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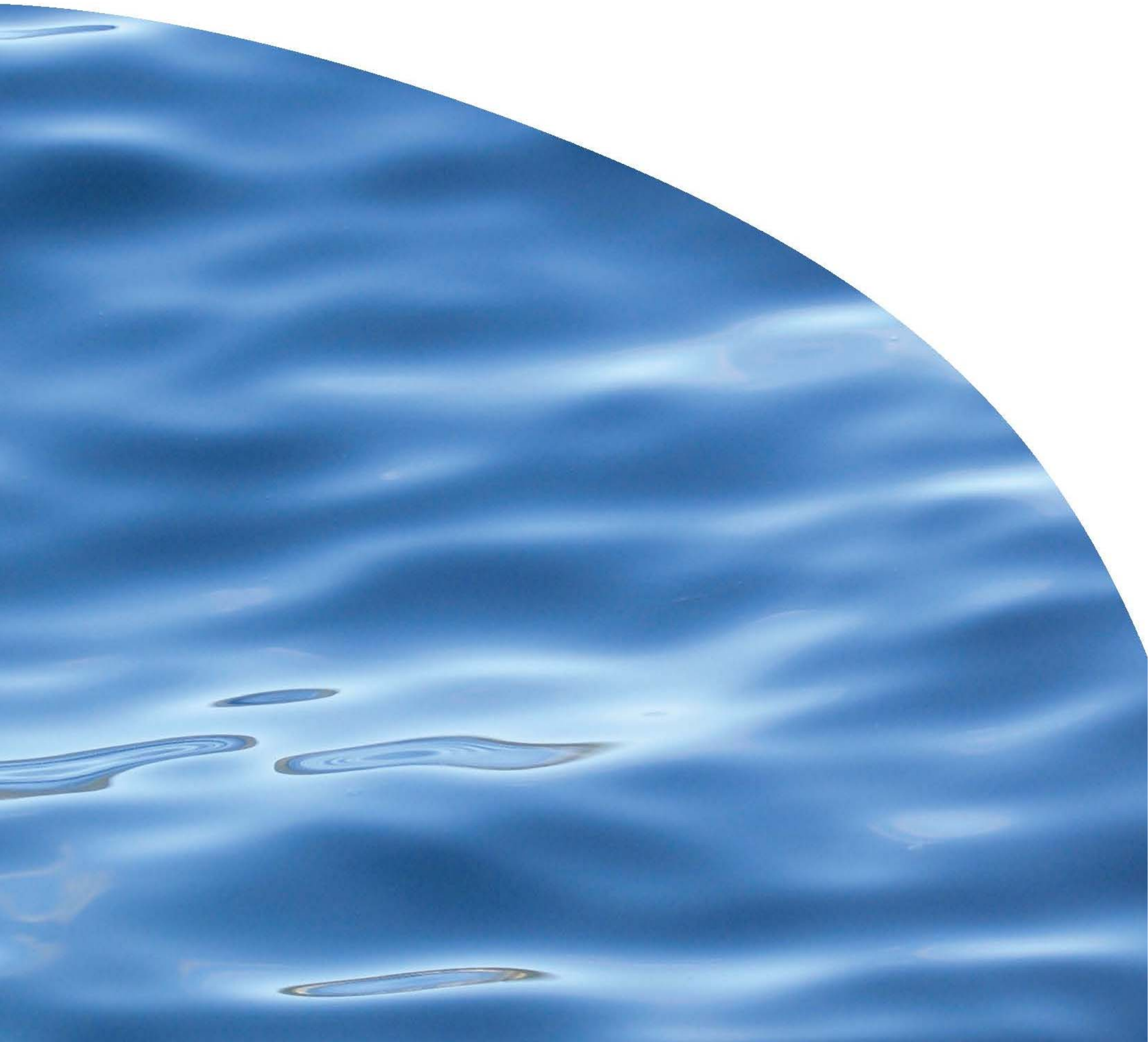
THE DEVELOPMENT OF CATCHMENT SCALE LIFE CYCLE COSTING METHODS FOR STORMWATER MANAGEMENT



THE DEVELOPMENT OF CATCHMENT SCALE LIFE CYCLE COSTING METHODS FOR STORMWATER MANAGEMENT

SUE IRA

Report commissioned by Cawthron Institute

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EXECUTIVE SUMMARY

This report describes the development of a method to assess the life cycle costs associated with the development and operation of systems of stormwater mitigation devices at the catchment scale. The key innovation that arises from this research is the extension of existing device-specific costing methods to the assessment of the life cycle costs of systems of mitigation and remediation devices at the catchment scale.

Research has shown that urban development within New Zealand is contributing to the ecological degradation of coastal and freshwater receiving waters (Moores *et al.* 2011). The source of this impact is not only the increased volume and rate of stormwater discharges, created as a result of increasing impervious surfaces, but also contamination of the receiving environment due to declining water quality. Despite this increasing level of degradation, there is no consistent way of linking stormwater effects and associated mitigation measures to responses in the receiving environment. As a result, local government has identified a need to develop a catchment-scale spatial decision support system (SDSS) to assist in the evaluation of the impacts of urban development.

The Cawthron Institute and NIWA are collaborating in a Ministry for Science and Innovation funded programme of research to create an SDSS to assess the effects of alternate urban development scenarios on the freshwater and estuarine water bodies that receive urban stormwater. The assessment of those effects is expressed in terms of environmental, social, economic and cultural wellbeing. This approach will enable planners to consider these impacts holistically. In the SDSS the economic wellbeing indicator is assessed by comparing costs and benefits associated with any given urban development scenario. This report focuses on the estimation of the costs associated with any urban development scenario that may arise from controlling or mitigating the effects of urban development on the values of receiving freshwater and estuary environments. Given that these effects can be related back to stormwater discharges, the costs incurred are generally as a result of the construction, operation and maintenance of stormwater and riparian management facilities and practices. Accordingly, a life cycle costing approach is taken to ensure all relevant costs are included.

The key limitation to incorporation of catchment scale stormwater mitigation life cycle costing in the SDSS is that current international practice is to assess life cycle costs on a device specific basis, as opposed to the catchment level assessment required for the SDSS. This has been overcome by developing a method to assess those costs at the catchment scale. A large number of hypothetical catchment scale stormwater management scenarios were generated based on recent New Zealand policy and engineering practice reflected in regional government reports. The types of approach include at source, end of pipe and combinations of each that include both ponds and wetlands. The resulting life cycle costs expressed as dollars per hectare per year ($/ha/yr), are derived as a function of the proportion of impervious area in the catchment and the level of treatment required expressed in terms of the proportion of total suspended solids removed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

COSTING TERMINOLOGY

Term	Definition
Decommissioning costs	Costs associated with the complete removal of the treatment device/measure at the end of its life span either due to redundancy or to the need for total replacement (*e.g.* a wetland may be decommissioned in the future due to inadequate maintenance funds, an in-ground gross pollutant trap may need to be totally replaced every 50 years).
Land costs	The cost associated with purchasing land required for stormwater treatment. It is a one-off cost which is spent within the first year of the life cycle analysis period.
Life cycle analysis period	The period over which a user will run the life cycle model.
Life cycle cost	The sum of the acquisition and ownership costs of an asset over its life cycle from design stage, manufacturing, use, and maintenance through to disposal.
Life span	The functional life of the treatment device/measure in years.
Maintenance costs	Costs associated with the maintenance of a stormwater treatment device. These costs have been divided into two types: • **Corrective maintenance costs:** Costs associated with significant alterations to the treatment device/measure. These costs will occur infrequently (*e.g.* the addition of safety fencing, new landscaping features, new access road, replacing a rain garden's filtration media, etc.). • **Routine maintenance costs:** Annual costs associated with routine maintenance events (*e.g.* mowing the grassed area around a pond), including costs associated with relevant administration, inspections, staff training and waste disposal.
Net present value (NPV)	The value of a stream of costs when discounted back to the present time (*i.e.* the sum of money that needs to be spent today to meet all future costs as they arise throughout the life cycle of a facility).
Total acquisition cost (TAC)	Includes total cost associated with defining the need for the treatment device/measure (*e.g.* running site-selection processes, feasibility studies, grant application costs), total conceptual, preliminary and detailed design costs, total costs associated with environmental assessment, acquisition of consents and public consultation (following, or as part of, the design process), and total construction costs (including internal and external project management costs and contract management costs).

1. INTRODUCTION

1.1. Background

Research has shown that urban development within New Zealand is contributing to the ecological degradation of coastal and freshwater receiving waters (Moores *et al.* 2011[1]). The source of this impact is not only the increased volume and rate of stormwater discharges, created as a result of increasing impervious surfaces, but also contamination of the receiving environment due to declining water quality. Despite this increasing level of degradation, there is no consistent way of linking stormwater effects and associated mitigation measures to responses in the receiving environment. As a result, local government has identified a need to develop a catchment-scale spatial decision support system (SDSS) to assist in the evaluation of the impacts of urban development. NIWA is leading a programme of research designed to create such a SDSS, and is developing a sustainability indexing system to integrate the measurement of environmental, social, economic and cultural wellbeing. This approach would enable planners to consider these impacts holistically.

The Cawthron Institute is leading the development of methods to derive indicators of economic wellbeing. This is assessed by comparing costs and benefits associated with any given urban development scenario. The focus of the project brief is to develop a method for the estimation of relevant costs associated with any urban development scenario that may arise from controlling or mitigating the effects of urban development on the values of receiving freshwater and saline environment. Given that these effects can be related back to stormwater discharges, the costs incurred are generally as a result of the construction and maintenance of stormwater and riparian management practices.

This document reports on the methodology used to generate a catchment-wide approach to life cycle costs (LCC) of stormwater management, as well as the resulting costs for a number of different treatment scenarios.

1.2. Problem definition and approach

The cost of stormwater quality and quantity mitigation, and riparian management need to be determined for each urban development option (UDO) within the SDSS, and at a planning unit (PLU) scale (or catchment-wide scale). The most appropriate way of assessing the cost of a stormwater management approach is to estimate the LCC, *i.e.* the sum of the total acquisition, long term operational and decommissioning costs over the relevant planning horizon.

[1] Moores, J., Semadeni-Davies, A., Batstone, C., Green, M., Gadd, J. and Harper, S. (2011). *Conceptualising a spatial decision support system to evaluate the impacts of urban development on waterbodies in New Zealand*. 12th International Conference on Urban Drainage. Porto Alegre/ Brazil.

1.2.1. *Life cycle costing*

A life cycle costing (LCC) approach has been previously used to assess costs associated with stormwater devices in Australia, the United States of America (USA) and the United Kingdom (UK) (Vesely *et al.* 2006[2]). The Australian/New Zealand Standard 4536:1999[3] defines LCC as the process of assessing the cost of a product over its life cycle or portion thereof. The LCC is the sum of the acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage, and maintenance through to disposal. The consideration of revenues 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[4]).

LCC has a number of benefits and supports a number of applications and analyses (Lampe *et al.* 2005[5]):

- it allows for an improved understanding of long-term investment requirements
- it helps decision-makers make more cost-effective choices at the project scoping phase
- it provides for an explicit assessment of long-term risk
- it reduces uncertainties and helps local authorities determine appropriate development contributions
- it assists local authorities in their budgeting, reporting and auditing processes.

Decision-making on the use of stormwater devices needs quality data on the technical and financial performance of these devices. The financial performance will depend on the sum and distribution over the life cycle of the device of costs associated with design, construction, use, maintenance, and disposal. LCC can be used for structuring and analysing this financial information. It is therefore recommended that a LCC approach be utilised to quantify the cost implications of stormwater mitigation.

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[2] Vesely, E-T., Arnold, G., Ira, S. and Krausse, M. (2006). *Costing of Stormwater Devices in the Auckland Region.* NZWWA Stormwater Conference.
[3] Australian/New Zealand Standard. (1999). Life Cycle Costing: An Application Guide, AS/NZ 4536:1999. Standards Australia, Homebush, NSW, Australia and Standards New Zealand, Wellington, NZ.
[4] Australian National Audit Office. (2001). Life Cycle Costing: Better Practice Guide. Canberra, Commonwealth of Australia.
[5] Lampe, L., Barrett, M., Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Hollon, M. (2005). Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems. WERF Report Number 01-CTS-21T.

1.2.2. *The stormwater management cost calculator*

The only available LCC model for stormwater management in New Zealand is COSTnz, developed by Landcare Research. COSTnz is a site-specific model and requires a good understanding of the local site conditions, contaminant inputs and stormwater device design. In general, the LCC are assessed using a unit-based approach. Consequently, the model is aimed at a vastly different scale to that utilised in the SDSS. COSTnz has therefore been utilised to undertake a series of model runs to develop PLU-scale cost relationships which can be incorporated into the SDSS. A series of look-up tables and graphs have been developed which will form the basis of the economic cost indicators within the SDSS. The calculators will run in the background of the model, with minimal inputs required by the user. This portion of the SDSS is termed the 'stormwater management cost calculator' (SWMCC). Figure 1 highlights the information that is needed from the user (*i.e.* user interface). In addition, it provides an indication of how the results may be displayed in the model and the proposed process that has been followed in order to generate the resulting SWMCC.

As can be seen from Figure 1, the approach that has been taken is outlined in three steps:

- Step 1. creation of theoretical treatment catchment scenarios
- Step 2. COSTnz modelling
- Step 3. results.

This report is structured according to the above three steps, with the methodology and findings of each step provided within the subsequent sections.

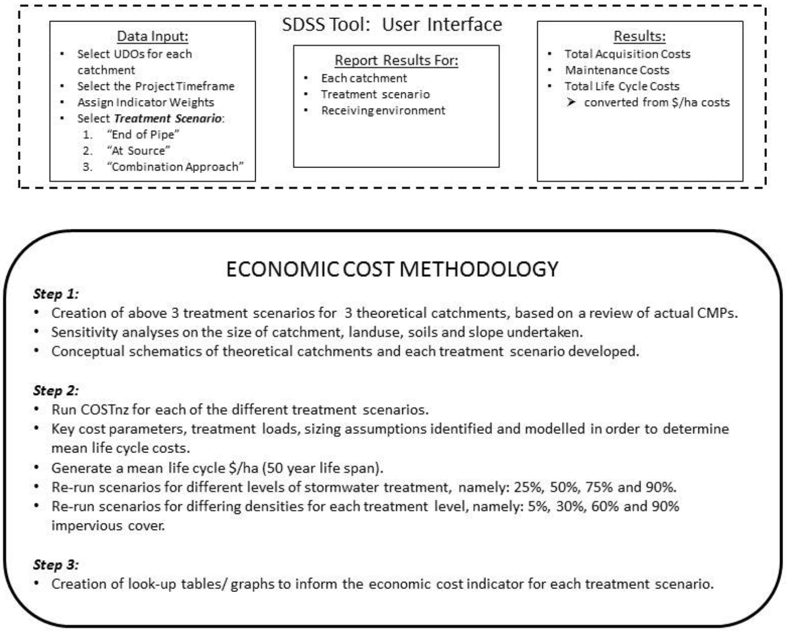


Figure 1. Proposed process and interface for the development of an economic cost indicator for stormwater management in the spatial decision support system (SDSS).

2. CREATION OF THEORETICAL CATCHMENT TREATMENT SCENARIOS

2.1. Introduction

A selection of catchment management plans (CMPs) were reviewed in order to gain an understanding of the spatial positioning of stormwater management, as well as how variables such as soils, slope and density affect the type and number of stormwater management devices. In addition, a brief literature review was conducted on research encompassing national and international costs of stormwater management. This focussed particularly on other 'catchment scale' costing approaches which may have been developed, and sought to validate key assumptions which would need to be made during the costing process.

2.2. Summary of catchment management plans reviewed

The following CMPs were reviewed in order to obtain an understanding of the spatial distribution of stormwater management and device sizing:

- Hobsonville Peninsula Integrated Catchment Management Plan (ICMP)
- Airport Oaks Sub-catchment Report
- Orewa West ICMP
- Pukekohe North ICMP
- Shoal Bay ICMP
- Hauraki ICMP
- Acacia Heights CMP (Taupo)
- Tauranga-Taupo CMP.

As can be seen from the above list, the majority of CMPs were sourced from the Auckland Region. The reasons for this are two-fold: firstly, the Auckland Region CMPs are detailed and contain specific information regarding sizing of stormwater management practices, and secondly, CMPs outside of the Auckland Region tended to focus on rural issues or only provided general stormwater recommendations for urban areas. Other regions within New Zealand that were investigated, but found to be not suitable for the purposes of this project included; Whangarei, Tauranga (their CMPs are only due to be completed in 2012), Marlborough (rural CMPs for the Rai River area only), Porirua (detailed catchment information and research, but no solutions provided), Tasman, and Nelson.

Tables summarising the review parameters for each CMP are included in Appendix 1. In terms of the information reviewed, the key factors which affect the sizing of treatment practices include the desired level of treatment and the density of development. The percentage of impervious area which drains to a device is significant, and this is frequently determined by land-use type (and density). The CMPs indicate that slope and soil type are not as important in terms of sizing devices, however, they do have an impact on device selection.

The review also assisted in the development of a number of theoretical catchment scenarios for stormwater treatment. These scenarios were modelled using COSTnz and are explained in more detail in Section 2.3 below.

2.3. Theoretical treatment scenarios

2.3.1. 'End of Pipe' scenario

The 'End of Pipe' treatment scenarios consist of a mix of large scale stormwater mitigation measures which can be used to treat stormwater at the bottom of sub-catchments. Two key mitigation measures can be utilised, namely wetlands and ponds. The following scenarios, based on actual CMPs, were modelled:

Scenario A: Hobsonville Catchment (177ha, four wetlands) (Mixed catchment)

- Scenario A1: four wetlands
- Scenario A2: four ponds
- Scenario A3: two ponds; two wetlands.

Scenario B: Airport Oaks Sub-catchment (137.5ha, three wetlands) (Developed catchment)

- Scenario B1: three wetlands
- Scenario B2: three ponds
- Scenario B3: two ponds; one wetland.

Scenario C: Orewa West – Northern Sub-catchment (51.67ha, six ponds) (Greenfields catchment)

- Scenario C1: three wetlands
- Scenario C2: three ponds.

The catchment maps for each of these catchments, and on which the COSTnz modelling has been based, are included in Appendix 2.

All scenarios were run for stormwater treatment to 25%, 50%, 75% and 90% total suspended solids (TSS) removal levels. In addition, each treatment level included a 5%, 30%, 60% and 90% impervious area scenario.

2.3.2. Sensitivity analysis

The purpose of the sensitivity analysis was to test the sensitivity of costs to density (comparison of pond/ wetland size in relation to impervious area treated in scenarios A, B and C), soils and slope. However, during the review of the CMPs it became very clear that density/ percentage impervious area is a significant factor determining the size of stormwater management devices, and this parameter was therefore included in each scenario. The percentage of impervious area used in the models, for each different treatment level, was based on the average impervious area percentages provided in the CMPs, namely: 35%, 65% and 85%. Therefore, each modelled scenario accounted for incremental increases in impervious area (5%, 30%, 60% and 90%) for each different treatment level.

Within the CMPs reviewed, the catchment size ranged from 61 ha to 223 ha. Two catchments had areas greater than this range; however, these catchments incorporated a significant portion of rural land. The average catchment size for the CMPs reviewed was 135.6 ha[6]. As a result, the sensitivity analysis scenarios were created using this 'theoretical' (136 ha) catchment area and the average $/ha values generated through the COSTnz modelling. The model results were also further analysed in order to determine whether or not a factor was needed to account for increased costs of retrofitting stormwater management within developed catchments.

2.3.3. 'At Source' scenario

The 'At Source' treatment scenarios involve the use of on-site stormwater treatment only for the whole catchment. Rain gardens, swales, infiltration practices and sand filters were modelled through the 'At Source' scenarios. The scenarios are completely theoretical and based on sizing each device to treat a small (1 ha), medium (2 ha) and large (3 ha) catchment area. Combinations of these three sizings, along with combinations of different types of devices, were then added together to provide for a catchment-wide treatment approach for a hypothetical 136 ha catchment. It was estimated that each device type would treat 25% of the catchment (approx. 34 ha). The theoretical scenarios that were modelled included:

- Scenario A: Small and large - rain gardens (s - 35), swales (l - 11), infiltration trenches (s -35), sand filters (l - 11)
- Scenario B: Medium - rain gardens (m – 17), swales (m -17), infiltration trenches (m -17), sand filters (m – 17)
- Scenario C: Large and small - rain gardens (l - 11), swales (s - 35), infiltration trenches (l - 11), sand filters (s - 35).

[6] This size is considered to be consistent with a typical 'growth node' or structure plan area and would therefore fit in well with the definition of 'planning level unit'.

All scenarios were run for stormwater treatment to 25%, 50%, 75% and 90% TSS removal levels. In addition, each treatment level also included a 5%, 30%, 60% and 90% impervious area scenario.

2.3.4. 'Combination' scenario

The 'Combination' treatment scenarios involved providing 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 136 ha. The scenarios run were split according to differing proportions of catchment area, and were loosely based on the catchment map shown in Figure 2. This figure is reflective of the fact that, in the majority of instances, on-site stormwater management is located within the top part of the catchment. The theoretical scenarios that were modelled included:

Scenario A:

- Scenario A1: ⅓ At Source, ⅔ Wetlands
- Scenario A2: ⅓ At Source, ⅔ Ponds
- Scenario A3: ⅓ At Source, ⅔ Wetlands + Ponds.

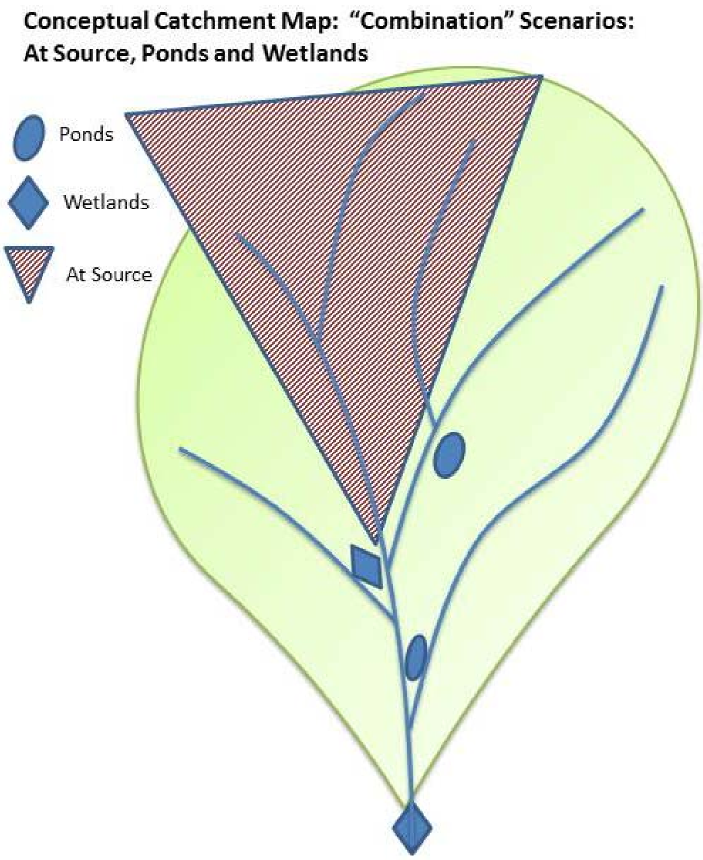
Scenario B:

- Scenario B1: ½ At Source, ½ Wetlands
- Scenario B2: ½ At Source, ½ Ponds
- Scenario B3: ½ At Source, ½ Wetlands + Ponds.

Scenario C:

- Scenario C1: ⅔ At Source, ⅓ Wetlands
- Scenario C2: ⅔ At Source, ⅓ Ponds
- Scenario C3: ⅔ At Source, ⅓ Wetlands + Ponds.

All scenarios were run for stormwater treatment to 25%, 50%, 75% and 90% TSS removal levels. In addition, each treatment level included a 5%, 30%, 60% and 90% impervious area scenario.



Scenario A:
- ⅓ At Source, ⅔ End of Pipe

Scenario B:
- ½ At Source, ½ End of Pipe

Scenario C:
- Scenario C1: ⅔ At Source, ⅓ End of Pipe

Figure 2. Theoretical catchment map for the 'Combination' scenario.

2.4. Summary of literature review

A number of different papers relating to stormwater management were sourced. The most relevant papers, and their key points, are summarised and included in Appendix 3.

3. MODELLING ASSUMPTIONS

The following sections outline the assumptions for the Step 2 model runs which were outlined in Section 2.

3.1. Treatment assumptions

3.1.1. Treatment levels

As discussed in the project scope of works, the treatment levels for each scenario were matched to the treatment levels provided in the SDSS, *i.e.* 25%, 50%, 75% and 90% TSS removal. In terms of sizing the devices for the COSTnz models, the relative levels of removal efficiency were extrapolated from Table 3-1 of Technical Publication 10: Stormwater Management Devices: Design Guideline Manual (ARC, 2003), as shown in Table 1 below.

Table 1. Relative levels of removal efficiency (ARC, 2003[7]). Note: WQV is water quality volume.

Table 3-1
Relative levels of removal efficiency

Practice Volume	Efficiency
150% of WQV	82%
100% of WQV	75%
75% of WQV	70%
50% of WQV	60%
25% of WQV	50%
10% of WQV	40%
5% of WQV	30%

Therefore, the following calculations were used:

- 75% TSS removal = 100% of the WQV
- 25% TSS removal = approx. 5% of the WQV
- 50% TSS removal = approx. 25% of the WQV
- 90% TSS removal = approx. 175% of the WQV.

[7] Auckland Regional Council. (2003). *Stormwater Device Guideline: Design Manual.* Technical Publication 10.

3.1.2. Contaminant load model

A simple contaminant load model (CLM) was built for each impervious area scenario. The approximate sediment load being treated by each device is needed in order to determine cleanout/ maintenance frequencies. The models assumed that only the impervious areas within each catchment would drain to the stormwater management devices. A breakdown of the type of impervious areas used in the CLM is as follows:

- 70% roads
- 20% roofs (coloursteel)
- 10% other impervious areas.

This breakdown was based on information provided within the reviewed CMPs. A review of CMPs and international literature[8] has shown that up to approximately 70% of catchment imperviousness relates to roads, driveways and parking areas. It is considered that this estimate is likely to be conservative since roads are the highest producers of contaminants and the default TSS yields in the Auckland Council's CLM are higher for roads than for other impervious surfaces[9]..

3.2. Device design

3.2.1. Wetland and pond sizing

The wetland and pond design was based on the sizing provided within the reviewed CMPs, namely, Hobsonville (Scenario A), Airport Oaks (Scenario B) and Orewa West (Scenario C). It was determined that the average water quality volume (WQV) per hectare of impervious area is as follows:

A. Hobsonville	259 m^3	determined by working out the total WQV for each hectare of impervious area draining to each wetland, divided by the number of wetlands.
B. Airport Oaks	323 m^3	
C. Orewa West	304 m^3	

The Hobsonville and Orewa West wetlands were designed for 75% TSS removal. The Airport Oaks wetlands were designed for 30% and 75% TSS removal. Using the

[8] Wong, T H F, Breen, P F and Lloyd, S D. (2000). *Water Sensitive Road Design – Design Options for Improving Stormwater Quality Road Runoff.* Cooperative Research Centre for Catchment Hydrology.
[8]Schueler, T.R. (1987) Site Planning for Urban Stream Protection, Washington Metropolitan Water Resources Planning Board, 232p.
[8] National Research Council. (2008). Stormwater Management in the United States. National Academic Press. Washington D.C.
[9] Timperley., M., Skeen, M. and Jayaratne, R. (2010). *Development of the Contaminant Load Model*. Report prepared for Auckland Regional Council. Technical Report 2010/004

wetlands designed to remove 75% of total suspended solids (TSS), the modelled WQV was extrapolated for a range of impervious areas.

The following formula was used:

$$WQV \quad = \quad CA * IMP * \overline{WQV} \qquad (1)$$

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.*

For example, if the wetland catchment area in Hobsonville was 35 ha, then for 5% impervious area and 75% TSS removal, the formula would be: *WQV = (35 x 0.05) x 259.*

In order to determine the wetland surface area (in m^2), it was assumed that the wetlands would have an average depth of 1 m. Therefore the surface area would be equal to the WQV divided by 1.

The modelled WQV for each percentage TSS removal and impervious area were therefore extrapolated from the wetlands sized to remove 75% TSS using the approach outlined in Section 3.2.1. A separate COSTnz model was built for each wetland and a total of 144 wetland scenarios were run.

For the purposes of the model, the ponds have been sized using a similar methodology. The key difference was that it was assumed that the ponds would be deeper than the wetlands, and therefore an average depth of 2 m was used. A total of 144 pond scenarios were run.

In addition to the individual pond and wetland models, catchments were modelled using a combination of both ponds and wetlands.

3.2.2. Sizing of ‘At Source’ devices

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[7]. 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 High Intensity Rainfall System (HIRDS) database. One third of the 90^{th} percentile storm was used as the water quality design storm event (27 mm rainfall depth[10]).

[10] http://hirds.niwa.co.nz/
[7] Auckland Regional Council. (2003). *Stormwater Device Guideline: Design Manual.* Technical Publication 10

As mentioned in Section 2.3.2, each 'At Source' device was designed for a 1 ha, 2 ha and 3 ha 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 TP107 (see Figure 3). 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 TP107 (as explained in Section 3.2.1 and shown in Table 1).

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

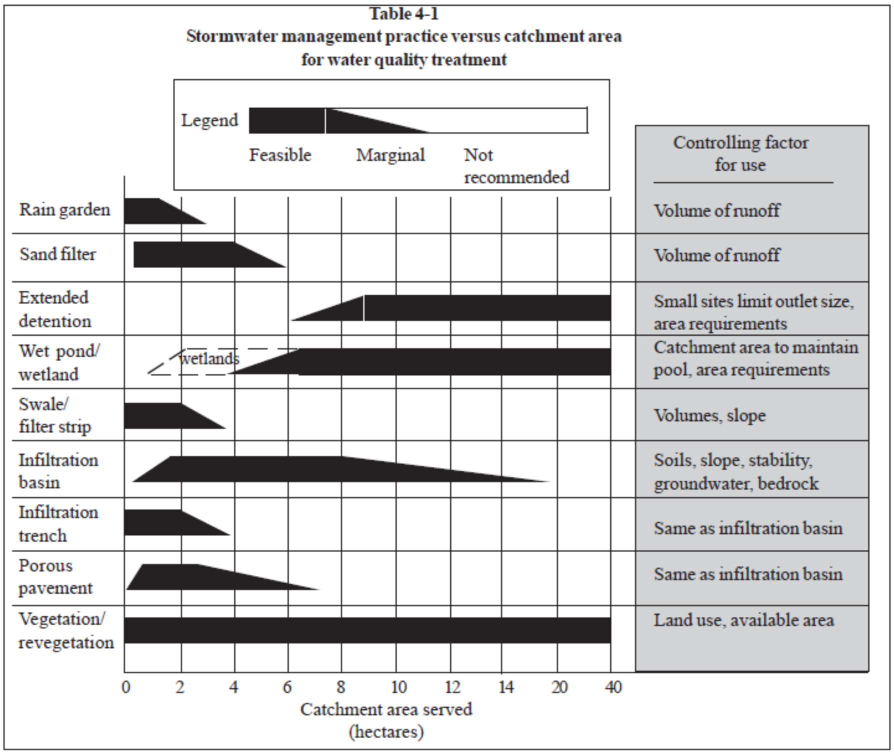


Figure 3. Catchment area constraints for a range of stormwater treatment devices (ARC, 2003[7])

3.3. COSTnz ASSUMPTIONS

3.3.1. Life cycle 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 [11].
- 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.

The SDSS focuses on mitigation of stormwater effects on aquatic environments, as a result, the determination of economic cost relates solely to the treatment and/ or attenuation measures required to mitigate effects of stormwater discharges. Therefore, only the actual stormwater treatment device has been costed. The COSTnz models do not take account of piping to and from the device, nor any associated reticulated network that would otherwise be required for development to occur. In addition, it focuses on the cost to the public rather than private individual, so does not include costs of source control measures such as roof painting. Potentially this is an area for future development and expansion of the SDSS where the issue of public versus private costs and benefits could be further explored.

3.3.2. Total acquisition costs

In COSTnz, total acquisition costs (TACs) relate to the design, planning, consenting and construction costs of a device, and land costs have been excluded. The terminology used in this report is consistent with that used in COSTnz, and land costs are therefore dealt with separately in Section 3.4.4.

Ponds and wetlands

Both the wetland and pond TACs were determined using formulas that estimate the statistical relationship between the TAC and the surface area of a device. The formula used within the COSTnz Wetland Model is (COSTnz user manual [12]):

$$TAC = -1524093 + 378008*Ln(TZA \qquad (2)$$

Where TZA = Treatment Zone Area (or Surface Area)

The formula used within the COSTnz Pond Model is (COSTnz user manual[12]):

$$TAC = 6802 \times TZA^{0.4436} \times 1.94 \qquad (3)$$

Where TZA = Treatment Zone Area (or Surface Area).

[11] Whilst it would make a difference which level of cost is used, particularly when different device configurations, and in turn resulting cost profiles, are applied between development options within the SDSS, this issue would be dealt with at implementation.
[12] http://www.costnz.co.nz/index.aspx

The R^2 value of the analysis for the wetland relationship is 0.835 and is indicative of a strong relationship. With respect to the pond formula, the analysis resulted in a relationship for which the P-value of the regression is smaller than 0.05, and the R^2 value of the regression is $0.48 < R^2 < 0.79$ (strong). The on-line pond formula has been used as the low cost statistical relationship for off-line ponds seems to equate to dry detention ponds. Additional data regarding pond TAC was collected from a number of CMPs (including and additional to those reviewed), as well as directly from consulting engineering firms. It was found that the on-line pond formula provides a reasonable cost estimate of a TP10-designed wet pond.

At source devices

The COSTnz models for rain gardens, swales and infiltration trenches do not utlise a statistical relationship between the size of the device and its likely TAC. The primary reason for this is that, during the data collection phase of the COSTnz model development, there was insufficient data to establish any significant relationships[13]. As a result, a unit cost approach has been used, where a schedule of activities and associated unit costs is provided. The quantities of each activity are linked to the size and dimensions of the device (as obtained through the device design and sizing spreadsheet as explained in Section 3.3.2). An example of the unit cost spreadsheet for the rain garden model is shown in Table 2.

Table 2 provides an indication of the type of items that have been costed for a rain garden, their relevant quantity and the 2011 unit cost. For the rain gardens, swales and infiltration trenches, the design and consent related costs are estimated to be 15% of the construction cost (this approach is used frequently within the civil engineering community when estimating project costs). In addition, a 20% contingency has been included to account for any uncertainty associated with the design.

Although not included in the final COSTnz models, a statistical relationship was obtained for sand filter TACs. The relationship was found to be 'modest' (P-value = 0.08), as opposed to 'strong' (P-value < 0.05) for ponds and wetlands[14]. Subsequent further testing, however, has shown that it does provide comparable results to that obtained when using the unit costing approach. As a result, it was used to determine sand filter TAC costs in this project.

[13] Ira, S.J.T., Vesely, E-T. and Krausse, M. (2008). *Life cycle costing of stormwater treatment devices:a practical approach for New Zealand*. 11th International Conference on Urban Drainage. Edinburgh, Scotland.

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

The formula used is as follows (Vesely *et al.* 2006)[14]:

$$TAC = 7986 + 4658 \text{ (Filter Area)} \qquad (4)$$

Where Filter Area = total surface area of the sand filter (*i.e.* the filtration area + sedimentation area).

Table 2. Unit costing spreadsheet for an example rain garden sized to treat 75% TSS over a long term average basis for a 1ha catchment which has 60% impervious area.

Site Name: At Source

Rain Garden Location: RG1 60% Imp 75% TSS

Description: 1 Ha

Total Acquisition Costs

RAIN GARDEN DESIGN AND CONSENTING	TOTAL COST
Costs associated with defining the need for the measure (e.g. running site selection processes, feasibility studies)	$14,210.89
Conceptual, preliminary and detailed design costs (including preparation of tender documents)	
Costs associated with environmental assessment, acquisition of consents and public consultation	
Fees for project management, site management of construction phase	
Subtotal: Design, Consenting and Fees	**$14,210.89**

RAIN GARDEN EARTHWORKS & FILTER MEDIA	UNIT	2011 UNIT COST	QUANTITY	TOTAL COST
Preliminary & General				
Site Establishment	LS	$11,167.92		$11,167.92
Asbuilt plans	LS	$1,675.19		$1,675.19
Insurances & Bonds	LS	$1,116.79		$1,116.79
Existing Services				
Locate Existing Services prior to Construction and Protect During Construction	LS			
Break into existing pipe and make new connections (1.5m deep)	No			
Site Clearance				
Site clearance, inclusive of disposal to approved site	LS	$2,233.58		$2,233.58
Strip & sort existing topsoil on site to stockpile	m^3	$3.57	75	$267.75
Sediment and Erosion Control - silt fence TP90 spec	m	$14.52	375	$5,445.00
Dewatering (Pumping) with 75 mm pump	hrs	$33.50	24	$804.00
Flow Diversion using rock check dams 0.5 m high/metre	m			
Earthworks				
Clay cut to stockpile, inclusive of excavation, uplift, carting & stockpiling.	m^3	$3.46	300	$1,038.00
Condition (wet or dry), uplift, cart & place clay material from stockpile to fill specifications as	m^3	$5.03	270	$1,358.10
Excavate, load and cart unsuitable material to stockpile onsite	m^3			
Removal of Unsuitables off site (clay material, includes cartage of up to 10km and dump fees	m^3	$27.92	30	$837.60
Additional cartage costs of excavated material (each addition 5km over 10km)	m^3			
Water-Proofing/ Erosion Protection				
Impermeable liner (Permaliner P300 or equivalent)	m^2	$13.40	552	$7,396.80
Anchor liner edges	LS	$1,675.19		$1,675.19
Recessing of the liner under manhole and sealing	LS	$714.75		$714.75
Erosion protection at inlets (reno mattress or equivalent)	m^2	$70.36	17	$1,196.12
Filter Media				
Supply and lay gravel underdrain layer (20/7 drainage material)	m^3	$71.81	60	$4,308.60
Supply and lay sand drainage layer (No 3 Sand)	m^3	$77.06	45	$3,467.70
Supply and transport rain garden filter media (TP10 soil mix)	m^3	$105.26	195	$20,525.70
Placing of soils in rain garden & compaction testing	m^3	$17.87	300	$5,361.00
Other Items (Earthworks, Water Proofing & Filter Media Requirements) - please describe				
SUBTOTAL: Earthworks & Filter Media				**$70,589.79**

Continued on next page

PIPING AND CONCRETE WORKS	UNIT	2011 UNIT COST	QUANTITY	TOTAL COST
Pipe work				
Supply, excavate, lay, bed & backfill 225mm dia RCRRJ Class X pipe	m	$122.85	17	$2,088.45
Supply, excavate, lay, bed & backfill 300mm dia RCRRJ Class X pipe	m			
Supply, excavate, lay, bed & backfill 375mm dia RCRRJ Class X pipe	m			
Supply, excavate, lay, bed & backfill 450mm dia RCRRJ Class X pipe	m			
Supply & lay 110mm dia Nova Coil drains in rain garden gravel underdrain	m	$10.05	17	$170.85
Supply & lay 160mm dia Nova Coil drains in rain garden gravel underdrain	m			
Supply & lay 150mm heavy duty perforated PVC pipe in rain garden gravel underdrain	m			
Concrete Works				
Precast concrete wingwalls (including excavation, 200mm compacted hardfill base and back	No			
Precast concrete wingwalls (including excavation, 200mm compacted hardfill base and back	No			
Installation of manholes (1050mm dia; 1500 deep; with concrete base and reinfoced heavy d	No	$2,010.23	1	$2,010.23
Pipe connections to rain garden (225mm diameter RCRRJ)	m	$89.34	1	$89.34
Installation of catchpits	No	$2,680.30	2	$5,360.60
Trash rack -safety grille (galvanised scruffy dome 1050 dia.)	No	$2,233.58	1	$2,233.58
Installation of Kerbing	m			
Other Items (Stormwater Piping and Concrete Works) - please describe				
SUBTOTAL: Pipes and Structures				**$11,953.05**

LANDSCAPING, ACCESS AND PLANTING	UNIT	2011 UNIT COST	QUANTITY	TOTAL COST
Reinstatement of Surrounding Area				
Cart, load and placement of topsoil from stockpile for landscaping	m^3	$23.17	75	$1,737.75
Spread fertiliser and rework the surface	m^2	$0.28	75	$21.00
Supply and place grass seed at 400 kg/ha	m^2	$0.61	75	$45.75
Planting and Mulching				
Supply & place mulch layer	m^3	$32.39	45	$1,457.55
Supply & place 5 native plants (sedges & grasses)/m2	m^2	$27.92	300	$8,376.00
Provide maintenance for the duration of the vegetation establishment period (controlled water	LS	$558.40		$558.40
Other Landscaping Items				
Benches - Promenade Sea (with tubular frame, and perforated sheet steel to seating)	No			
Signage	LS			
Pedestrian Walkway				
Insitu concrete paving on 50mm sand bed, 150mm basecourse layer with broomed finish (75	m^2			
Insitu concrete paving on 50mm sand bed, 150mm basecourse layer with broomed finish (10	m^2			
Other Items (Landscaping, Access and Planting) - please describe				
SUBTOTAL: Reinstatement and Planting				**$12,196.45**

Subtotal				**$108,950.18**
Contingency				$21,790.04
TOTAL: TOTAL ACQUITISION COSTS				**$130,740.22**

3.3.3. Maintenance costs

Ponds and wetlands

It is interesting to note that the categories of maintenance for both ponds and wetlands are very similar. As a result, the same frequency of maintenance was chosen for both devices. Where the models differ are the unit of maintenance (*i.e.* per wetland or pond *vs.* per m^2) and the unit costs themselves. The frequency of desilting the forebay, main pond/ wetland and replanting the wetland zone is set by contaminant load and the treatment efficiency of the pond/ wetland. The maintenance activities and frequencies used in the modelled scenarios are shown in Tables 3 and 4. Decommissioning costs were not included in the life cycle analysis due to a lack of data and the likelihood that the ponds and wetlands would not be decommissioned.

Table 3. Pond maintenance activities and frequencies.

Maintenance Costs

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
Routine General Maintenance (mowing, maintaining healthy vegetation cover)	12	4	m^2
Removing debris (eg litter, dead vegetation) from outlet and inlet structures	12	4	per pond
Inspections (Ducks, QA, inspection of embankments, spillways, outfalls, overall functioning of facility)	1		per visit
Scheduled Routine Mechanical Maintenance (pumps, outlets, removing mosquito breeding areas)	1		per pond
Make good from vandalism	12	4	per pond
Weed Management	1		per pond
Other Activities		1	
TOTAL ROUTINE MAINTENANCE COSTS	**Annual Cost**	**Annual Cost**	

Do you envisage elevated maintenance costs in the first 5 years?	Yes
If Yes, please detail the percentage increase of these costs above the average?	15%

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments, erosion)	10	20	per pond
Replacement of parts (grates, trash screens)	20		per pond
Desilting - forebay	6		m^3
Desilting - main pond	50		m^3
Disposal to managed fill	per disposal		m^3
Other Activities			m^3

Do you envisage having to clean out the pond forebay in the first 5 years?	Yes

*Note: Desilting forebay and main pond frequency will change depending on the contaminant load, treatment level and pond size.

Table 4. Wetland maintenance activities and frequencies.

Maintenance Costs

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
Routine General Maintenance (mowing, maintaining healthy vegetation cover)	12	4	m^2
Removing debris (eg litter, dead vegetation) from outlet and inlet structures	12	4	per pond
Inspections (Ducks, QA, inspection of embankments, spillways, outfalls, overall functioning of facility)	1		per visit
Scheduled Routine Mechanical Maintenance (pumps, outlets, removing mosquito breeding areas)	1		per pond
Make good from vandalism	12	4	per pond
Weed Management	1		m^2
Initial Aftercare of Plants (for first 5 years)	4		m^2
Other Activities			
TOTAL ROUTINE MAINTENANCE COSTS - Annually for the first 5 years			
TOTAL ROUTINE MAINTENANCE COSTS - Annually for subsequent years			

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments, erosion)	10	20	per pond
Replacement of parts (grates, trash screens)	20		per pond
Replanting the wetland zone	50		m^2
Desilting - forebay	13		m^3
Desilting - main pond	50		m^3
Disposal to managed fill	per disposal		m^3
Other Activities			m^3

Do you envisage having to clean out the wetland forebay in the first 5 years? Yes

*Note: Desilting forebay and main pond frequency will change depending on the contaminant load, treatment level and pond size.

At source devices

As with the ponds and wetlands, maintenance costs for the ‘At Source’ devices were determined on a unit cost basis. The activities, frequencies and units of maintenance for each of the devices are shown in Tables 5 to 8. The frequency of cleanout for each device is set by contaminant load (*i.e.* build of sediments within the device) and the treatment efficiency of device. However, it should be noted that the infiltration trench model does not account for sediment build-up in relation to contaminant load, due to insufficient data. As a result, cleanout of the trench was estimated based on TP10 maintenance guidelines. Decommissioning costs were not included in the life cycle analysis due to a lack of data and the likelihood that the devices would not be decommissioned.

Table 5. Rain garden maintenance activities and frequencies.

MAINTENANCE COSTS

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
Routine General Maintenance (removing debris, clearing inlets and outlets, maintaining vegetation)	12	4	m^2
Inspections (for debris, outlets, integrity of biofilter)	1		per rain garden
Minor repairs	1		per rain garden
Make good following vandalism	1		per rain garden
Initial aftercare of plants (for 3 years)	4		m^2
Other activities			
TOTAL ROUTINE MAINTENANCE COSTS - Annually for the first 3 years			
TOTAL ROUTINE MAINTENANCE COSTS - Annually for subsequent years			

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Removal & disposal of sediments	50		m^3
Replanting	50		m^2
Replacement of parts	10	25	per rain garden
Other activities			

Table 6. Swale maintenance activities and frequencies.

Maintenance Costs

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
Routine General Maintenance (mowing, maintaining healthy vegetation cover, weeding)	6		m^2
Inspections (for debris, outlets, integrity of swale/ dispersed flow)	4		per swale
Removing debris (eg litter; dead vegetation from inlet and overflow structures)	4		per swale
Make good following vandalism	1		per swale
Pruning Plants (wetland swales)	2		m^2
Other activities			
Do you envisage elevated maintenance costs in the first 3 years? If Yes, detail percentage above annual costs:			
TOTAL ROUTINE MAINTENANCE COSTS - Annually (after initial 3 year maintenance period)			

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Maintaining disbursed flow - removing accumulated sediment; regrading	6.78		per swale
Disposal of sediment to Landfill	6.78		m^3
Replanting grassing	6.78		m^2
Minor repairs to inlet or outlet pipes	10		per swale
Replacement of bollards (discontinous kerbing)	10		m
Replacement of underdrain	10		m
Other activities			

Table 7. Infiltration trench maintenance activities and frequencies.

MAINTENANCE COSTS

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
General Maintenance: removing debris, clearing inlets, checking sediment traps, forebays/ swales, etc	12	4	per trench
Inspections (sediment traps/ forebays, pretreatment swales, inlets, outlets/ overflow spillway, overall functioning of facility)	4		per trench
Maintaining healthy vegetation around device, weeding, mowing, etc	6	4	m^2
Minor repairs	1		per trench
Make good following vandalism	1		per trench
Other activities			
Do you envisage elevated maintenance costs in the first 3 years? If Yes, detail percentage above annual costs:			
TOTAL ROUTINE MAINTENANCE COSTS - Annually (after initial 3 year maintenance period)			

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Cleanout sediment, oils, etc and removal of top layer of stone and re-establishment	5	10	m^3
Removal and disposal of sediments	10	50	m^3
Rehabilitation of trench (i.e. replacement of full trench filtration media)	10		m^3
Replacement of permeable pavers (if necessary)	10		m^2
Erosion repair	2	5	per trench
Repairs to structural components	10		per trench
Other activities			

Table 8. Sand filter maintenance activities and frequencies.

MAINTENANCE COSTS

Routine Maintenance	Frequency (Per Year)		Unit
	Model/ Default	User Defined	
Routine General Maintenance (removing debris, oil & grease, water retention, sediment deposition, clearing inlets and outlets)	4		per filter
Inspections (outlets/ overflow spillway, overall functioning of facility)	4		per filter
Clean out of Filtration Chamber (Skim surface of sand to re-establish permeability) & disposal of sediment	2		per filter
Minor repairs	1		per filter
Make good following vandalism	1		per filter
Other activities			
Do you envisage elevated maintenance costs in the first 3 years? If Yes, detail percentage above annual costs:			
TOTAL ROUTINE MAINTENANCE COSTS - Annually (after initial 3 year maintenance period)			

Corrective Maintenance	Frequency (Number of Years)		Unit
	Model/ Default	User Defined	
Removal and Disposal of Sediments from Sedimentation Chamber	5		m^3
Replacement of sand filter media	10		m^3
Replacement of parts (grates, outlet structures; other concrete components)	5		per filter
Other activities			

3.3.4. Land costs

Land costs are not included in the COSTnz models. As a result, a second phase of analysis was required in order to determine if a factor could be used to account for land costs in the different types of development scenarios. In addition, by developing a land cost factor, the catchment economic cost would potentially be able to account for the increased land costs of redevelopment within existing urban areas. Greenfield catchment land costs were determined using an average figure of $80/m^2. In developed catchments, land costs were initially investigated using the Airport Oaks catchment data. However, there was insufficient data to be able to determine a relationship. As a result, the developed catchment factor has been based on an average figure of $140/m^2. These costs were sourced from research undertaken into life cycle costing of stormwater management in the Rodney District, Auckland[15]. The resulting land cost factors are presented in Section 4.

[15] Ira, S.J.T. and Buchanan, K.S. (2009). *Using Life Cycle Costing as a Tool to Support a Development Contributions Policy*. NZWWA Stormwater Conference.

4. RESULTS AND DISCUSSION

4.1. Summary of results

Appendix 4 contains a summary of the tabulated results for each of the three catchment treatment scenarios, namely:

- 'End of Pipe'
- 'At Source'
- 'Combination'.

The results have also been graphed, and those presented in this document are provided in Figures 4 - 12. The graphs are shown for each treatment scenario, treatment level and percentage impervious area. Only the dollar per hectare per year ($/ha/yr) undiscounted graphs have been presented within this report (the NPV graphs are shown in Appendix 5).

4.2. 'End of Pipe' modelling results

The graphs illustrate $/ha/yr costs over a 50 year life cycle for each treatment level and percentage impervious area. The graphs clearly show that, over the life cycle, wetlands are more expensive than ponds. However, closer inspection of the models themselves show 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 activities and the high cost associated with weed control in open water ponds.

Analysis of the 25% TSS removal graphs (both undiscounted and NPV costs) do not show such a clear relationship between the cost of ponds and wetlands. In all likelihood this is due to the very small size of the devices. Given that some of these devices are below the 'range' of the wetland TAC statistical formula, the TAC for each device was calculated individually using the unit costing approach. 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.

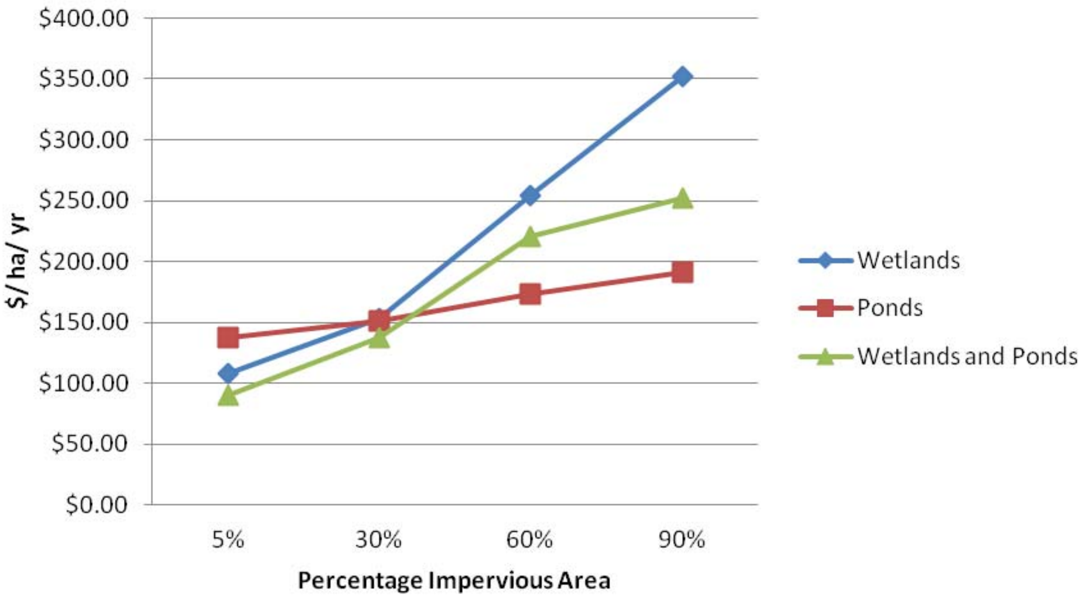


Figure 4. 'End of Pipe' – 25% TSS removal: $/ha/yr LCC.

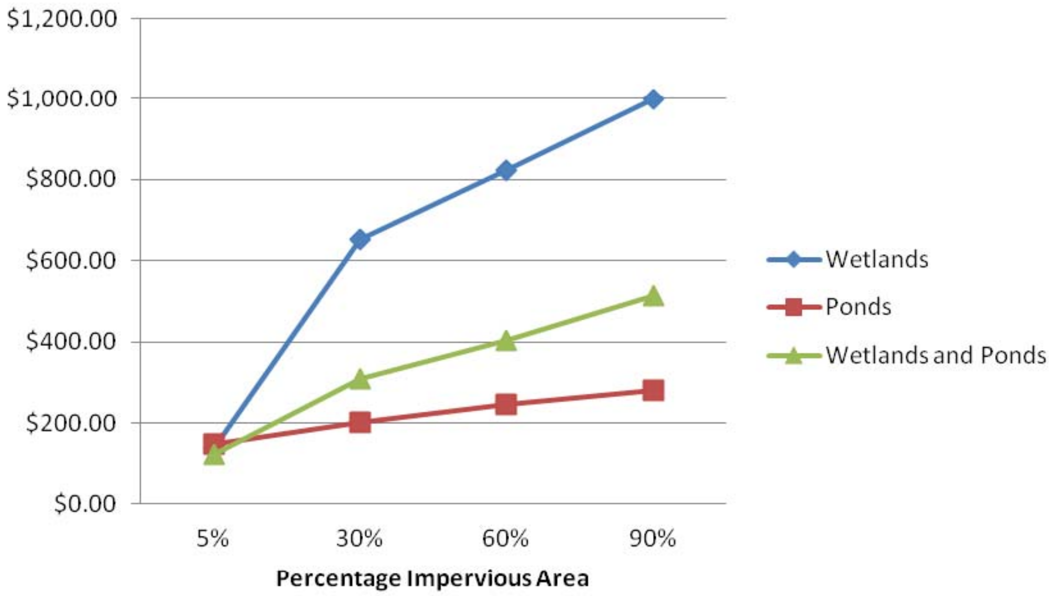


Figure 5. 'End of Pipe' – 50% TSS removal: $/ha/yr LCC.

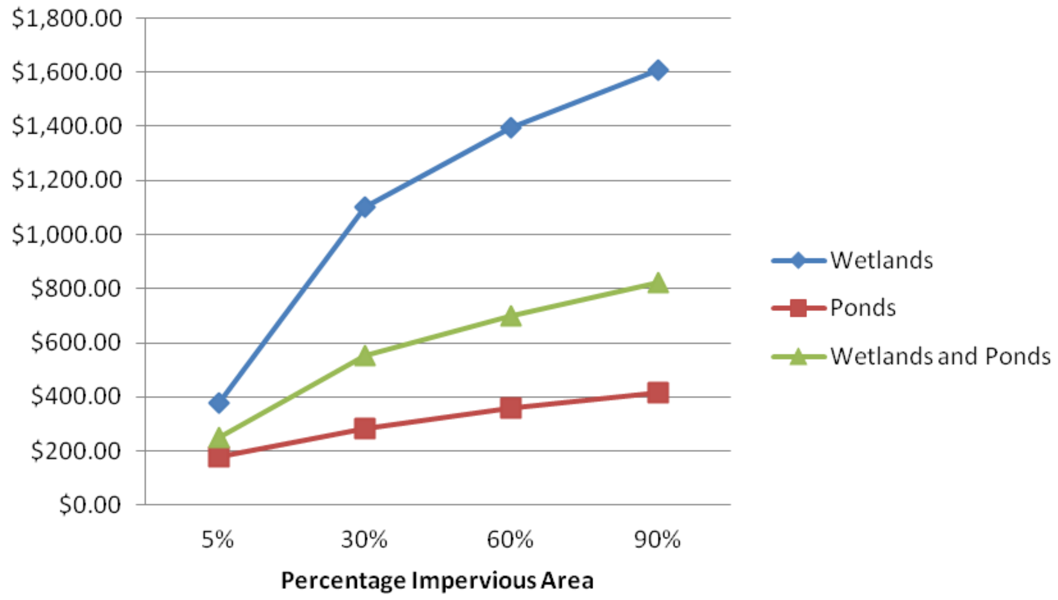


Figure 6. 'End of Pipe' – 75% TSS removal: $/ha/yr LCC.

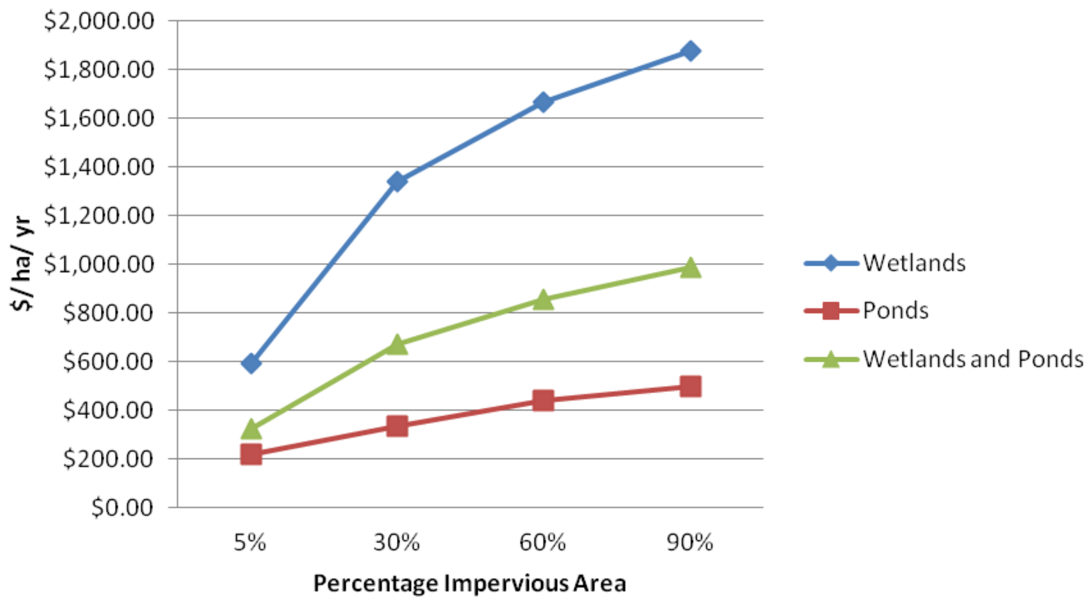


Figure 7. 'End of Pipe' – 90% TSS removal: $/ha/yr LCC.

The proportion of cost relating to the design, planning and construction of the 'End of Pipe' solutions (*i.e.* the TAC) was also determined. Table 9 highlights that the majority of costs associated with wetlands relate to the TAC. In addition, as the level of treatment increases, so the proportion of TAC becomes higher.

Table 9. 'End of Pipe' TAC as a percentage of the LCC.

Scenario	25% TSS	50% TSS	75% TSS	90% TSS
Wetland Average TAC Proportion	58.5%	76.3%	88.4%	88.7%
Pond Average TAC Proportion	32.7%	47.1%	59.5%	68.8%
Wetland/ Pond Average TAC Proportion	47.8%	66.9%	80.3%	84.3%

4.3. 'At Source' modelling results

Figure 8 graphs the $/ha/yr LCC for the 'At Source' scenarios. In order to generate these results, all the 'At Source' devices (*i.e.* rain gardens, swales, infiltration trenches and sand filters – Scenarios A, B and C – as described in Section 2.3.2) were combined into a single theoretical catchment of 136 ha. The mean total LCC was utilised in order to generate the $/ha cost. The results show that there is not a significant difference in cost between the different treatment levels for a 5% impervious area. However, as the impervious area increases, so the cost margin between each treatment level expands.

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 NPV cost for wetlands is approximately $1,350 as opposed to about $3,400 for the at source treatment devices.

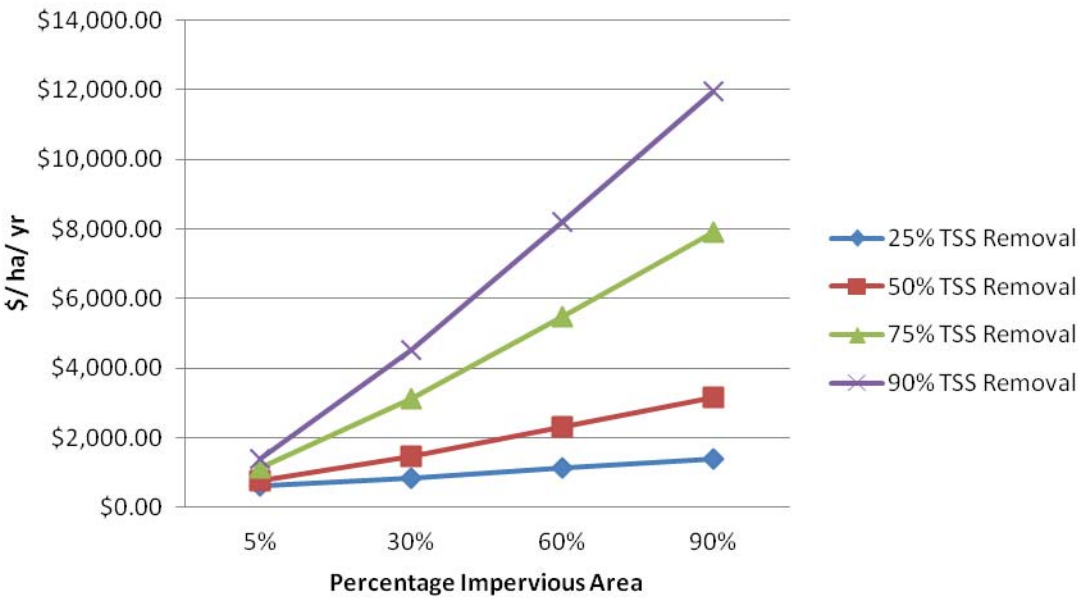


Figure 8. 'At Source': $/ha/yr LCC.

The proportion of cost relating to the design, planning and construction of the 'At Source' scenarios (*i.e.* the TAC) was also determined. It is interesting to note that the proportion of TAC to LCC is far lower in Table 10 than for the 'End of Pipe' scenarios (Table 9). Furthermore, there is a converse relationship between treatment level and TAC percentage, *i.e.* as the level of treatment increases, so the proportion of TAC is reduced. It is likely that the incremental increase in device size, as result of providing a higher level of treatment, is outweighed by the increased cost of maintenance. However, it is recommended that this finding be investigated further to better understand this trend.

Table 10. 'At Source': TAC as a percentage of the LCC

Scenario	25% TSS	50% TSS	75% TSS	90% TSS
At Source TAC Proportion	39.8%	38.2%	34.9%	33.9%

4.4. 'Combination' modelling results

Figures 9 – 12 illustrate the results for the 'Combination' scenarios. As described in Section 2.3.3, 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 costs shown in the figures below.

The graphs highlight 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.

The proportion of cost relating to the design, planning and construction of the 'Combination' scenarios (*i.e.* the TAC) was also determined. As with Table 9, Table 11 shows an increase in the proportion TAC as the level of treatment increases.

Table 11. 'Combination': TAC as a percentage of the LCC.

Scenario	25% TSS	50% TSS	75% TSS	90% TSS
Combination (Wetlands) Average TAC Proportion*	49.1%	57.2%	61.7%	61.3%
Combination (Ponds) Average TAC Proportion*	36.2%	42.7%	47.2%	51.3%
Combination (Wetlands & Ponds) Average TAC Proportion*	43.8%	52.5%	57.6%	59.1%

*Based on half 'At Source' treatment; half 'End of Pipe' treatment.

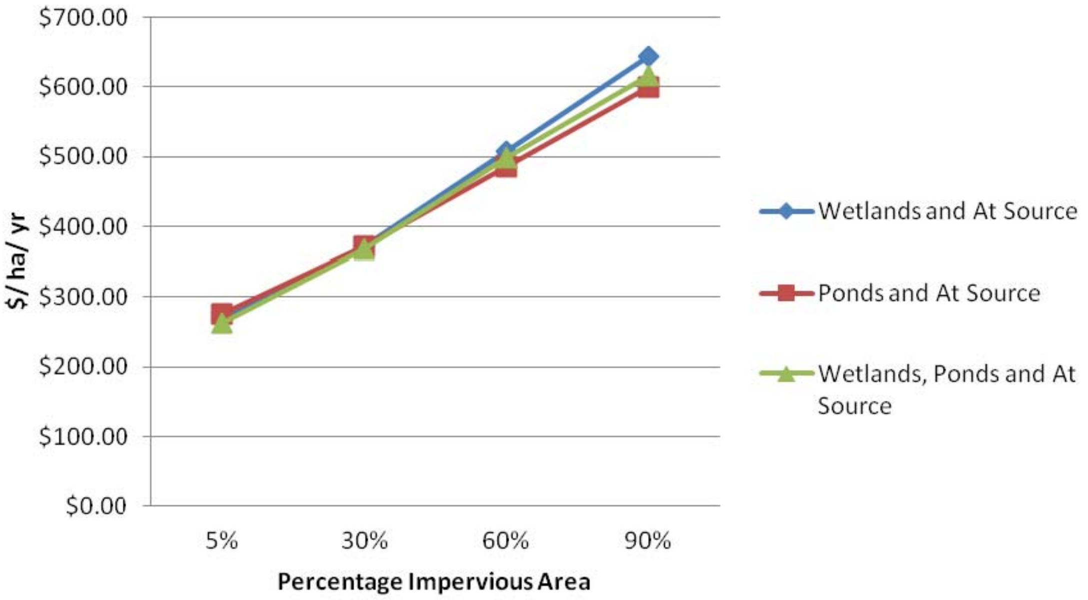


Figure 9. 'Combination' – 25% TSS Removal: $/ha/yr LCC.

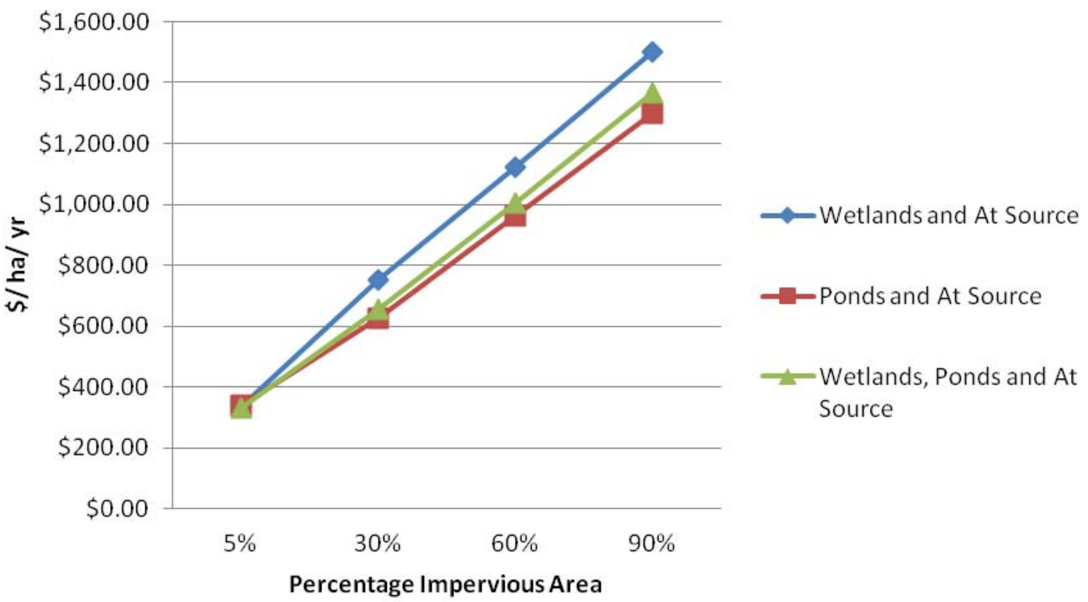


Figure 10. 'Combination' – 50% TSS Removal: $/ha/yr LCC.

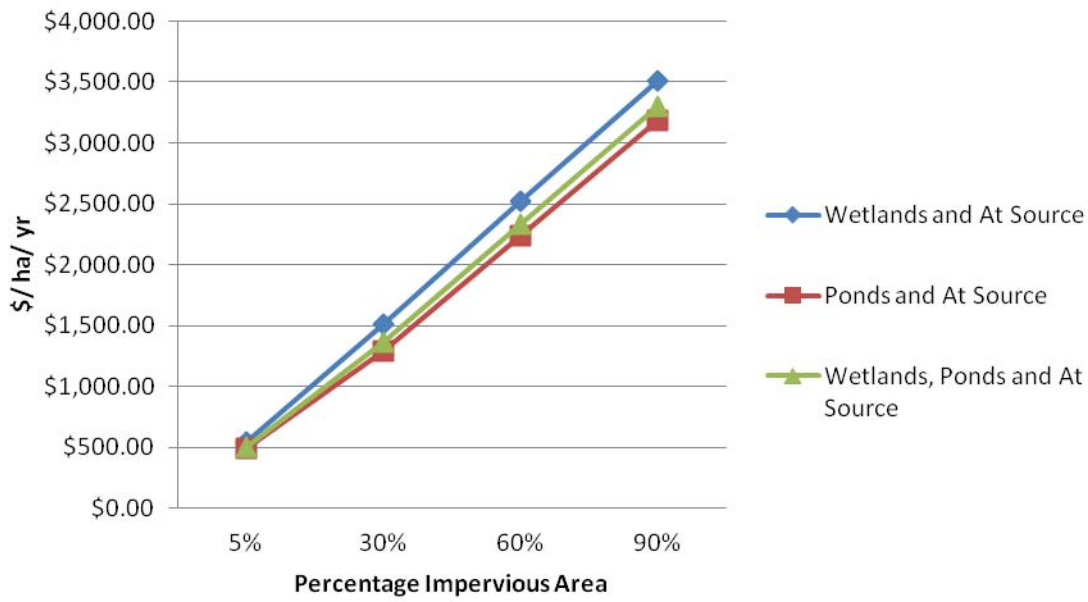


Figure 11. 'Combination' – 75% TSS Removal: $/ha/yr LCC.

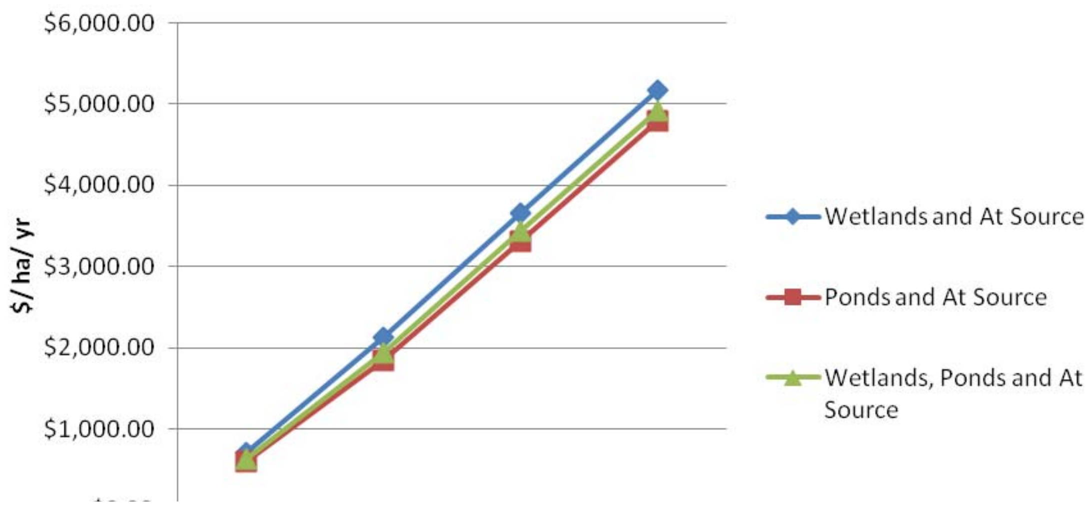


Figure 12. 'Combination' – 90% TSS Removal: $/ha/yr LCC.

4.5. Sensitivity analysis

As mentioned in Section 2.3.1,, a sensitivity analysis was only undertaken for the ‘End of Pipe’ scenarios. Scenarios were created for a theoretical catchment using the average $/ha values generated through the COSTnz modelling work. These $/ha values were then checked against individual COSTnz models, purpose built for each device. The analysis showed that soils and slopes do not influence the overall costs in any significant way. In addition, the cost check found that, for each density and removal efficiency, the mean $/ha values were closely matched (within a $2000/ha range over a 50 year LCC period).

4.6. Land cost factor

COSTnz does not include land costs in the total life cycle analysis. Therefore, in order to generate an accurate catchment-scale LCC, land costs need to be accounted for. As discussed in Section 3.4.4, further modelling work was undertaken in an attempt to determine whether or not a land cost factor could be used to account for land costs in the different types of development scenarios (*i.e.* greenfield *vs.* retrofit development). The resulting land cost factors are shown in Tables 12 and 13 below.

The recommended approach in applying the land cost factor is to firstly use the relevant $/ha/yr cost to determine the total LCC for a particular scenario (as sourced from the graphs), and then multiply the total LCC by the relevant land use factor (see Appendix 6).

Table 12. Land cost factor per hectare – Greenfield catchments.

	25%	50%	75%	90%
Wetlands	0.04	0.07	0.16	0.24
Ponds	0.02	0.04	0.08	0.12
Ponds & Wetlands	0.03	0.05	0.12	0.18
At Source	0.022	0.038	0.052	0.064

Table 13. Land cost factor per hectare – Developed catchments.

	25%	50%	75%	90%
Wetlands	0.08	0.13	0.29	0.41
Ponds	0.04	0.06	0.14	0.21
Ponds & Wetlands	0.06	0.09	0.22	0.31
At Source	0.039	0.067	0.092	0.112

4.7. Implementation of costs

This section describes the way in which the results presented in this report are to be used in the UPSW SDSS. The SDSS will calculate the life cycle cost for any given planning unit (PLU) or for each land use type within a PLU based on the following information:

1. The percentage imperviousness in the PLU, calculated by the SDSS from the land use mix specified by the user as part of defining the urban development option (UDO).
2. The level of stormwater treatment (*i.e.* percentage TSS removal), specified by the user as part of defining the UDO.
3. The effectiveness of stormwater treatment on other contaminants (*e.g.* metals), specified by the user as part of defining the UDO.
4. The type of stormwater treatment (*i.e.* 'End of Pipe'; 'At Source'; 'Combination'), which could be either determined by the SDSS based on the choice of land use or specified by the user as part of defining the UDO.

The values of these four inputs are used to determine the annualised life cycle cost per unit area of catchment ($/ha/yr) by querying a look up table or interpolating between point values held within the SDSS (as graphed in this report in Figures 4 – 12). This $/ha/yr value is used to determine the net present value total LCC by:

5. Multiplying the $/ha/yr value by the PLU area, held within the SDSS, to give the annualised LCC for the whole PLU;
6. Multiplying the $/yr cost generated in Point 5 above by life cycle analysis period, held within the SDSS, to obtain the LCC;
7. Using Tables 9 – 11 to work out the percentage of LCC which is comprised by the TAC.
8. Multiplying the LCC generated in Point 6 above by the land cost factor, held within the SDSS and generated from Tables 12 and 13, and adding this to the LCC to obtain the Total LCC.
9. Discounting the Total LCC, using the discounting methodology held within the SDSS (see Appendix 6), to obtain the NPV Total LCC. It should be noted that land costs will fall within the first year of the life cycle analysis period, whilst the TAC are spread over a period of three years.

Once the NPV Total LCC has been calculated, it can be compared with the economic benefits of a given scenario in order to determine the economic wellbeing indicator.

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

$$EW_{i,j} = \frac{B_{i,j}}{C_{i,j}} \qquad (5)$$

The methodology described above has therefore been developed in order to determine the cost (C) portion of this equation.

5. CONCLUSIONS

5.1. Summary and conclusions

Urban development within New Zealand is contributing to the ecological degradation of coastal and freshwater receiving waters, and the source of this impact is not only the increased volume and rate of stormwater discharges, but also contamination of the receiving environment due to declining water quality. Despite this increasing level of degradation, there is no consistent way of linking stormwater effects and associated mitigation measures to responses in the receiving environment. As a result, local government has identified a need to develop a catchment-scale spatial decision support system (SDSS) to assist in the evaluation of the impacts of urban development. NIWA is leading a programme of research designed to create a SDSS which will link stormwater effects and associated mitigation measures to responses in the receiving environment. The SDSS will provide a platform for the creation of a sustainability indexing system to integrate the measurement of environmental, social, economic and cultural wellbeing.

In order to derive an economic wellbeing indicator the costs and benefits associated with any given urban development scenario need to be compared. This report has focussed on developing the methodology 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.

A number of theoretical stormwater management scenarios were developed, and the assumptions for each scenario are outlined in Section 2.3. Approximately 480 COSTnz model scenarios were run. The assumptions and methodology used in these model runs is described in Section 3, and the models were run for various levels of stormwater treatment and varying percentages of catchment imperviousness. The COSTnz results were analysed and aggregated in order to generate a series of $/ha/yr LCC presented for different types of treatment scenarios, namely 'End of Pipe', 'At Source' and 'Combination stormwater treatment solutions (Sections 4.2 – 4.4).

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 (as described in Section 4.7). 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.

5.2. Further work

As mentioned previously, 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. A life cycle costing analysis of various stream mitigation options would assist in quantifying the cost of stream protection and remediation from stormwater effects. These costs could be included within the SDSS tool in a manner similar to the results of this report.

As mentioned in Section 3.4.1, the costs are only associated with 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 C-CALM or another type of contaminant load model and used for catchment planning purposes.

6. ACKNOWLEDGEMENTS

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7. APPENDICES

Appendix 1. CMP review parameters.

Table 1 - 1. Stormwater Economic Cost Calculator – Hauraki CMP review parameters.

Catchment Name	**Hauraki CMP**
Catchment Size (ha)	61 ha
Catchment Type (greenfields/ brownfields)	Brownfields – 52% impervious
Soils	Waitemata sandstones and mudstones
Topography	Relatively flat, but with low coastal cliffs in the south
Average Slope	Moderate slopes with few valleys
Receiving Environment (Stream)	Mostly piped with 300 m of open stream
Receiving Environment (Estuary)	Shoal Bay
Number of Devices	1
Type of Devices:	
1. Device Name	Harley Close Wetland Retrofit
2. Area Treated	14 ha
3. Design Objectives	32% TSS removal
4. Landuse	70% impervious, Residential and Commercial
5. Cost Information	$220,000
6. Retrofit; online; greenfield	Retrofit
7. Other Considerations	Volume – 230 m^3 TSS Load – 9,005,845 kg/yr = 6 m^3 sediment Cleanout is every 20 years, but mixing with coastal sediment means cleanout should be 5 – 10 yearly
Additional Comments	Review of Harley Close design report to provide further information.

Table 1 - 2. Stormwater Economic Cost Calculator – Takapuna (Shoal Bay) CMP review parameters.

Catchment Name	**Takapuna (Shoal Bay) CMP**
Catchment Size (ha)	82 ha
Catchment Type (greenfields/ brownfields)	Brownfields (49% impervious)
Soils	Fragmented basalts with Waitemata silts and clays
Topography	Relatively flat CBD/ residential area
Average Slope	16 – 18 degrees (moderate slopes)
Receiving Environment (Stream)	12 piped outfalls and two small streams (unnamed)
Receiving Environment (Estuary)	Shoal Bay
Number of Devices	Five retrofit devices (see tables below)
Additional Comments	Construction cost breakdowns are provided and can be used as a check against the COSTnz schedules.

Table 1 - 3. Shoal Bay catchment imperviousness (source: Shoal Bay CMP).

Catchments

Catchment characteristics are summarized as follows:

Catchment	Area(ha)	Pervious(ha)	Impervious(ha)	
Outfall 1	5.5	1.65	3.85	Residential, Area(70% impervious)
Outfall 2	3.26	0.652	2.608	Residential, Road and Commercial (20%impervious)
Outfall 3+4	1.05	0.105	0.945	Commercial Area(Roof + Carpark) (90% impervious)
Outfall 5	0.8	0.08	0.72	Commercial Area(Roof + Carpark) (90% impervious)
Outfall 6	0.7	0.07	0.63	Commercial Area(Roof + Carpark) (90% impervious)
Outfall 7(South)	0.26	0.03	0.234	Commercial Area(Roof + Carpark) (90% impervious)
Outfall 7 (North West)	0.4	0.12	0.28	Commercial Area, Pantoune Reserve(30% impervious)

Table 1 - 4. Proposed stormwater treatment devices and sizing parameters for Shoal Bay (source: Shoal Bay).

Summary

Outfall No	Treatment Device Proposed	TP10 Requirements	Achieved	TSS removal effciency
Outfall 1	Wetland Forebay	WQ volume = 930m3	Wetland Area = 280 m2	52%
Outfall 2	Raingarden	WQ volume = 610m3, Raingarden Area = 1831m2	RG Area = 390 m2	48%
Outfall 3,4	Swale	WQ volume = 215m3, Swale length = 90m	Swale Length =50m	53%
Outfall 5	Wetland	WQ volume = 164m3	Wetland Area = 184 m2	82%
Outfall 6	Dispersal Trench/filter strip	WQ volume = 143m3, filter strip length = 18m	Filter strip length = 3m	44%
Outfall 7 South	Raingarden Based Swale	WQ volume = 53m3, Raingarden area = 160m2	RG Area = 100 m2	65%
Outfall 7 North West	Raingarden Based Swale	WQ volume = 67m3, Raingarden area = 203m2	RG Area = 110 m2	62%

Table 1 - 5 Stormwater Economic Cost Calculator – Acacia Heights (Draft) CMP review parameters.

Catchment Name	**Draft Acacia Heights CMP**
Catchment Size (ha)	470 ha
Catchment Type (greenfields/ brownfields)	Greenfields
Soils	Limestone clays (very erosion prone and potential for tomo formation)
Topography	Hilly with deep, incised gullies
Average Slope	Seven slope classes up to >35 degrees
Receiving Environment (Stream)	Unnamed gullies
Receiving Environment (Estuary)	Lake Taupo (Acacia Bay)
Number of Devices	Actual devices and sizes not provided. Solutions to be onsite solutions (rain gardens; soakage) – no ponds due to potential tomo formation.
Additional Comments	8 – 10 households per hectare. Table 1 of the stormwater report appendix provides information on flows and impervious area breakdowns. No sizing of devices.

Table 1 - 6. Stormwater Economic Cost Calculator – Upper Whangapouri Catchment (Pukekohe North) CMP review parameters.

Catchment Name	**Upper Whangapouri Catchment (Pukekohe North) CMP**
Catchment Size (ha)	16.5 km^2
Catchment Type (greenfields/ brownfields)	Greenfields with small portion of the catchment as existing brownfields Pukekohe township.
Soils	Pukekohe and Patamahoe clay loams
Topography	Western catchment hilly (Pukekohe hill), eastern catchment is undulating.
Average Slope	Not provided.
Receiving Environment (Stream)	Whangapouri Stream
Receiving Environment (Estuary)	n/a
Number of Devices	17 stormwater ponds – mainly to be used for water quantity attenuation (conversion of culverts to provide attenuation storage).
Type of Devices:	
1. Device Name	North Pond
2. Area Treated	Not provided
3. Design Objectives	7175 m^3
4. Landuse	Residential
5. Cost Information	
6. Retrofit; online; greenfield	
7. Other Considerations	
1. Device Name	South Pond
2. Area Treated	Not provided
3. Design Objectives	7175 m^3
4. Landuse	Residential
5. Cost Information	
6. Retrofit; online; greenfield	
7. Other Considerations	
1. Device Name	Jutland St Pond
2. Area Treated	Not provided
3. Design Objectives	30,000 m^3
4. Landuse	Residential
5. Cost Information	
6. Retrofit; online; greenfield	
7. Other Considerations	
Additional Comments	Central residential and commercial Pukekohe township. 56% rural, 30% residential and business, 3% school, 10% roads and rail, and 10% growth area.

Table 1 - 7. Stormwater Economic Cost Calculator – Airport Oaks sub-catchment plan ICMP review parameters.

Catchment Name	**Airport Oaks Sub-catchment Plan**
Catchment Size (ha)	137.5 ha
Catchment Type (greenfields/ brownfields)	Brownfields – fully developed
Soils	Alluvium soils of the Tauranga Group (some gravel, peat and pumice)
Topography	Relatively flat and gently sloping
Average Slope	Around 4%
Receiving Environment (Stream)	Fully piped catchment discharging to the Oruarangi Stream
Receiving Environment (Estuary)	Manukau Harbour
Number of Devices	Three options as part of the BPO
Type of Devices:	
1. Device Name	Option 1 (Jetpark Wetland)
2. Area Treated	18.5 ha
3. Design Objectives	75% TSS removal
4. Landuse	Residential catchment
5. Cost Information	NPV LCC $880,603.37
6. Retrofit; online; greenfield	Greenfield
7. Other Considerations	Has a separate open water forebay to capture gross sediments
1. Device Name	Option 2 (Wetland swale)
2. Area Treated	137.5 ha
3. Design Objectives	31%TSS removal
4. Landuse	Commercial and Residential
5. Cost Information	NPV LCC $2,334,807.71
6. Retrofit; online; greenfield	Retrofit and online
7. Other Considerations	Cost includes land purchase
1. Device Name	Option 5a (Montgomery Road Wetland)
2. Area Treated	137.5 ha
3. Design Objectives	41% TSS removal
4. Landuse	Commercial and Residential
5. Cost Information	NPV LCC $4,293,783.64
6. Retrofit; online; greenfield	Offline
7. Other Considerations	Cost includes land purchase
	SEE FIGURE 2
Additional Comments	CMP is a draft, but have obtained Council permission for use. Likely BPO is provided by the above three options and provides a good indicator of different treatment efficiencies in a brownfields catchment

Table 1 - 8. Stormwater Economic Cost Calculator – Orewa West CMP review parameters.

Catchment Name	**Orewa West CMP**
Catchment Size (ha)	223 ha [NDC/ Planning area only]
Catchment Type (greenfields/ brownfields)	Greenfields
Soils	Onerahi Chaos/ Breccia (highly unstable)
Topography	Steep with short incised gullies
Average Slope	14% (upper catchment); 3.4% (lower catchment)
Receiving Environment (Stream)	West Hoe Stream, Unnamed Tributary; Southern Stream
Receiving Environment (Estuary)	Orewa Estuary
Number of Devices	10 ponds, one stormfilter (no data for the stormfilter)
Type of Devices:	
1. Device Name	Devices included in table below.
2. Area Treated	
3. Design Objectives	75% TSS removal
4. Landuse	Residential
5. Cost Information	None
6. Retrofit; online; greenfield	Greenfield
7. Other Considerations	Ponds A – D have approx. 3 – 4% contributing slope.
	SEE FIGURE 3
Additional Comments	Average depth of ponds 0.5 – 2m in depth - deeper ponds tend to have smaller surfaces areas (therefore can affect cost). In addition, steeper slopes generally mean deeper ponds. Investigate through sensitivity analysis.

Table 1 - 9. Summary of the catchment areas and water quality volumes for each proposed pond/ wetland within Orewa West (source: Orewa West CMP).

TABLE 7.3: POND/ WETLAND WATER QUALITY VOLUMES

Pond/ Wetland Name	Catchments Treated	Catchment Area[a] (ha)	Water Quality Volume (m^3)
A	15A (undeveloped portion), 15B, 15C (part)	17.38	3398
B	15C, 15E (part)	5.94	1280
C	15D (part)	15.66	3061
D	15D (part)	15.63	3055
E	15I and 15F (part)	7.29	1072
F	15G	5.55	729
G	15J	12.3	1547
H	15K	13.51	1986
14A	14A	3.13	495
15E	15E and 15G (part)	9.98	1467

a. Data for southern catchments from (Woods, 2009)

Table 1 - 10. Stormwater Economic Cost Calculator – Hobsonville Pennisula CMP review parameters.

Catchment Name	**Hobsonville Peninsula CMP**
Catchment Size (ha)	177 ha [NDC/ planning area only]
Catchment Type (greenfields/ brownfields)	Mixed
Soils	Alluvium, C1 soils – Waitamata Clays
Topography	Localised steep gully areas, but otherwise generally flat
Average Slope	0 – 11 degrees
Receiving Environment (Stream)	Three main unnamed tributaries which discharge to the 3 main bays: Catalina Bay, Bombay Inlet, Nimrod Inlet
Receiving Environment (Estuary)	Upper Waitamata Harbour
Number of Devices	Four wetlands
Type of Devices:	
1. Device Name	W1
2. Area Treated	24 ha impervious, 11 ha pervious
3. Design Objectives	75% TSS removal (6375 m^3 WQV)
4. Landuse	Medium Density Residential
5. Cost Information	Provided – Table 11.9 (see below)
6. Retrofit; online; greenfield	Online
7. Other Considerations	
1. Device Name	W2
2. Area Treated	5 ha impervious, 3 ha pervious
3. Design Objectives	75% TSS removal (1274 m^3 WQV)
4. Landuse	Medium Density Residential
5. Cost Information	Provided – Table 11.9 (see below)
6. Retrofit; online; greenfield	Online
7. Other Considerations	
1. Device Name	W3
2. Area Treated	23 ha impervious, 10 ha pervious
3. Design Objectives	75% TSS removal (6097 m^3 WQV)
4. Landuse	Medium Density Residential
5. Cost Information	Provided – Table 11.9 (see below)
6. Retrofit; online; greenfield	Online
7. Other Considerations	
1. Device Name	W4
2. Area Treated	13 ha impervious, 6 ha pervious
3. Design Objectives	75% TSS removal (3529 m^3 WQV)
4. Landuse	Town centre
5. Cost Information	Provided – Table 11.9 (see below)
6. Retrofit; online; greenfield	Online
7. Other Considerations	
	SEE FIGURE 1
Additional Comments	PC13: airbase and rural to industrial, commercial and

Catchment Name	Hobsonville Peninsula CMP
	residential. Two schools. Future impervious area is 73% of 177 ha (current is 9%) Use of proprietary devices for industrial areas (rain gardens (sub-catchments B, C, D & J) and stormfilters

Option	Description	Wetland Treatment	Dry Detention	Total Wetland WQV Volume and/or Dry detention m3	Land Required (ha)	Storage Construction Cost ($)	Proprietry Construction Cost ($)	LID Construction Cost ($)	Total
Option 3	Construction of wetlands W1- W2-W5-W6. Proprietry devices all other areas. Dry detention at W4.	W1-W2-W5-W6	W4	14868	4.66	2,358,500	8,850,000	0	11,208,500
Option 4	Treatment by wetlands W1, W2 and W5 - remainder of industrial catchment by proprietry and residential by LID	W1-W2-W5	W4	23030	2.50	3,378,750	3,600,000	4,080,000	11,058,750
Option 4a	Treatment by wetlands W1, W2 and W5 - remainder of industrial catchment by proprietry and residential by LID, dry detention of EDV in basins W4 and W6	W1-W2-W5	W4, W6	26530	2.85	4,253,750	3,600,000	4,080,000	11,933,750

Assumptions :

1. Plan Change Area 177 ha
2. W1, W2 ,W6 and W5 catchments 59 ha
3. Proprietry (Option 3) 118 ha
4. W4 Dry Detention 4000 m3
5. W6 Dry Detention 3500 m3
6. LID (Option 4) 68 ha
7. Proprietry (Option 4) 48 ha
8. Land area for wetland based on 0.5 m depth and 1.5 times pond surface area
9. Storage construction cost 125 per/m3
10. Proprietry devices cost 75000 per/ha
11. LID construction 60000 per/ha
12. Costs are indicative only and subject to confirmation by detailed design and costing
13. Land purchase cost not included for any treatment devices including wetlands
14. Rain water tank cost not included
15. Excludes stream enhancement/riparian planting costs

Figure 1 - 1. Option indicative costs estimates.

43

Appendix 2. Catchment maps.

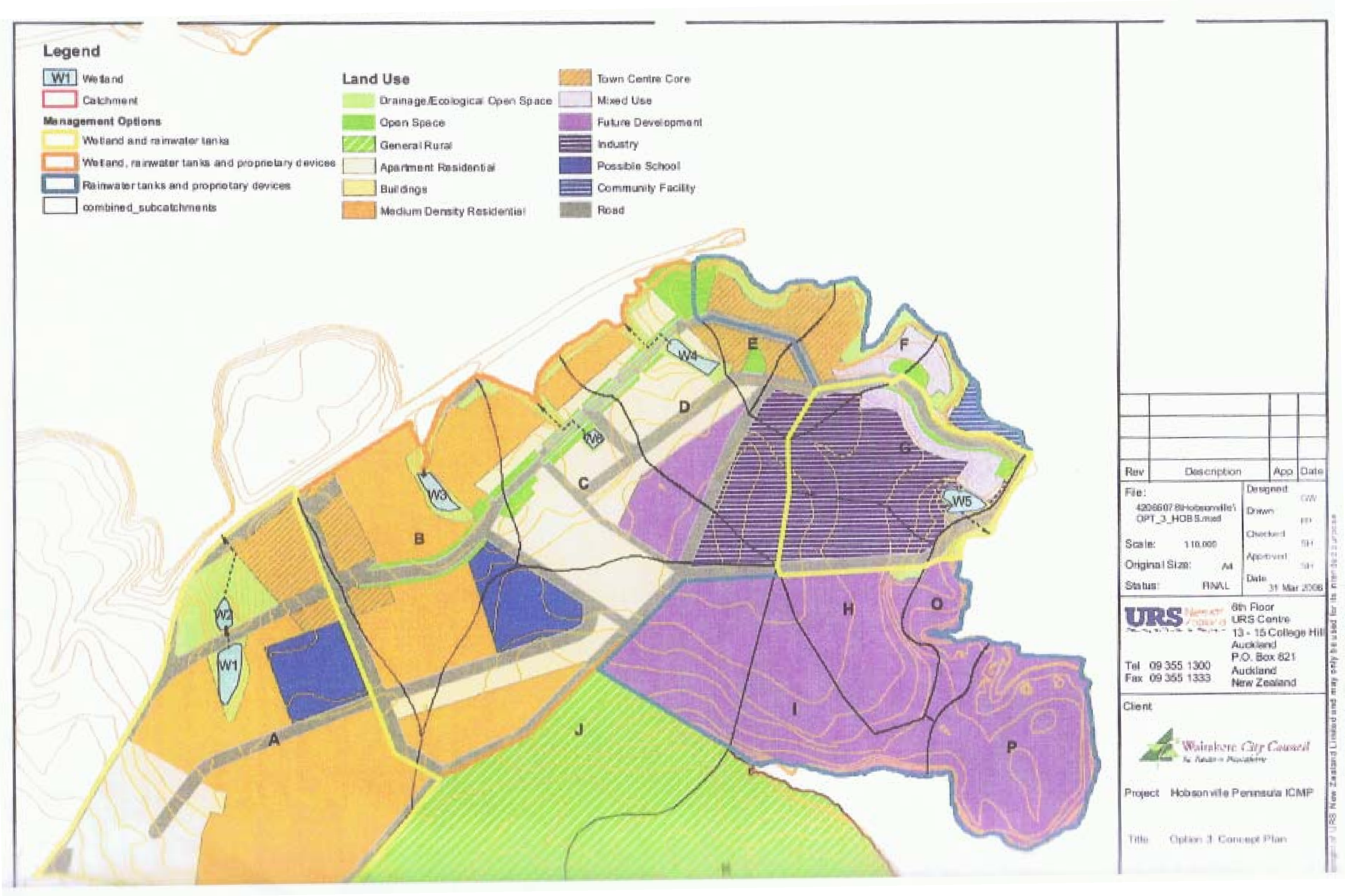

Figure 2 - 1. Hobsonville catchment.

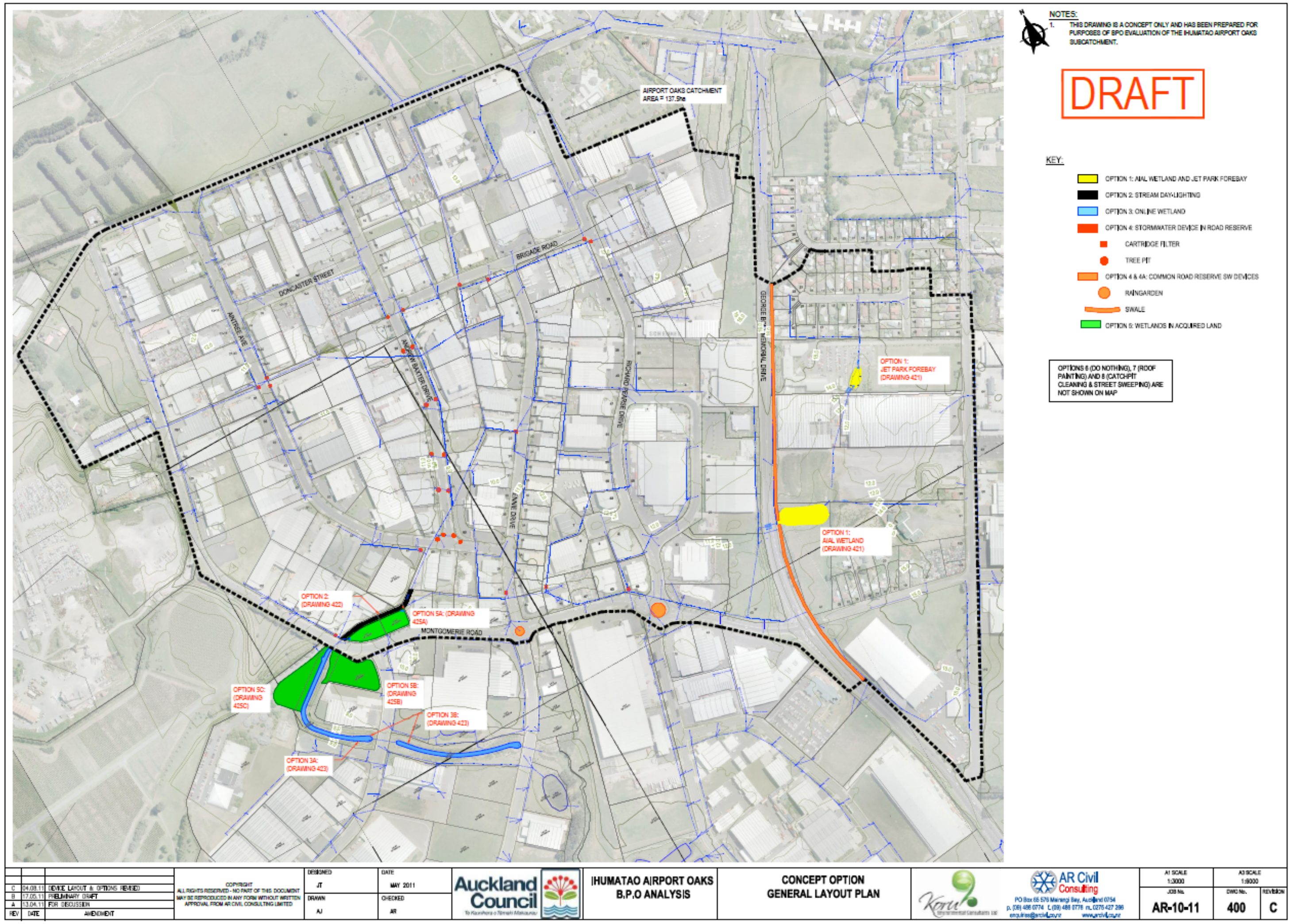

Figure 2 -2. Airport Oaks sub-catchment.

45

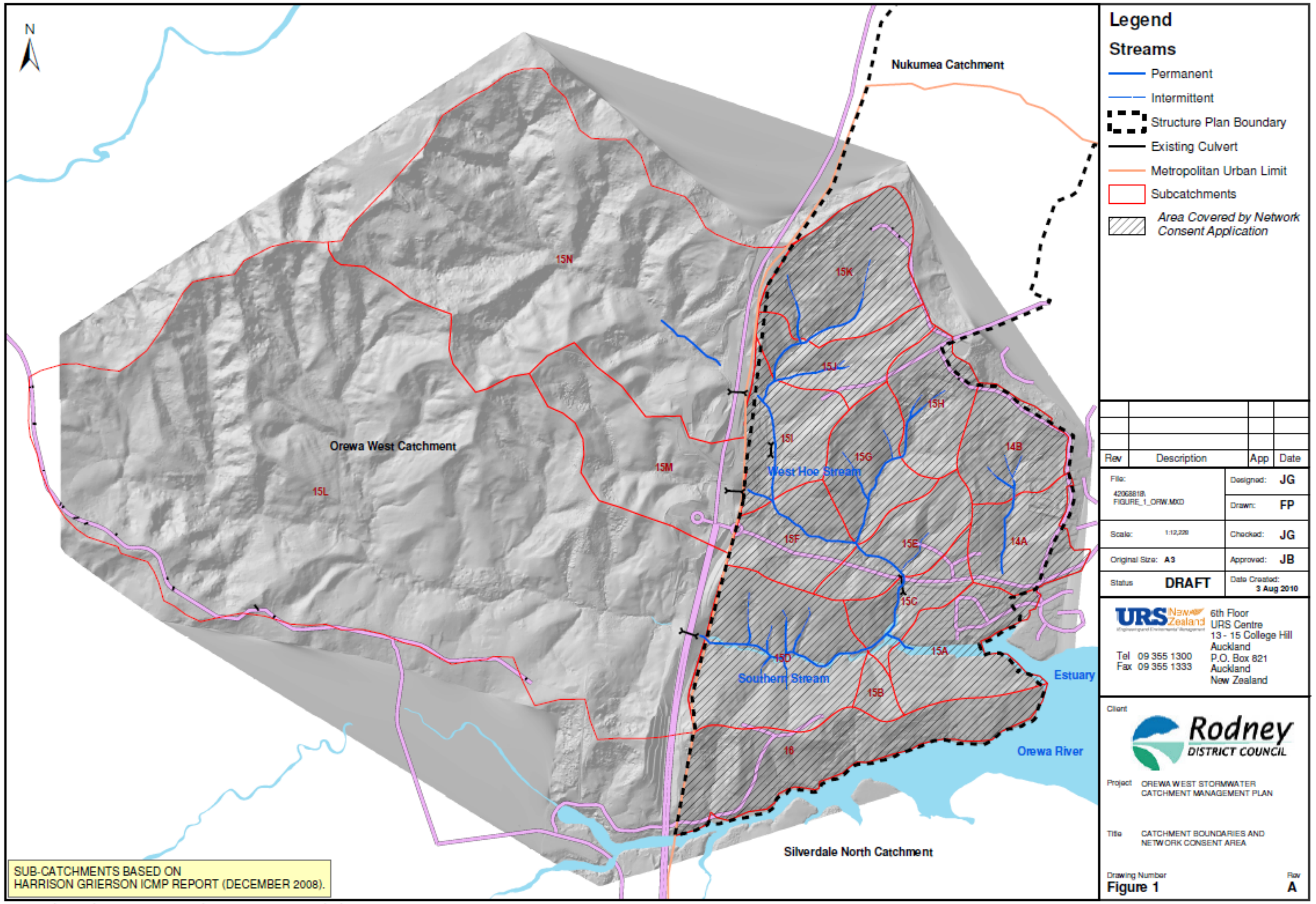

Figure 2 – 3. Orewa West catchment.

Appendix 3. Literature review.

Summary of literature review

Bastien N, Arthur S, Wallis S, Scholz M. (2010) Water Science & Technology. 61.1. The best management of SuDS treatment trains: a holistic approach. [Scotland]

- A comparison of the potential performance and effectiveness of end of pipe solutions *vs.* on-site management. Life cycle costs are determined over a 50 year period. SuDS in series can provide significant pollutant benefits. The issue of cost is not directly answered, however they state that when attenuation is required, ponds and wetlands are the most cost effective solutions. Discount rate of 3.5% and 3% is used.

Davis BS, Birch GF. (2009) Environmental Science and Policy. 12: 84 -91. Catchment-wide assessment of the cost effectiveness of stormwater remediation measures in urban areas. [Australia]

- Investigation of the cost effectiveness of catchment-wide funding for contaminant removal within a major metropolitan catchment in Sydney. Paper focuses on funding allocation per different type of treatment device and compares this to contaminants removed.

Duffy A, Jefferies C, Waddell G, Shanks G, Blackwood D, Watkins A. (2008) Water Science & Technology. 59.7. A cost comparison of traditional drainage and SUDS in Scotland.

- A robust whole of life cycle cost analysis of a mixed use development near the ancient city of Dunfermline. SUDS in this case is taken to be infiltration and underground storage. Interesting categorisation of maintenance frequencies:

    - Low/ Minimum: basic level of maintenance required to maintain to desired function.
    - Medium: level required to maintain both desired function and appearance.
    - High: enhanced maintenance regime driven by appearance and amenity.
      [suggest that COSTnz models be built to require a 'medium' level of maintenance]. It is noted that the frequencies provided in the paper are similar to those set in COSTnz. Land costs are excluded. Paper found that traditional drainage maintenance costs are 20 – 25% greater.

Elliot AH, Trowsdale SA. (2006) Environmental Modelling and Software. 22: 394 – 405. A review of models for low impact urban stormwater drainage.

- Discusses different parameters for stormwater models/ pollutant removal and ability of models to assess LID performance.

Erickson AJ, Gulliver JS, Kang J-H, Weiss PT, Wilson CB. (2010). Journal of Contemporary Water Research and Education. 146: 75-82. Maintenance for Stormwater Treatment Practices. [United States of America]

- To determine and define the key parameters of maintenance, as well as the frequencies of maintenance. Maintenance types and classifications similar to COSTnz (non-routine and routine), and routine maintenance also occurred once or more per year.

Farreny R, Gabarrell X, Rieradevall J. (2011) Resources, Conservation and Recycling. 55:686 – 694. Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. [Spain]

- No further costing ‘lessons’ learnt from this paper. Rainwater tanks are not included in this project.

Dasch Houdeshel D, Pomeroy CA, Hair L, Moeller PE. (2011). Journal of Irrigation and Drainage Engineering. Cost-estimating tools for low impact development best management practices: challenges, limitations and implications. [United Kingdom]

- Description of a unit-based costing approach to life cycle costing. Very similar to the COSTnz model. Paper highlights the difficulties of obtaining cost data and the electives in design assumptions and personal choice (*e.g.* construction methodology, maintenance regime) affecting cost. Useful paper for describing limitations of the approach.

Ira SJT. (2009) Quantifying the costs of low impact design in New Zealand. Report prepared for Aqua Terra International for inclusion in the Tauranga City Council Stormwater Manual.

- A detailed literature review of national and international stormwater costing data/ papers to assess the current state of knowledge (hence the focus of this literature review on post 2008 papers). LID construction costs show considerable savings, however, not enough data exists surrounding maintenance costs. Where available, national and international costs are provided per device or per LID practice (e.g. reducing impervious areas). Cost comparisons were provided, but these are based on a subdivision scale. The three NZ examples can be used as a ‘cost check’.

Ira SJT, Vesely E-T, Krausse M. (2008) 11th International Conference on Urban Drainage, Edinburgh. Life Cycle Costing of Stormwater Treatment Devices: A Practical Approach for New Zealand.

- An explanation of the COSTnz data collection process, methodology and model structure.

Koru Environmental Consultants Ltd. (2009) COSTnz (Version 1) User Manual. Prepared on behalf of Landcare Research.

- An explanation of assumptions used in the COSTnz models will be taken from the User model (for example, discount rate, inflation rate, explanation of TAC, RMC, CMC, etc). The current literature review has not highlighted any new information which invalidates the current COSTnz assumptions.
    - Discount rate: 3.5%
    - Inflation rate: 2.8% (this is consistent with the average annual inflation rate provided by the Reserve Bank of New Zealand - http://www.rbnz.govt.nz/statistics)
    - Base year for cost data 2007 (however, using the above inflation rate costs will be inflated to 2011 values so the base year for the economic cost calculator will be 2011).
    - Life span: max allowed in the proof of concept model = 50 years

Riley AL. (2009) Putting a price on riparian corridors as water treatment facilities. Regional Water Quality Control Board - Watershed and River Restoration, San Francisco Bay.

- Comparison of costs of stormwater treatment using 'man-made' systems *vs*. naturally occurring systems. Potentially useful for the stream costs portion of the project.

Wossink A, Hunt B. (2003) University of North Carolina – Water Resources Research Institute. Project No. 50260. The economics of structure stormwater BMPs in North Carolina.

- A 'Present Value of Costs' approach was used to assess construction, land and maintenance costs. Annual costs were related to the area treated and to the removal effectiveness of the specific BMP. All BMPs displayed economies of scale and large differences in cost were found between the different BMPs. Wetlands are the least expensive device for over 10 acres, and bioretention (rain gardens) the most economical up to about six acres, followed by wet ponds for mid-sized watersheds. No statistically significant relationships could be assessed between removal efficiency and watershed size. Interesting discussion on land opportunity costs. Discount rate of 10% was used.

Additional information obtained or technical publications reviewed include:

- Auckland Council Catchment Management Planning Dept. – cost summaries for stormwater improvement works have been obtained from Auckland Council and can be used as a 'check' against some of the COSTnz model results.
- Auckland Regional Council. (2003) Technical Publication 10: Stormwater Management Devices: Design Guideline Manual.
- New Zealand Transport Authority. (2010) Stormwater Treatment Standard for Highway Infrastructure.
- Wong THF, Breen PF, Lloyd SD. 2000. Water Sensitive Road Design – Design Options for Improving Stormwater Quality Road Runoff. Cooperative Research Centre for Catchment Hydrology.

Appendix 4. Tabular results $/ha life cycle costs (LCC) for each scenario.

Table 4 – 1. NPV 'End of Pipe' scenario.

Scenarios	5%	30%	60%	90%	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv
	25% TSS Removal				50% TSS Removal				75% TSS Removal				90% TSS Removal			
WETLANDS: Mean $/ha LCC over 50 yrs	$3,540.39	$5,616.97	$10,486.46	$15,146.79	$5,070.21	$30,096.91	$38,375.93	$46,743.97	$16,682.98	$52,089.64	$66,318.32	$75,067.98	$27,445.69	$63,451.56	$78,033.74	$87,068.54
WETLANDS: Mean $/ ha/yr	$70.81	$112.34	$209.73	$302.94	$101.40	$601.94	$767.52	$934.88	$333.66	$1,041.79	$1,326.37	$1,501.36	$548.91	$1,269.03	$1,560.67	$1,741.37
PONDS: Mean $/ha LCC over 50 yrs	$4,141.43	$4,707.50	$5,658.97	$6,394.76	$4,654.71	$7,148.87	$9,059.29	$10,511.44	$6,242.21	$11,186.28	$14,478.56	$17,089.55	$8,124.55	$14,326.42	$18,417.52	$21,216.50
PONDS: Mean $/ ha/yr	$82.83	$94.15	$113.18	$127.90	$93.09	$142.98	$181.19	$210.23	$124.84	$223.73	$289.57	$341.79	$162.49	$286.53	$368.35	$424.33
WETLANDS & PONDS: Mean $/ha LCC over 50 yrs	$3,125.35	$5,368.92	$9,336.84	$10,763.13	$4,753.07	$13,708.45	$18,087.85	$23,329.62	$10,901.63	$25,608.39	$32,812.62	$37,823.90	$14,804.05	$31,252.32	$39,505.44	$45,224.45
WETLANDS & PONDS: Mean $/ ha/yr	$62.51	$107.38	$186.74	$215.26	$95.06	$274.17	$361.76	$466.59	$218.03	$512.17	$656.25	$756.48	$296.08	$625.05	$790.11	$904.49

Table 4 –2. NPV 'At Source' scenario.

Scenarios	5%	30%	60%	90%	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv
	25% TSS Removal				50% TSS Removal				75% TSS Removal				90% TSS Removal			
AT SOURCE: Mean $/ha LCC over 50 yrs	$18,545.10	$28,695.14	$40,501.52	$52,643.06	$24,335.63	$49,200.80	$78,211.24	$107,942.28	$36,042.82	$96,061.01	$167,346.12	$239,647.89	$44,008.09	$130,701.15	$232,476.11	$336,118.72
AT SOURCE: Mean $/ ha/yr	$370.90	$573.90	$810.03	$1,052.86	$486.71	$984.02	$1,564.22	$2,158.85	$720.86	$1,921.22	$3,346.92	$4,792.96	$880.16	$2,614.02	$4,649.52	$6,722.37

Table 4 –3. NPV 'Combination' scenario.

Scenarios	5%	30%	60%	90%	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv	5% Imperv	30% Imperv	60% Imperv	90% Imperv
	25% TSS Removal				50% TSS Removal				75% TSS Removal				90% TSS Removal			
AT + WETLANDS: Mean $/ha LCC over 50 yrs	$8,195.42	$12,719.49	$18,663.50	$24,679.74	$10,872.25	$27,493.90	$41,075.46	$54,961.99	$18,650.82	$51,826.40	$83,500.80	$114,048.62	$24,738.06	$68,453.66	$112,083.42	$154,898.54
AT + WETLANDS: Mean $/ ha/yr	$163.91	$254.39	$373.27	$493.59	$217.44	$549.88	$821.51	$1,099.24	$373.02	$1,036.53	$1,670.02	$2,280.97	$494.76	$1,369.07	$2,241.67	$3,097.97
AT + PONDS: Mean $/ha LCC over 50 yrs	$8,362.38	$12,466.86	$17,322.53	$22,248.62	$10,756.83	$21,119.44	$32,931.95	$44,897.40	$15,750.60	$40,464.36	$69,100.87	$97,943.50	$19,371.08	$54,807.79	$95,523.35	$136,606.31
AT + PONDS: Mean $/ ha/yr	$167.25	$249.34	$346.45	$444.97	$215.14	$422.39	$658.64	$897.95	$315.01	$809.29	$1,382.02	$1,958.87	$387.42	$1,096.16	$1,910.47	$2,732.13
AT + WETLANDS & PONDS: Mean $/ha LCC over 50 yrs	$8,080.13	$12,650.59	$18,344.16	$23,462.06	$10,784.15	$22,941.55	$35,439.89	$48,458.00	$17,044.88	$44,470.50	$74,193.66	$103,703.04	$21,226.49	$59,509.43	$101,381.11	$143,275.18
AT + WETLANDS & PONDS: Mean $/ ha/yr	$161.60	$253.01	$366.88	$469.24	$215.68	$458.83	$708.80	$969.16	$340.90	$889.41	$1,483.87	$2,074.06	$424.53	$1,190.19	$2,027.62	$2,865.50

Table 4 –4. Land cost factors per hectare.

Greenfield Catchments				
	25%	50%	75%	90%
Wetlands	0.04	0.07	0.16	0.24
Ponds	0.02	0.04	0.08	0.12
Ponds & Wetlands	0.03	0.05	0.12	0.18
At Source**	0.022	0.038	0.052	0.064
Re-development				
	25%	50%	75%	90%
Wetlands	0.08	0.13	0.29	0.41
Ponds	0.04	0.06	0.14	0.21
Ponds & Wetlands	0.06	0.09	0.22	0.31
At Source**	0.039	0.067	0.092	0.112

** Note: to apply the landuse factor work out the total LCC for the whole catchment, then muliply that by the factor and add the answer to the LCC.*

*** When scenario is "combination" apply at source factor to half the catchment and end of pipe factor to the remaining half.*

Appendix 5. Net present value (NPV) graphical results.

Net present value (NPV) graphical results – ‘End of Pipe’ scenarios.

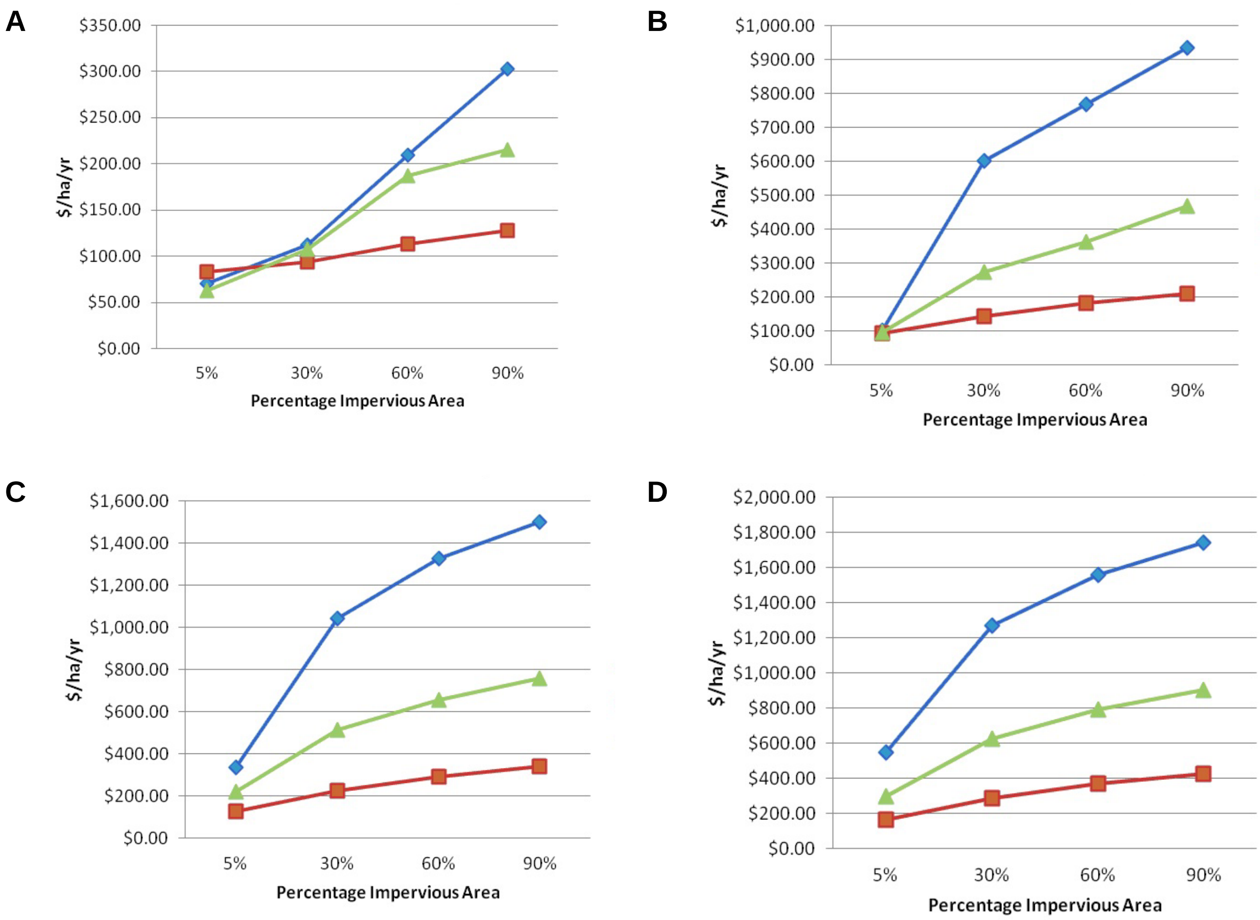

Figure 5 - 1. ‘End of Pipe’ scenario – (A) 25% (B) 50% (C) 75% (C) 90% TSS Removal: NPV $/ha/yr/ LCC. Note: Axes are as follows: ponds (red), wetland and ponds (green) and wetlands (blue).

Net present value (NPV) graphical results – ‘Combination’ scenarios.

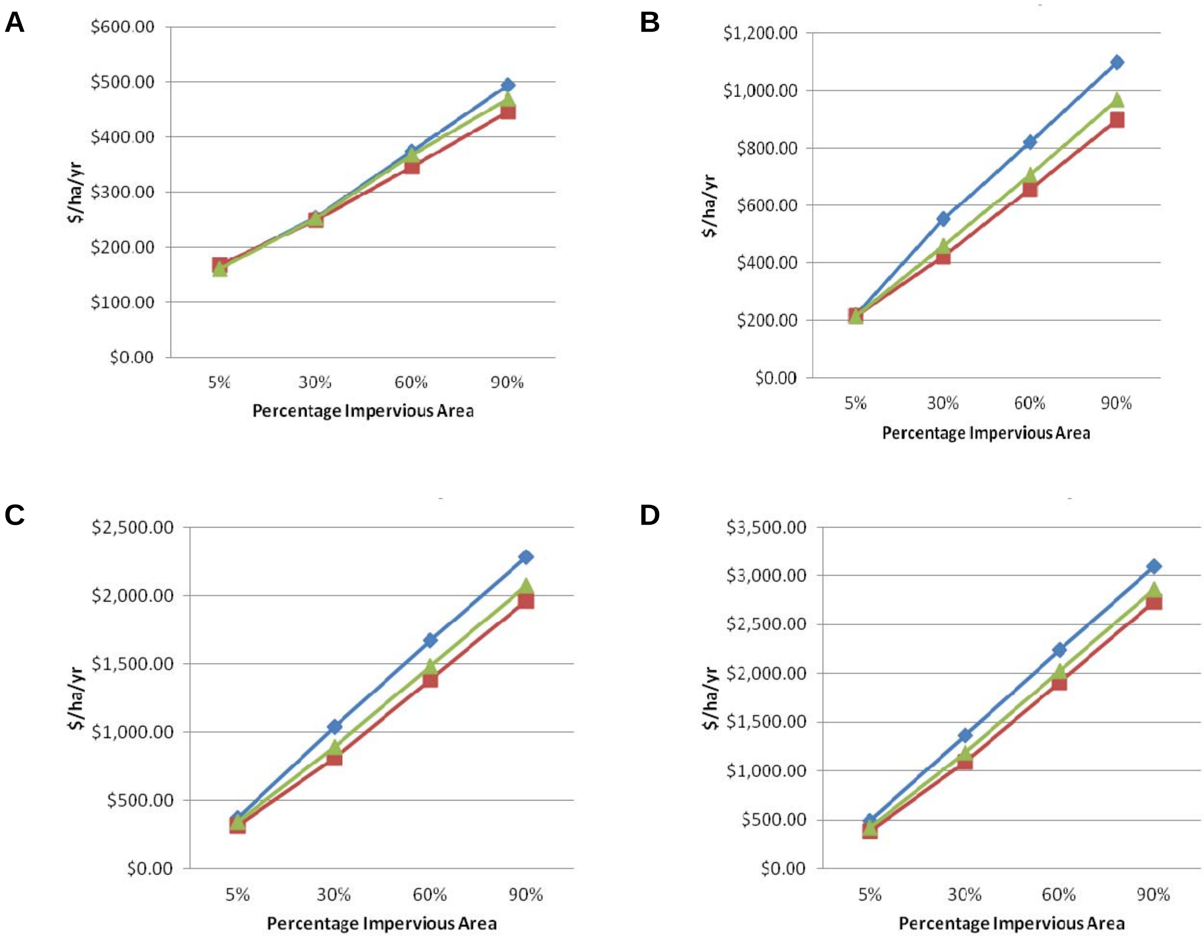

Figure 5 - 2. ‘Combination’ scenario – (A) 25% (B) 50% (C) 75% (C) 90% TSS Removal: NPV $/ha/yr/ LCC. Note: Axes are as follows: ‘At Source’ and ponds (red), ‘At Source’, wetlands and ponds (green) and ‘At Source’ and wetlands (blue).

Net present value (NPV) graphical results – 'At Source' scenarios.

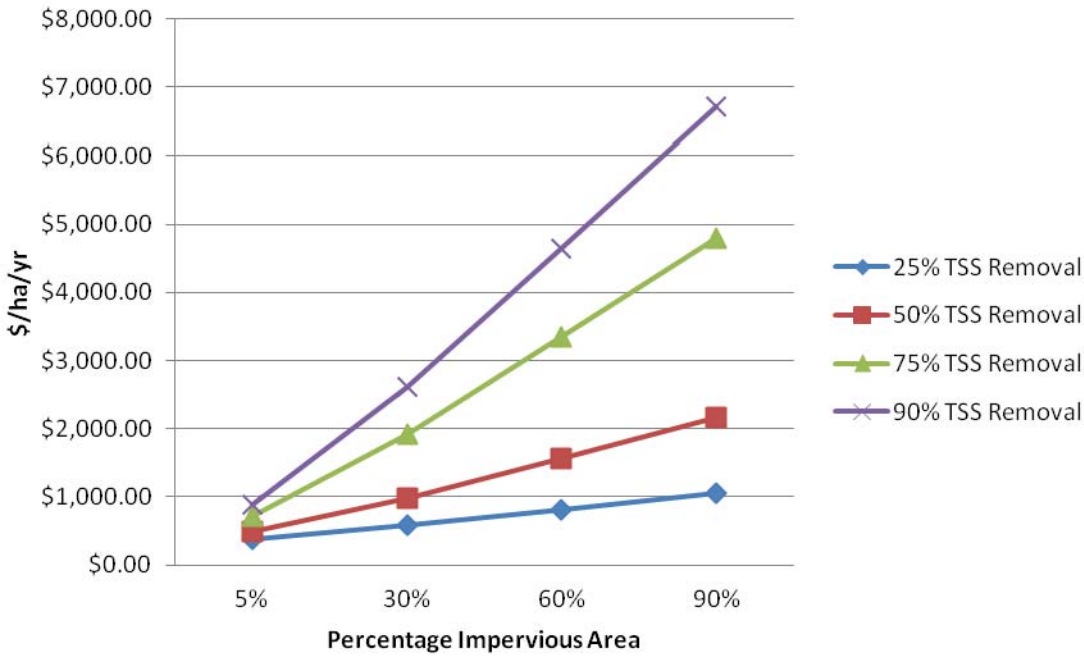

Figure 5 - 3. 'At Source' scenario - TSS Removal: NPV $/ha/yr/ LCC.

Appendix 6. Discounting spreadsheet.

METHODOLOGY TO DETERMINE THE CATCHMENT NPV
(Steps 5 - 8 in Section 4.7 of the Main Report)

Only complete those cells shaded in green:

Discount Rate:	3.50%

Relevant $/ ha/ yr value	$500.00	(From Figures 4 - 12)
Life Cycle Analysis Period (yrs)	50	
PLU Size (ha)	23	
Annualised Life Cycle Cost	$11,500.00	
Life Cycle Cost (LCC)	$575,000.00	
TAC Ratio	32%	(From Tables 9 - 11)
TAC Cost	$184,000.00	
TAC $/ha/yr	$61,333.33	
Maintenance $/ha/yr	$8,319.15	
Land Cost Ratio	0.04	(From Tables 12 & 13)
Land Cost	$23,000.00	
Total Life Cycle Cost	$598,000.00	

Year	LAND COSTS	ANNUALISED LCC	
		Undiscounted Costs	NPV
0			
1	$23,000.00	$84,333.33	$82,895.14
2		$61,333.33	$59,259.26
3		$61,333.33	$57,255.32
4		$8,319.15	$7,503.40
5		$8,319.15	$7,249.66
6		$8,319.15	$7,004.50
7		$8,319.15	$6,767.63
8		$8,319.15	$6,538.78
9		$8,319.15	$6,317.66
10		$8,319.15	$6,104.02
11		$8,319.15	$5,897.60
12		$8,319.15	$5,698.17
13		$8,319.15	$5,505.47
14		$8,319.15	$5,319.30
15		$8,319.15	$5,139.42
16		$8,319.15	$4,965.62
17		$8,319.15	$4,797.70
18		$8,319.15	$4,635.46
19		$8,319.15	$4,478.71
20		$8,319.15	$4,327.25
21		$8,319.15	$4,180.92
22		$8,319.15	$4,039.54
23		$8,319.15	$3,902.93
24		$8,319.15	$3,770.95
25		$8,319.15	$3,643.43

26		$8,319.15	$3,520.22
27		$8,319.15	$3,401.18
28		$8,319.15	$3,286.17
29		$8,319.15	$3,175.04
30		$8,319.15	$3,067.67
31		$8,319.15	$2,963.93
32		$8,319.15	$2,863.70
33		$8,319.15	$2,766.86
34		$8,319.15	$2,673.30
35		$8,319.15	$2,582.90
36		$8,319.15	$2,495.55
37		$8,319.15	$2,411.16
38		$8,319.15	$2,329.62
39		$8,319.15	$2,250.85
40		$8,319.15	$2,174.73
41		$8,319.15	$2,101.19
42		$8,319.15	$2,030.13
43		$8,319.15	$1,961.48
44		$8,319.15	$1,895.15
45		$8,319.15	$1,831.06
46		$8,319.15	$1,769.14
47		$8,319.15	$1,709.32
48		$8,319.15	$1,651.51
49		$8,319.15	$1,595.67
50		$8,319.15	$1,541.71
TOTAL	$23,000.00	$598,000.00	$377,247.09

CHECK: Total LCC	$598,000.00	**OK**
CHECK: NPV LCC	$377,247.09	**OK**

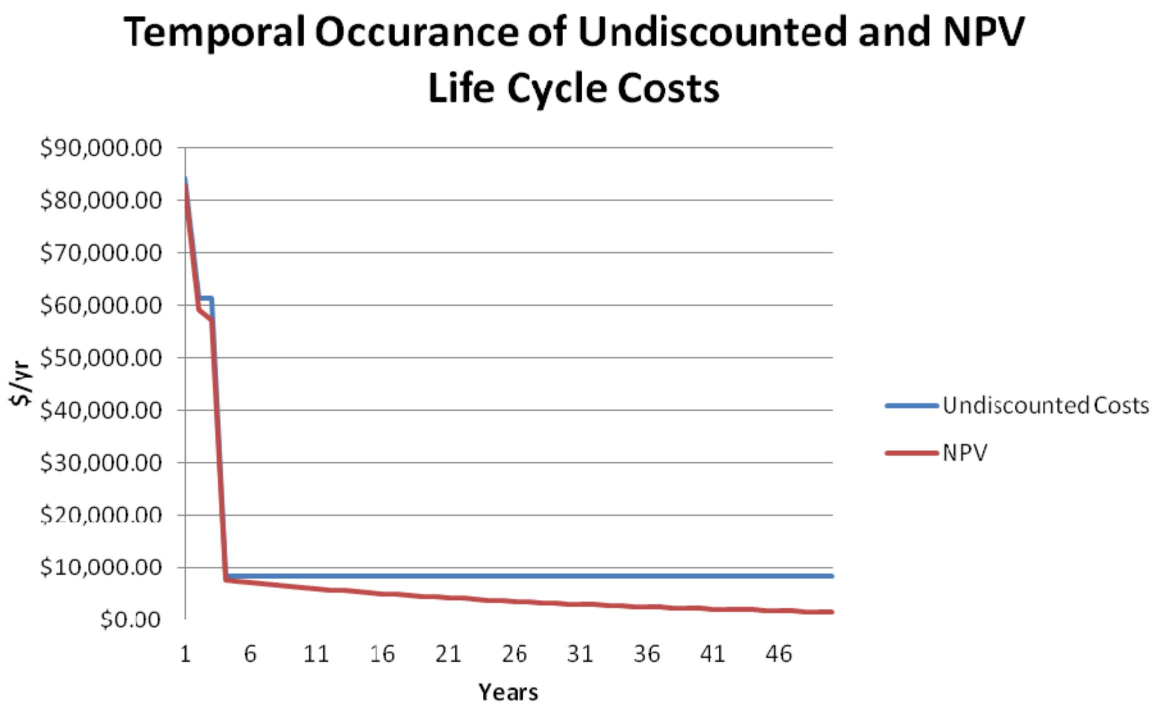

Figure 6 – 1. Time series of life cycle costs contrasting annual discounted (NPV) with undiscounted costs.

Figure 6 - 1 provides an indication of the distribution of life cycle costs over a 50 year period for the hypothetical costing example illustrated within the discounting spreadsheet. The discounting spreadsheet distinguishes between the distribution of total acquisition costs (shown as the spike in this graph from years 1 – 3) and maintenance costs. At present, the methodology provides an average %/ha/yr maintenance cost. Further work needs to be undertaken to determine a temporal distribution of actual maintenance costs over time.