. There are additional parameters which could be investigated in order to refine these results. Analysis of life cycle costing of various stream mitigation options is currently underway. This research will assist in quantifying the cost of stream protection and remediation from stormwater effects.

The life cycle costs presented in this paper only relate to the stormwater treatment devices themselves. The cost implications of other low impact design solutions (such as source control – roofing materials, reducing impervious areas, etc) have not been investigated. Aligned to this is the discussion of private versus public costs and benefits. These issues could be explored further and is a potential area of expansion of the SDSS.

An additional area of research could be the investigation into the temporal distribution of stormwater management costs. This would involve further investigation into the costs of specific stormwater management devices in order to determine a $/ha life cycle cost, as well as a breakdown of $/ha maintenance costs over time. In addition, the proportion of TAC to maintenance cost could be further refined. The results of this type of research could be used within the SDSS tool or, alternatively, it could be linked to the Catchment Contaminant Annual Load Model (C-CALM) or another type of contaminant load model and used for catchment planning purposes.

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