COST IMPLICATIONS OF ADAPTING STORMWATER MANAGEMENT DEVICES TO CLIMATE CHANGE

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ABSTRACT

Low impact stormwater management devices for stormwater treatment are increasingly common elements in the urban landscape around the world. Their use has been suggested as a means of adaptation in areas with projected increases in the intensity and frequency of extreme rainfall. However, there is little advice on how to design these devices for climate change and the costs involved. This point is important as the perceived cost is often a barrier to device installation. This paper investigates the costs of adapting ponds and raingardens for climate change. The work builds on an investigation of the impacts of adaptation on the sizing of wet detention ponds and raingardens where hypothetical examples of such devices were sized using TP 10 for a range of climate projections and levels of imperviousness. The COSTnz life cycle costing tool is used to determine the associated costs of design adaptation. Along with a baseline (no change) scenario, two adaptation strategies to the end-of-the-century were investigated for ponds (proactive and incremental adaptation) and one for raingardens (proactive adaptation). For the ponds, the increase in total life cycle cost is between 8.7 – 12.3 %, and there is an increase of 8.5 % for raingardens.

KEYWORDS

Climate change, ponds, rain gardens, imperviousness, total life cycle costs.

PRESENTER PROFILE

Annette Semadeni-Davies has been a researcher in the Urban Aquatic Environments group at NIWA since 2006. She has published five papers on the impacts of climate change on stormwater management in international peer review journals. She was also responsible for the Auckland storm- and wastewater case study of the recently published Urban Impacts Toolbox which is a web-based set of guidelines for assessing the climate change adaptation needs of urban infrastructure. This paper was written in conjunction with the Toolbox. (http://www.niwa.co.nz/climate/urban-impacts-toolbox)

1 INTRODUCTION

This paper explores the cost implications of adapting stormwater management devices for anticipated climate change and imperviousness over the coming century using Auckland, as an example. It follows on from Semadeni-Davies (2011; 2012) which investigated the implications with respect to design, namely sizing requirements.

The combination of impervious surfaces and frequent rainfall in Auckland has resulted in poor ecological health in many of the city's urban streams, estuaries and beaches (e.g., Bibby & Webster-Brown 2005, 2006; Kelly 2010). Projected increases in the frequency and intensity of extreme rainfalls along with further urbanisation over the coming century are likely to exacerbate the impacts of stormwater drainage. As a response to the historical degradation of aquatic environments, there is increasing use of stormwater management devices. Devices installed in Auckland include ponds and wetlands, rain gardens, bio-swales, green roofs, infiltration strips and porous paving.

The purpose of stormwater management devices is to replace natural drainage pathways lost as a consequence of urbanisation, and they can be installed for both water quality and quantity control. In addition to stormwater management, they can provide urban blue-green corridors and have other social and environmental functions. The type of device chosen for a particular site varies according to, amongst other considerations land use, land availability, catchment area and physical characteristics and the device's primary purpose and target level of service. By fulfilling the requirements for multi-functionality, redundancy, modularisation, diversity, multi-scale networks and connectivity discussed by Ahern (2011), these devices can add resilience to cities, as such they are an integral part of low impact or water sensitive urban design (WSUD e.g., Pahl-Wostl 2007; Wong & Brown 2009).

The emergence of stormwater management devices internationally has been roughly parallel to, but separate from, rising concerns over global warming. Their ability to attenuate flows and reduce peak volumes means that they have been mooted as possible adaptations for existing reticulated stormwater networks to the long-term environmental risks associated with climate change (e.g., Scholz and Yang, 2010; Semadeni-Davies et al., 2008 a and b; Ashley et al., 2008; Shaw et al., 2007; Watt et al., 2003).

This paper investigates the cost implications of adapting retention ponds and raingardens for anticipated changes in climate and urban land use intensity so that they are able to continue operating to a specified level of service over their life-span. The objectives are to:

- Develop a methodology to determine the cost implications of adapting stormwater management devices for projected increases in heavy rainfalls and imperviousness as a proxy for land use intensity; and.

- Demonstrate the methodology by costing a hypothetical pond and raingarden sized for different projections of climate change and imperviousness as described in Semadeni-Davies (2011; 2012).

A life cycle costing (LCC) tool, COSTnz (Vesely et al., 2006; Ira et al., 2007, 2008) is used to investigate the costs associated with the construction and maintenance of the devices over their life-span. The costs of adapting the reticulated network are outside the paper's scope as are the associated costs of system failure, these costs require a different set of tools and assumptions (see example in Arnbjerg-Neilsen, 2011 and Arnbjerg-Neilsen and Fleischer, 2009). Neither are savings to the future operation of reticulated networks due to the installation of the devices considered. Rather, it is assumed that there has already been a decision to install the devices as part of WSUD. Like Semadeni-Davies (2011; 2012), the paper uses tools which are publically available to stormwater managers in order to make the methodology both accessible and understandable to a range of stakeholders.

2 ADAPTATION

In the context of climate change, adaptation is defined by the Intergovernmental Panel on Climate Change (IPCC, 2007) as *"the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities".* Adaptation can be both structural (i.e., changes to infrastructure) and non-structural (e.g., changes to policy and behaviour), the former is of interest to this study.

The Ministry for the Environment (MfE, 2008) provides risk assessment guidelines for local government in order for them to assess the need for adaptation. MfE defines risk associated with climate change as "*the chance of an event being induced or significantly exacerbated by climate change, that event having an impact on something of value to the present and/or future community*".

It is noted that, since climate change is progressive, impacts and associated risks can evolve over time which means that the need for adaptation may also change. There is therefore a need to consider the duration, or life-span, of an activity or service when planning adaptation. Due to their relative novelty, the asset life of stormwater management devices is uncertain but is likely to be in the order of 20-50 years (see review in Lampe et al., 2004). In contrast, the planned life-span of the reticulated network is typically 100+ years (e.g., Arnbjerg-Nielsen, 2011). Hence, in addition to routine maintenance, the devices may need to be replaced or undergo corrective maintenance such as dredging of accumulated sediments for ponds and replacement of the filter medium and replanting for raingardens irrespective of the need for adaptation.

There are several adaptation strategies which can be followed:

- **Reactive adaptation** - do not alter infrastructure until an unacceptable impact occurs.
- **Proactive adaptation** – adjust infrastructure for anticipated future risks at either the time of construction of new infrastructure or as part of capital works for existing infrastructure. This form of adaptation is currently being written into New Zealand design guidelines which advocate adjusting design storms for projected climate changes (e.g. NZ standards for Land and Subdivision Infrastructure, NZS 4404:2010; New Zealand Transport Agency, NZTA 2010) according to the same method set out by MfE (2008) for risk assessment.
- **Incremental adaptation** – this strategy has elements of both reactive and proactive adaptation and involves flexible design which allows infrastructure construction to be staggered over time as our knowledge about climate change improves or needs arise (e.g., Jones, 2010; Riesinger et al., 2010; Donovan et al., 2007). Staggering construction also leads to the prospect of discounting to reduce the eventual costs of adaptation and can allow future adoption of emerging technologies.

The choice of adaptation strategy depends, amongst other considerations, on the level of risk associated with failure under current and future conditions, whether the adaptation is for new infrastructure or needs to be retrofitted to existing infrastructure and the costs involved. The latter is the focus of this paper. Adaptation is discussed in more depth with respect to this study in Semadeni-Davies (2011; 2012).

3 MODELLING LIFE CYCLE COSTS

COSTnz is a web-based[1] comprehensive LCC tool which allows users to quantify the relative costs of stormwater management devices specific to New Zealand. COSTnz is not without precedent internationally, Vesely et al. (2006) noted that LCC has been previously used to assess costs associated with stormwater management devices in Australia, the United States of America and the United Kingdom (e.g. Taylor, 2003; 2005). The model follows the Australian/New Zealand Standard 4536:1999 for LCC.

The standard defines life cycle costing as *"the process of assessing the cost of a product over its life cycle or portion thereof".* The LCC is therefore the sum of the acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage, and maintenance through to disposal (see also Emblemsvåg, 2003; Boussabaine and Kirkham, 2004). 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). The consideration of revenues is excluded from LCC.

COSTnz uses a unit costing approach to LCC supplemented with statistical relationships for the estimation of the different cost elements. A unit costing approach is based on the premise that there are standard elements or units involved in the construction and maintenance phases of a device (Ira et al., 2007, 2008). These different elements can be costed by engineers using average tender rates. As a result, the construction and maintenance activities for each device have been broken down into discrete elements or units.

Once the decision to install stormwater management devices has been made, COSTnz allows users to identify and combine acquisition, routine and corrective maintenance, and, if available, decommissioning costs to determine the full LCC for each of a number of commonly used stormwater devices. It therefore assists consultants, developers and decision-makers in assessing the relative performance and cost of different devices.

The default costs in COSTnz are real costs with a base year of 2007 and exclude goods and services tax. Discounting is used to find the value at the base year (i.e., 2007) of future costs associated with a stormwater device. COSTnz uses a real discount rate which does not include inflation to discount the real costs. Two other key parameters of the LCC analysis are the life span (LS) of the device and the life cycle analysis period (LCAP). The LCAP is the period of time (in years) over which the model will analyse the costs, while the life span is the actual period of time in years over which the device itself will function. The LS differs depending on the type of device, and a range of options has been provided in the model.

4 SCENARIO DEVELOPMENT

The following section gives an overview of the development of rainfall and land use change scenarios, more detail can be found in Semadeni-Davies (2011; 2012).

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[1] COSTnz is available under license from Landcare Research Ltd, www.costnz.co.nz

Auckland is undergoing rapid population growth and associated urbanisation. The city's population is projected to increase from its current 1.5 million to between 1.8 and 2.5 million by 2041, requiring the construction of up to 400,000 new dwellings (Auckland Council, 2012). It is anticipated that this increased population will largely be accommodated by an intensification of landuse within the existing urban footprint.. At the same time, it is expected that there will be an increase in the intensity and frequency of heavy rainfalls. Thus combination of city infill and climate change will likely to increase pressure on stormwater drainage infrastructure requiring adaptation.

4.1 CLIMATE PROJECTIONS FOR AUCKLAND

Regional climate change projections for New Zealand have been published in a range of documents over recent years including in MfE (2008). Climate change projections are available for two future periods, 2030-2049 (2040) and 2080-2099 (2090); and six greenhouse gas emission scenarios, SRES scenarios B1, A1T, B2, A1B, A2 and A1FI (IPCC, 2000). These projections were obtained from an ensemble of 12 global circulation models (GCMs). Projected seasonal and annual changes in temperature and rainfall are reproduced for the Auckland region from MfE (2008) in Tables 1 and 2, respectively. The rainfall projections are for decreased mean annual rainfall, but increased frequency and intensity of heavy rainfalls.

Table 1 Projected changes in seasonal and annual mean temperature (°C) from 1990 to 2040 and to 2090, for the Auckland region. The mean average change, and the lower and upper limits (in brackets) over the 6 gas emission scenarios are given (Source: MfE, 2008).

Period	**Summer**	**Autumn**	**Winter**	**Spring**	**Annual**
1990-2040	1.1 [0.3, 2.6]	1.0 [0.2, 2.8]	0.9 [0.2, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.5]
1990-2090	2.3 [0.8, 6.5]	2.1 [0.6, 5.9]	2.0 [0.5, 5.5]	1.9 [0.4, 5.4]	2.1 [0.6, 5.8]

Note: This table covers the period from 1990 (1980-1999) to 2040 (2030–2049) and to 2090 (2080–2099), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 illustrative emission scenarios (B1, A1T, B2, A1B, A2, and A1FI).

For the purposes of preliminary screening as part of climate change risk assessment, MfE (2008) recommends a method for adjusting extreme rainfalls whereby the rainfall intensity of a storm with a specific duration and recurrence interval is increased a semi-empirical factor for every degree increase in annual mean average temperature. Extreme rainfalls are familiar to urban water managers as design storms and are used for a range of applications such as system design modelling system capacity and flood risk assessment. Thus, while the method advocated by MfE was intended for risk assesment, it has been adopted for adapting the design of stormwater devices in New Zealand (e.g. New Zealand standards for Land and Subdivision Infrastructure, NZS 4404:2010; New Zealand Transport Agency, NZTA 2010). Adjusting design storms for impact assessment of urban drainage systems is by no means unique; design storms have been adjusted for climate change, albeit with varying methodologies, by, amongst others, Arnbjerg-Nielsen and Fleischer (2009); He et al, (2006); Denault et al (2006) and, in New Zealand, Shaw et al. (2005). However, there are limitations of applying a methodology which relies on a stationary climate to future design (Mailhot & Duchesne

2010). The implications of this method for design are discussed in more detail in Semadeni-Davies (2011; 2012).

*Table 2 Projected changes in precipitation for two selected stations within the Auckland Region in seasonal and annual precipitation (%) from 1990 to 2040 and to 2090. The average change, and the lower and upper limits (in brackets) over the 6 gas emission scenarios are given (*Source: MfE, 2008*)*

Period	**Location**	**Summer**	**Autumn**	**Winter**	**Spring**	**Annual**
1990 - 2040	Warkworth (north)	1 [-16, 20]	1 [-13, 22]	-4 [-22, 2]	-6 [-18, 6]	-3 [-13, 5]
	Mangere (south)	1 [-17, 20]	1 [-14, 17]	-1 [-10, 5]	-5 [-15, 10]	-1 [-10, 6]
1990 2090	Warkworth (north)	-2 [-31, 20]	-1 [-20, 12]	-4 [-24, 5]	-12 [-33, 6]	-5 [-19, 6]
	Mangere (south)	-1 [-33, 20]	-2 [-21, 12]	-1 [-12, 9]	-9 [-30, 11]	-3 [-13, 9]

Note: This table covers the period from 1990 (1980-1999) to 2090 (2080–2099), based on downscaled precipitation changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 indicative emission scenarios.

4.2 STORMWATER MANAGEMENT

Stormwater management devices in Auckland are sized according to the volume required to detain runoff generated by specified design-storms. The MfE design storm adjustment method was used to investigate the impact of climate change on ponds and raingardens sized according to the regional criteria (ARC, 2003; TP10).

Design rainfalls were adjusted for incremental increases in annual temperature over the range of projected climate change in Table 1 (from no change up to 6ºC). The design rainfalls and climate change adjustments were derived from the High Intensity Rainfall Design System (HIRDS, Thompson 2002) developed by NIWA[2]. HIRDS returns extreme rainfalls for any location in New Zealand and automatically applies the MfE adjustments for user specified temperature changes. The reference location used here is Henderson, West Auckland (New Zealand Map Grid Easting 2655797 and Northing 6478716).

The impact of urban development was also assessed by changing imperviousness which increases the runoff volume simulated for a design storm. Imperviousness was increased from 30 to 90% for ponds and the catchment area was set to 4 ha. For raingardens, it was assumed that the contributing area, set to a recommended maximum of 1000 m^2, is 100% impervious. On the basis of the investigation presented in Semadeni-Davies (2011; 2012), it was suggested that ponds be resized following an incremental adaptation strategy as part of corrective maintenance as needs arise, whereas raingardens should be sized for climate change at the time of initial construction. The design process is overviewed briefly below.

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[2] HIRDS is available for free public use at http://hirds.niwa.co.nz

4.3 RUNOFF VOLUMES

The size of a stormwater management device is determined by the volume of water to be detained by the device. Devices intended primarily for water treatment are sized for the runoff volume generated by 1/3 of the 2-year 24 hour design storm (i.e., the water quality volume, WQV). Devices intended for water quantity control are generally sized to store and release the runoff generated by the 2- and 10-year, 24-hour to attenuate flow. In areas prone to flooding, detention of the 100-year rainfall may also be required, but is not considered here. Runoff volumes generated by the design storms are calculated using a variation of the SCS curve method (U.S. Department of Agriculture, Soil Conservation Service, 1986) outlined in the TP 108 (ARC, 1999). The initial abstraction for the investigation was set to 0 and 0.5 mm for impervious and permeable surfaces respectively according to ARC recommendations. The soil was assumed to have a curve number of 70 which is fairly typical of grassed lawns in suburban Auckland.

4.4 PONDS

Wet detention ponds consist of a permanent pool of water into which stormwater is directed and detained for gradual release. Ponds are large, typically end-of-pipe devices intended for both water quality and quantity control at the neighbourhood to catchment scale. The criteria for Auckland advocates a conservative approach whereby all runoff generated by the design storm is detained and released over 24 hours. Stormwater detention ponds in the Auckland Region commonly combine water quality and quantity control by providing a set of outlet structures at different levels to regulate discharge. In this investigation, a rectangular pond with a trapezoid bathymetry was sized according to the runoff volumes calculated for changed design rainfalls and imperviousness according the criteria in TP10 (ARC, 2003). The design variables used were taken from ARC recommendations and are as follows:

- Catchment area - 4 ha
- Pond depth at WQV - 2 m
- Length-to-width ratio at WQV - 3:1
- Side slope (vertical to horizontal) - 1:3
- Design storms (24-hour duration)
    - 1/3 2-year (i.e., WQV)
    - 2-year (quantity control)
    - 10-year (quantity control)

The results are summarised in Table 3 for a hypothetical example whereby the pond is to be constructed in a catchment that currently has medium density housing (45% imperviousness) but is planned for redevelopment over the coming decades with imperviousness to reach 60% (mid to high density housing) by 2040 and 75% (infilling with high density housing and commercial land use) by 2090. The levels of imperviousness have been chosen to illustrate the effects of land use intensification. The designs costed in this paper are shaded in the table.

4.5 RAINGARDENS

Raingardens are bio-retention devices which consist of a planted filter-bed usually filled with a lower sand or gravel drainage layer, a soil layer and surface mulch. They are intended primarily for water quality control at the site or neighbourhood scale. They treat water through a combination of settling of coarse sediments (i.e., in stormwater detained in a forebay or ponded on the surface), filtration and bio-retention. Typical locations include traffic islands and median strips, car parks, roadside berms and courtyards. Their location and the hydrological isolation from surrounding soils means that raingardens usually only drain overland flow from impervious surfaces. Here, a square raingarden is sized for incremental changes in annual mean temperature as for ponds with reference to TP10 (ARC, 2003) recommendations. The results are summarised in Table 4. The sizing variables are summarised as follows:

Table 3 Summary of results for a hypothetical trapezoidal pond sized according to local design criteria (ARC, 2003) for changes in imperviousness and climate. The shaded designs are costed in this paper. (Source, Semadeni-Davies, 2011; 2012).

Pond scenario		**Volume (m^3)**		**Surface area (m^2)**		**Depth (m)**	
		WQV	**10-year**	**WQV**	**10-year**	**WQV**	**10-year**
Baseline: Present climate 45% imperviousness		725	3696	691	1881	2	4.6
2040 mid-century 60% imperviousness	No climate change	894	4091	804	2018	2	4.5
	MfE lower projection (0.2°C)	904	4150	811	2037	2	4.5
	MfE mean projection (0.9°C)	938	4358	833	2104	2	4.6
	MfE upper projection (2.5°C)	1018	4837	885	2254	2	4.7
2090 end-of-century 75% imperviousness	No climate change	1063	4486	915	2154	2	4.6
	MfE lower projection (0.6°C)	1097	4672	937	2213	2	4.5
	MfE mean projection (2.1°C)	1181	5138	991	2358	2	4.6
	MfE upper projection (5.8°C)	1391	6297	1124	2702	2	4.8

- Catchment area – 1000 m^2
- Imperviousness – 100 %
- Hydraulic conductivity of growing medium – 0.3 m/day
- Drainage time
    - Non-residential land – 1.5 days
    - Residential land – 1 day
- Depth of filter bed – 1 m
- Live/surface storage depth - 0.22 m
- Design storms (24-hour duration)
    - 1/3 2-year (i.e., WQV)

The upper limit of the contributing area (i.e., 1000 m^2) recommended in TP10 means increases in imperviousness should be met by construction of new raingardens as part of development or retrofitting programmes rather than reconstruction of existing raingardens. Hence the primary consideration for future raingarden adaptation is climate change. It is interesting to note that the size difference between current and future raingardens sized using the adjusted design storms is less than the size difference between raingardens designed for residential areas and those designed for other landuses. The size difference is due to aesthetics (i.e., avoidance of pooled standing water) rather than treatment function.

Table 4 Summary of results for a hypothetical raingarden sized according to local design criteria (ARC, 2003) for climate change. The designs costed in this paper are shaded.

Raingarden Scenario		**Volume (m^3)**	**Area (m^2)**	
			Residential	**Other land use**
Present climate (base line)		22.4	67.3	44.9
Mid-century	MfE lower projection (0.2°C)	22.6	68.0	45.3
	MfE mean projection (0.9°C)	23.4	70.4	46.9
	MfE upper projection (2.5°C)	25.2	75.8	50.5
End-of-century	MfE lower projection (0.6°C)	23.1	69.4	46.2
	MfE mean projection (2.1°C)	24.8	74.4	49.6
	MfE upper projection (5.8°C)	29.0	86.9	58.0

Only one adaptation strategy (100% imperviousness, end-of-century MfE mean temperature projection) was investigated for raingardens for a number of reasons:

- Local guidance is for increases in imperviousness to be met with the construction of new raingardens.
- The increase in raingarden size, even with the most extreme projected change in rainfall intensity, is modest.
- While undersized raingardens may have high bypass volumes, oversizing does not have serious downstream consequences negating the need for incremental adaptation.

5 APPLICATION OF COSTnz

COSTnz was used to estimate the costs associated with resizing ponds and raingardens for the mean annual temperature change projections to 2040 (+0.9°C) and 2090 (+2.1°C) shaded in Tables 3 and 4. For ponds, costs associated with changes in imperviousness from 45% to 60% (2040) and 75% (2090) were assessed assuming both adaptation at construction and incremental adaptation. Mean projections were chosen for costing as mid-range projections are the most commonly used by stormwater engineers in the Auckland region (Semadeni-Davies and Puddephatt, 2010).

The following assumptions were included in the model:

- Costs exclude land value, in the case of ponds, it is assumed that adequate land has been set aside for adaptation.
- LCAP: a span of 100 years has been chosen to ensure consistency with the climate change modelling and the design horizon of the reticulated network.
- Discount rate: 3.5% (a lower discount rate is used for longer life spans in order to be conservative and account for potential uncertainties in the future).

As much of the cost of corrective maintenance of stormwater management devices is generally influenced by the amount of sediment accumulation in the device (e.g., maintenance to remove and dispose of contaminants), COSTnz requires an estimation of the annual sediment load reaching the device and the treatment efficiency of the device. Where no runoff water quality monitoring data is available, the COSTnz manual suggests using a contaminant load model like that developed by the Auckland Regional Council (ARC, 2010).

In this study, it is assumed that devices designed using the TP10 design criteria (ARC, 2003) will meet the target sediment removal efficiency of 75%. The catchments for ponds and raingardens were broken into an assumed range of surface types. The breakdown of impervious surfaces draining to ponds included roofs (50%); roads (40%); and paving (10%) which is typical of suburban Auckland. The breakdown of impervious surface types draining to the raingarden are roads (75%) and paving (25%). For simplicity, only one class of roofing material (well painted galvanised steel), road-type (1000-5000 vehicles per day) and paving (residential) was included in the estimation. Permeable surfaces were assumed to be grassed lawns. The estimated annual sediment loads reaching the devices are given in Table 5.

Table 5 Annual sediment load (kg) generated by hypothetical stormwater catchments with varying levels of imperviousness.

Surface type	Sediment Yield (kg/ha/yr)	Annual load (kg) by device and percentage imperviousness*			
		Pond (catchment area = 4 ha)			Raingarden (catchment area = 1000 m^2)
		45%	60%	75%	100%
Roofing	50	45	60	75	-
Road	250	180	240	300	18.75
Paving	50	90	120	150	12.5
Lawn	280	616	448	280	-
TOTAL LOAD (kg)		**931**	**868**	**805**	**31.25**

*Loads estimated using yields from the ARC CLM spreadsheet tool.

5.1 PONDS

This section costs the hypothetical pond for the cases shaded in Table 3. In order to cost adaptation of ponds for climate change, a number of assumptions regarding construction methodology need to be made. As a result, three pond options, incorporating different adaptation methodologies, have been costed, namely:

A. Construction of a new pond according to the baseline scenario (i.e., design for today's climate and imperviousness with no adaptation).

B. Pro-active adaptation by construction of a pond large enough to accommodate the 2090 end-of-century 10 year storm attenuation volume with 75% imperviousness, but with incremental adaptation of the outlet structure to ensure that only the designed volume for each scenario is stored within the pond. Incremental adaptation of the outlet structure would be carried out as part of the corrective maintenance works.

C. Incremental adaptation of the baseline scenario pond A at both mid- and end-of-century as part of the corrective maintenance work. Adaptation would be undertaken by excavating around the perimeter of the pond to accommodate the future WQV with a constant depth of 2 m and using the spoil to build up the side banks to the correct height needed for the new 10 year attenuation volume level. There would be no change to the inlet and outlet structures.

In all the options, the forebay is assumed to be 15% of the pond area at the water quality volume level.

5.1.1 TOTAL ACQUISITION COSTS

Table 6 summarises the cost of constructing a new pond at the present day for each climate change scenario. The Total Acquisition Cost (TAC) was generated using the statistical relationship in COSTnz that relates the size of a pond surface area to the TACs for that pond. It can be seen that the TAC for Option A (the baseline scenario) would be NZ$142,335 (2007 currency baseline).

Table 6 Summary of TAC costs for ponds constructed today to accommodate future design rainfalls based on the COSTnz statistical relationship between pond wet surface area and TAC for ponds.

Scenario	WQV area (m^2)	TAC (2007 NZ$)	Relative change (%)
Option A	691	142,335	-
Option B	991	167,024	+17%
Option C	691*	143,935	+1%

* initially same size as Option A

If the end-of-century pond were to be constructed today (Option B), it would cost NZ$167,024 and be approximately 17% more expensive than a pond sized to the baseline scenario (Option A). In this option, the outlet structure is incrementally adapted in order to ensure that the pond is able to regulate out-flow over time. This would, in essence, mean that the permanent pool would be shallower (approximately 66 cm) in the baseline scenario and reach the recommended depth of 1m by 2090.

Option C starts with a pond the same size as Option A. However, there are some additional costs relating to the initial construction of Option C over and above the TAC presented in Table 6 for Option A. These relate to initially having to construct a longer access track (approximately 45m greater in length than would be required for the baseline pond) and having an increased landscaping cost for the larger land area which would have to be set aside at the initial construction phase. These additional costs raise the baseline TAC to NZ$143,935 for Option C – a relative change of 1%.

5.1.2 MAINTENANCE COSTS

Table 7 provides a summary of the different routine and corrective maintenance costs. It is interesting to note that the cost unit for the majority of pond routine maintenance activities is *per pond* (as opposed to, say, *per* m^2). What this means is that there is no difference in routine maintenance cost between Options A and B. The higher routine maintenance cost in Option C can be explained by the additional land (over and above the *normal* pond area) which has been set aside and would require regular maintenance (such as mowing).

Table 7 Summary of maintenance costs (2007 NZ$) for the 3 pond options using a 100 year life cycle analysis period.

Model Run/ Scenario	Routine Maintenance Costs	Annual Routine Maintenance Cost	Corrective Maintenance Costs	Total Maintenance Cost
Option A	331,086	3,344	132,539	463,625
Option B	331,086	3,344	160,539 [includes additional cost of adaptation of NZ$18,500 at 2040 and NZ$9,500 at 2090]	491,625
Option C	377,230	4,698	159,244 [includes additional cost of adaptation of NZ$7,626 at 2040 and NZ$19,079 at 2090]	496,474

In both Options B and C the additional corrective maintenance costs relate to the incremental adaptation of the pond at stages 1 (2040) and 2 (2090) of the adaptation. The model assumes that the pond would be adapted at the time at which corrective maintenance is required, and therefore additional site establishment costs would not need to be incurred.

5.1.3 TOTAL LIFE CYCLE COSTS

The total life cycle costs of the three options are presented in

Table 8; the Net Present Values (NPV) were calculated using a real discount rate of 3.5%. It should be noted that Option A is not a viable option from a climate change perspective (it only takes into account present day climatic conditions based on historical rainfall records). Option B is 8.7% more expensive than the present day scenario, whilst Option C is 12.3% more expensive.

Table 8 Summary of pond option costs (2007 NZ$) over a 100 year life cycle analysis period with and without discounting (Net Present Value).

Model Run/ Scenario	**Total Acquisition Costs**	**Routine Maintenance Costs (NPV*)**	**Corrective Maintenance Costs (NPV*)**	**Total Life Cycle Costs (NPV*)**	**Percentage difference from baseline Scenario (A)**
Option A	142,335	331,086 (46,401)	132,539 (14,779)	605,960 (203,515)	-
Option B	167,024	331,086 (92,381)	160,539 (39,826)	658,649 (299,231)	8.7% (47.03%)
Option C	143,935	377,230 (118,426)	159,244 (37,513)	680,409 (299,874)	12.3% (47.34%)

*NPV calculated using a real discount rate of 3.5%

5.2 RAINGARDENS

Two costing scenarios were run for raingardens, namely the baseline scenario and the end-of-century MfE mean projection scenario (see shaded scenarios in Table 4). As the difference in size was small for the mid-century climate projection, the impact on cost was negligible and is not shown in the table. The residential landuse scenario was costed in both cases, since the TP10 sizing parameters for residential areas are more restrictive and therefore the device's surface area is larger than for other land uses. Due to the small difference in sizing between the baseline scenario (67.3m^2) and the end-of-century scenario (74.4m^2), incremental adaptation of the raingarden is not warranted. As a result, the end-of-century raingarden is modelled as if it is built at the present day. Table 9 provides a summary of costs for the two scenarios, with and without discounting.

Table 9 Summary of raingarden costs (2007 NZ$) over a 100 year life cycle analysis period with and without discounting (Net Present Value).

Model Run/ Scenario	**Surface Area (m^2)**	**Costs (NZ$)**			
		Total Acquisition Costs	**Routine Maintenance Costs (NPV*)**	**Corrective Maintenance Costs (NPV*)**	**Total Life Cycle Costs (NPV*)**
Present Day	67.3	47,053	190,794 (55,325)	96,867 (26,169)	334,714 (128,548)
End-of-Century	74.4	48,502	208,200 (60,660)	106,551 (28,683)	363,253 (136,397)
% Difference	+10.5%	+3.1%	+9.1% (+9.6%)	+10.0% (+9.6%)	+8.5% (+6.11%)

*NPV calculated using a discount rate of 3.5%

Table 9 shows that there is a 10.5% increase in surface area for the end-of-century scenario and this is coupled with an 8.5% increase in total life cycle costs. The TAC shows a 3% increase, whilst the routine and corrective maintenance costs are approximately 10% higher for the end-of-century scenario.

6 DISCUSSION

There are a number of barriers, including perceived cost, to the widespread implementation of stormwater management devices for water treatment (e.g., Taylor et al., 2012; Morison and Brown, 2011; Brown and Clarke, 2007; Shaver, 2009; Puddephatt and Heslop, 2007). The analysis presented above takes the first step in overcoming the barrier of perceived cost by showing that the costs associated with adaptation are relatively small in comparison with the total costs involved for devices sized to current conditions.

The challenge for designers with regard to adaptation is to balance current costs and social values against potential environmental risks. The risk in the case of stormwater management is that devices which are too small or oversized may fail leading to negative impacts on receiving waters. Devices which are too small may have inadequate detention times and be by-passed or flushed / flooded during high flows. On the other hand, devices which are too large may be vulnerable to low flows and drying-out during dry weather. In open water bodies, such as ponds, shallow water could result in increased water temperatures during summer, scouring and resuspension of bed sediments due to both flow and wind currents, and decomposition of organic material. A further complication is that a device sized correctly for future change may be incorrectly sized for the intervening time period. Moreover, given the uncertainty surrounding climate change, the final size required to accommodate increased hydraulic loads in areas with projected increases in rainfall intensity, is by no means certain. This uncertainty is compounded by concurrent possible changes in other drivers, such as land use and imperviousness.

To illustrate the application of LCC to stormwater management devices designed for adaptation under a range of future conditions, three climate scenarios were investigated: present or baseline climate and for the MfE (2008) mean temperature projections to 2040 (mid-century) and 2090 (end-of-century). COSTnz was applied for ponds and raingardens, which have different functions and capital outlays for construction and maintenance. Ponds are generally installed for water quantity control, but also have an inherent water quality function, and operate at the neighbourhood to catchment scale. In contrast, raingardens are primarily water quality control devices which operate at the site or neighbourhood scale.

For ponds, it was assumed that imperviousness increases from 45% to 60% and finally to 75% due to urbanization for the three climate scenarios respectively. Alongside a no-change baseline (Option A), two adaptation strategies were investigated for ponds: Option B – construction at present to end-of-century sizing; and Option C – incremental adaption with resizing coinciding with corrective maintenance at 2040 and 2090. While Option B is the least expensive adaptation strategy (total cost 8.7 % more than the baseline), the drawback is that it would result in a shallower pond that is subject to heating and could dry-out in summer. Alternatively, if planted with wetland vegetation, the shallower pond could act as a constructed wetland for the first few decades. The incremental adaptation of the outlet structure is accounted for in the corrective maintenance costing, however, no allowance has been made for wetland planting. Option C is preferred as it tracks risk. This option is only slightly more expensive than Option B ponds (total cost 12.3 % more than the baseline). With either option, given the overall cost of pond construction and maintenance, the additional expenditure required to size or resize the hypothetical pond is small in comparison to having to build new ponds (i.e., additional acquisition and construction costs) to accommodate future growth and climate change. Furthermore, given the need to balance current and future pond performance by avoiding either under-sizing or oversizing the pond, we suggest that an incremental adaptation strategy be followed. Under this strategy, space would be made available for possible adaptation, but the pond would be constructed for current conditions with an eye to resizing in the future.

Since raingarden function is unlikely to be affected if the raingarden is oversized, and only small increases in size are required for climate change, incremental adaptation is not warranted. That is, it would be pragmatic to simply construct the raingarden to accommodate increased runoff rather than incurring the added costs of adaptation in the future. For this reason, only the costs of adaptation at the time of construction were investigated. It was found that the 10.5% increase in surface area required for the end-of-century scenario results in an 8.5% increase in total life cycle costs. Again, the additional costs are minor compared to the total costs for a raingarden designed using current design storms or for different land use types.

7 CONCLUSIONS

This paper represents the first steps in quantifying the cost of designing for maximum growth and mid-range climate change scenarios on stormwater management practices. Stormwater management devices are increasingly common elements in the urban landscape around the world. Their ability to attenuate flows and reduce peak volumes means that they have been suggested as a means of adaptation in areas with projected increases in the intensity and frequency of extreme rainfall. However, to date there is little advice on how to design such devices for climate change and other drivers and the relative costs involved.

Here, life cycle cost analysis has been undertaken for different pond adaptation and raingarden strategies. The study builds on an investigation of the impacts of urban development and climate change on the sizing of a hypothetical pond and raingarden (Semadeni-Davies, 2011; 2012). The devices were sized using local design criteria for a range of climate projections and levels of imperviousness. Like Semadeni-Davies (2011; 2012), the methods used are publically available making them accessible to a wide range of stakeholders. This study used the COSTnz model developed by Landcare Research to determine the costs associated with adaptation.

Along with a baseline (no change) scenario, two adaptation strategies to the end-of-the-century were investigated for ponds (proactive and incremental adaptation) and one for raingardens (proactive adaptation). For the ponds, the increase in total life cycle cost associated with adaptation is between 8.7 – 12.3 %, and there is an increase of 8% for raingardens. As could be expected, there is an increase in the costs due to adaptation, however, these are minor in comparison with other construction and maintenance costs and are far less than construction costs of new devices to accommodate future hydraulic loads.

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