Cost/Benefit Analysis for CSNDC Schedule 4D

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Prepared for	Environmental Canterbury (ECan)
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Purpose

This report is submitted to fulfil the requirements under Schedule 4D of the Comprehensive Stormwater Network Discharge Consent (CSNDC, CRC190445). The purpose of this cost/benefit analysis (CBA) is for the Christchurch City Council (CCC) to gain a better understanding of where to allocate limited financial resources for stormwater treatment and discharge in order to achieve the greatest, positive environmental impact.

Background

Schedule 4D requires that CCC "conduct a cost/benefit analysis of options of alternate methods of stormwater treatment and discharge including consideration of redirection to the sewer and Managed Aquifer Recharge/Discharge (For consideration as part of Council Annual Planning process)."

The scope has been interpreted to require a CBA of both existing methods of stormwater treatment as well as considering the redirection to sewer and Managed Aquifer Recharge (MAR). It has been assumed that the treatment devices are designed to capture the equivalent full first flush runoff of 25 mm rainfall depth[1] or 5 mm/hr intensity.

Devices reviewed

Methods of stormwater treatment included in the analysis are:

- Soil adsorption basins (also referred to as infiltration basins) – this is assumed to cover MAR as well and the reasons for this are discussed in detail at the end of this section
- First flush basin (wet or dry) followed by a wetland (often just written as 'wetland' in this analysis)
- Conventional rain gardens (also referred to as bioretention basins)
- Rapid filtration rain gardens (currently limited to the Filterra, a proprietary device)
- Proprietary filtration devices (PFDs, based on costs of a StormFilter, as this has been installed in Christchurch)
- Swales (although in Christchurch these are often considered to provide pre-treatment only)
- Discharge to sewer

The following methods of stormwater treatment were not included in the analysis as they do not provide full treatment of the first flush, or are limited to specific applications that are not sufficiently common to include in the analysis:

- Sumps and other gross pollutant traps
- Tree pits
- Floating treatment wetlands
- Green roofs

Note that the excluded methods do provide stormwater treatment benefits and are often a valuable element in a treatment train. Excluding them from this analysis does not represent a judgement on their value or applicability, and in some situations may be the best option for stormwater treatment.

The devices were assessed over a range of catchment sizes, as not all devices are appropriate for a small or large catchment (noting that there are always exceptions due to particular circumstances). While first flush basins and

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[1] This is the volume generated by 25mm depth of rain falling on impervious surfaces. Runoff generated by pervious areas is discounted.

wetlands could be used for catchments less than 5ha, this is typically not the case in Christchurch and so they have not been included in that category. The impervious catchment sizes were divided into small (≤5 Ha) and large (≥10 Ha). The following table shows the split of devices assessed between small and large catchments (Table 1).

Table 1 Treatment device catchment size applicability

Treatment Device	Small catchment (≤5 Ha)	Large catchment (≥10 Ha)
Soil adsorption basins/MAR	Y	Y
First flush basin & wetland		Y
Conventional rain gardens	Y	
Rapid filtration rain gardens	Y	Y
Proprietary filtration devices	Y	Y
Swale	Y	
Sewer redirection	Y	Y

Managed Aquifer Recharge (MAR)

In 2018, CCC commissioned a MAR report from Aqualinc (Weir & Flintoft 2018) to assess how shallow groundwater might respond to stormwater discharge, both gravity discharge (infiltration systems) as well as the potential for mechanical injection of stormwater into the aquifer. CCC has long had a programme of utilising infiltration systems to dispose of stormwater (after treatment of the first flush) in areas of the city where there are free draining soils at depth or where there is limited or no availability of the stormwater network.

Weir & Flintoft (2018) concluded that while a local mounding effect of large-scale infiltration was predicted (Awatea Basins were used as an example), mounding depths were minor, and it was considered unlikely that groundwater mounding from large-scale infiltration would adversely affect neighbouring land during periods of high groundwater. CCC continues to employ small- and large-scale infiltration as a stormwater mitigation method in areas of the city where it is supported favourably by hydrogeology. CCC requires that the first flush of stormwater runoff from new roads and hardstand areas be treated prior to discharge in nearly all situations, and the types of systems used are expected to remove 75-90% of contaminants from the first flush. Roof runoff is not currently required to be treated. Weir & Flintoft (2018) briefly discussed the potential for microbial migration from stormwater infiltration and concluded that further work is needed to estimate the travel distances of mircrobes from large scale infiltration systems. Because CCC already actively promotes infiltration in areas where it is feasible and low risk, only gravity infiltration is considered further in this analysis. This is assumed to be through soil adsorption basins (often referred to as infiltration basins), as these are the primary means currently used in the city for discharge to ground.

Weir & Flintoft (2018) also considered the option of injecting stormwater into the aquifer where gravity infiltration is not typically feasible, such as areas where groundwater levels are naturally high and hydraulic conductivity low. A couple of examples were considered where data was available, including the Central Library (Tūranga) and the Christchurch Golf Club on Lake Terrace Road. Weir & Flintoft (2018) concluded that disposal via injection is likely to be marginally feasible to infeasible in areas where shallow groundwater is currently near the surface, and feasibility would decrease over time with the expected rise in groundwater levels as a result of climate change and sea level rise. Injection of small flowrates (such as individual site systems) would be more feasible; however, the capital and operational costs of equipment and maintenance would be high and there would be limitations of injection pressures and the effects of mounding in shallow layers.

Injected stormwater would still need to be treated prior to disposal in order to mitigate contamination of the aquifer. The degree of treatment required is uncertain, but would likely need to be similar to that of the treatment devices listed above. As such, MAR through injecting stormwater into the aquifer is not considered economically feasible given the significant additional cost on top of the treatment. While it may be applicable in unique situations, it is not considered to have sufficiently widespread usefulness to include further in this analysis.

Discharge to sewer

Discharge to sewer has been considered at a concept level for Addington Brook and Riccarton Stream due to the current spare capacity identified in the Western Interceptor/Southern Relief sewers. While conceptually the hydraulic design could work, a number of disadvantages were identified (Table 2). It is included in this analysis as it is a requirement of Schedule 4D, but its inclusion is not an endorsement of discharge to sewer as a viable method of stormwater management as a number of issues remain to be fully understood and addressed. Note that discharge of stormwater to sewer as trade waste at individual sites is considered by a separate cost benefit analysis in response to the Schedule 4K source control requirements of the CSNDC (CCC, 2021a).

Table 2 Advantages and disadvantages of disposal of stormwater to sewer

Advantages	**Disadvantages**
Higher levels of stormwater treatment including almost complete removal of stormflow contaminants from the waterways	Increased pressure on wastewater system
Potentially lower capital costs depending on whether Development Contributions are required	Earlier capacity increase required for the Western Interceptor/Southern Relief sewers
	May be difficult to convey the message that it is not linked to sewer overflows
	Increase in levels of zinc (and other contaminants) to be managed at the treatment plant
	Increase in sediment in sewer network
	Transfer of contaminants from one environment to another (e.g. biosolids high in zinc need to be disposed somewhere)
	Higher climate change impact (due to emissions at wastewater treatment plant)?
	May lead to poorer environmental stewardship and management practices as stormwater is treated as something to be disposed of rather than a resource

Cost assessment

Capital costs for treatment methods were assessed at a high level based on data available from the reports/sources listed below. There are a number of factors which affect costs which could not be taken into account in this assessment and would need to be considered in assessments for particular projects. For instance, some devices may be more sensitive to costs introduced by contaminated land, whereas others may be more sensitive to cost of land. In general, where a range of costs are presented in the reports listed then the median costs were used. Where possible costs were benchmarked against known project costs to test the cost curves developed.

A range of data sources were used, including:

- Literature review of cost data (primarily work for Auckland Council's Freshwater Management Tool)
- CCC cost data, both estimated average costs and actual costs of devices
- *Stormwater Maintenance Cost Assessment*, Internal CCC document October 2019
- Internal CCC report for Schedule 4b *Street Sweeping - Consideration of Benefits and Costs* (16 Dec 2020, TRIM 20/1587156)
- Draft *Avon Stormwater Management Plan* as submitted in documents supporting the Comprehensive Stormwater Network Discharge Consent application (CRC190445)
- Aqualinc memo on *Stormwater Disposal to Christchurch Aquifers* (27 Nov 2018, TRIM 18/1259325)
- WSP report on discharge to sewer for Addington/Riccarton catchments (3 Dec 2020, TRIM 20/1538035)

- *Evaluation of Stormwater Treatment Construction Costs - A Canterbury Specific Assessment* Prepared by Opus for Canterbury Regional Stormwater Forum, unpublished October 2015
- *Auckland Unitary Plan stormwater management provisions: cost and benefit assessment. Auckland Council technical report, TR2013/043 Kettle and Kumar (2013)*

A more comprehensive reference list is provided at the end of this report.

To readily compare the costs of stormwater treatment for the various methods, the comparison is made in the cost of treatment per impervious hectare. Impervious hectares are used as it is the impervious surfaces of a catchment which typically drive device sizing, and it readily allows comparison between catchments with various degrees of imperviousness (such as between residential and commercial areas).

The devices were sized in accordance with the Waterways, Wetlands and Drainage Guide or other guidance adopted by CCC (Table 3).

Table 3 Water quality event used for each device

First flush basin & wetland	Rain gardens	Proprietary filtration devices (PFD)	Soil adsorption basins	Swales	Proprietary rain garden	Discharge to sewer
25 mm rainfall depth	20 mm rainfall depth[2]	5 mm/hr	25 mm rainfall depth	5 mm/hr	5 mm/hr	80% of annual runoff capture

Capital costs by treatment device were extracted from sources listed above. Where maintenance costs were not available simple assumptions were applied to make some allowance for ongoing operational costs. These figures have low confidence as they are highly catchment and device design specific.

The net present value of the whole of life cost (excluding renewal) was then estimated using a 5% discount rate. CPI inflation was applied to inflate historical rates to 2020 values.

Costs associated with replacement (renewal), decommissioning and / or demolition have generally not been included in the analysis. However, the media renewal costs for rain gardens, PFDs and proprietary rain gardens are included.

Land costs are excluded for all devices, as is commonly done for national studies to allow for comparison of device costs. This is in part due to the difficulty of assigning a uniform land cost to a device as it can be highly variable. A land value could be assigned to the various devices, and it will have a larger effect on wetlands and soil adsorption basins than smaller footprint devices. However, the smaller footprint devices are often used where land value is higher, and that would need to be taken into account. A range of values would be required to be tested. This does have the potential to change the analysis, particularly for large footprint devices. However, the larger devices also provide greater opportunity for non-drainage values, the benefits of which are not included in the analysis. At this stage it is recommended to not include land costs in the analysis, but land costs could be included in future iterations of the analysis, and will be included in any project-specific analysis.

The cost formulas used for each device are provided in Table 4 with the key assumptions for capital and operational costs summarised in Table 5 and Table 6, respectively.

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[2] In accordance with CCC (2015b).

Table 4 Key cost parameters

Parameter	**First flush basin & wetland**	**Rain gardens**	**Proprietary filtration devices (PFD)**	**Soil adsorption basins**	**Swales**	**Proprietary rain garden**	**Discharge to sewer**
Size catchment	Large	Small	Both	Both	Small	Both	Both
CAPEX cost ($) formula (where A = impervious hectares in the catchment)	602,499 x $A^{0.4559}$	A x 165,200 + 11,226	116.47 x $A^{0.8033}$ x 1000	23,951 x A + 29,899	271.08 / linear m of swale	72,471 x A + 23,919	30,000 + 1,500 x A + 1,665.90 per 0.572 m^3
Annual maintenance cost	$0.601/$m^2$ of device	11,149 x Imp $Ha^{0.57}$	$526.32/$m^2$ of device	$0.65/$m^2$ of device	$0.975/$m^2$ of device	$82.35/$m^2$ of device	$0.60/$m^3$ treated

Table 5 Key capital cost assumptions

Device	**Assumption**
First flush basin & wetland	The costs for a first flush basin and wetland were developed using a number of sources and benchmarked against actual wetlands. From this average a cost curve was developed which is applicable for CCC first flush basins and wetlands 10 Ha and above.
Rain gardens	The costs for rain gardens were assessed against the Avon SMP formula, as well as the upper and lower quartile figures from Ira and Simcock (2019) and high and low figures for rain gardens from the CostNZ model, as reported in Kettle and Kumar (2013). When adjusted for inflation, these were found to provide similar costs to the Avon SMP formula, so this was updated to reflect 2020 costs and used.
Proprietary filtration devices (PFD, e.g. StormFilter)	The costs for PFD were based on a formula developed for the Avon SMP and benchmarked against the Richardson Terrace StormFilter. When adjusted for inflation, this was comparable with figures reported by Stormwater360 in 2007 (Hannah, 2012).
Soil adsorption basins	The cost of soil adsorption basins was based on the 'medium' cost developed by Melvin (2015) for Canterbury infiltration basins. No soil adsorption basin costs were available for benchmarking.
Swales	Swale costs used the average rate from Ira and Simcock (2019) adjusted for inflation. A minimum length of 30 m was assumed for water quality treatment.
Proprietary rain garden	Proprietary rain gardens were based on 80% of the cost of a soil adsorption basin (for excavation and inlets etc) plus the media and plant supply and installation cost.
Discharge to sewer	Discharge to sewer capital cost is based on a fixed rate of $30,000 for design and consenting, plus an allowance of $1,500 per impervious hectare. This is based on recent options analysis for a catchment. In addition to this, a development contribution for the upgrade of downstream conveyance infrastructure and treatment plant capacity has been added. The Development Contribution was estimated from the current charge being consulted on for the central city (CCC 2021c). Development contributions are based on Household Unit Equivalents (HUEs). The wastewater collection, treatment and disposal HUE is 0.572 m^3/day with an associated potential one-off fee of $1,665.90 per HUE for the central city (CCC 2021c). If the current fee of $9,254.05 per HUE district-wide (CCC 2015a and CCC 2021b) was used, then the cost of discharge to sewer would increase dramatically. The volume to be treated through discharge to sewer was estimated at 80% of the annual runoff from the impervious area, with a runoff coefficient of 0.9.

Table 6 Key operational cost assumptions

Device	Assumption
First flush basin & wetland	First flush basin and wetlands based on the medium rate for maintaining the 'wet areas' of the facility (ponds or wetland) and the figure for dry areas (e.g. first flush basin) maintained to a 'local park' standard (as opposed to a regional park standard).
Rain gardens	Rain gardens based on Avon SMP operational and maintenance cost formula. This includes periodic media and plant renewal.
Proprietary filtration devices (PFD, e.g. StormFilter)	PFD cost is based on an estimated cost for the Richardson Tce StormFilter site of $150,000 per annum for 570 cartridges based on information currently available. The actual annual cost for the Richardson Tce device is currently unknown.
Soil adsorption basins	Soil adsorption basins used the figure for dry areas maintained to a 'local park' standard (as opposed to a regional park standard). This reflects that most soil adsorption basins are in residential areas with a high amenity value.
Swales	Swales used the figure for dry areas maintained to a 'local park' standard (as opposed to a regional park standard). This reflects that most swales are in residential areas with a high amenity value. A factor of 50% was added to reflect the small scale of swales.
Proprietary rain garden	Based on a figure supplied by Stormwater 360. No benchmarking was possible.
Discharge to sewer	Discharge to sewer is based on a trade waste discharge cost only. This was estimated as $0.60/m3 assuming 1/3 peak and 2/3 non-peak discharges for the annual rainfall volume (CCC 2021c).

Capital cost curves

The capital cost per impervious hectare for the various treatment devices is shown in the following graphs for small (Figure 1) and large (Figure 2) catchments. For small catchments, all device capital costs have higher unit costs less than 1 ha, after which for the cost curve flattens and is more consistent. In part this is due to the simplifications made in the costing, but also reflects the fixed costs incurred by each device. For larger catchments it is primarily wetlands and PFDs which are most heavily influenced by the scale. Wetlands clearly benefit from economies of scale as they get larger and the fixed costs (design, consenting, inlet and outlets) are spread across a larger area. This is likely the case for the other devices as well, and the flatness of the curves may reflect simplifications in the cost estimates rather than a completely linear increase in cost with catchment size.

Operational cost curves were not prepared as many of these are directly related to device area which is in turn directly related to impervious area. As such the information provided by these curves is minimal.

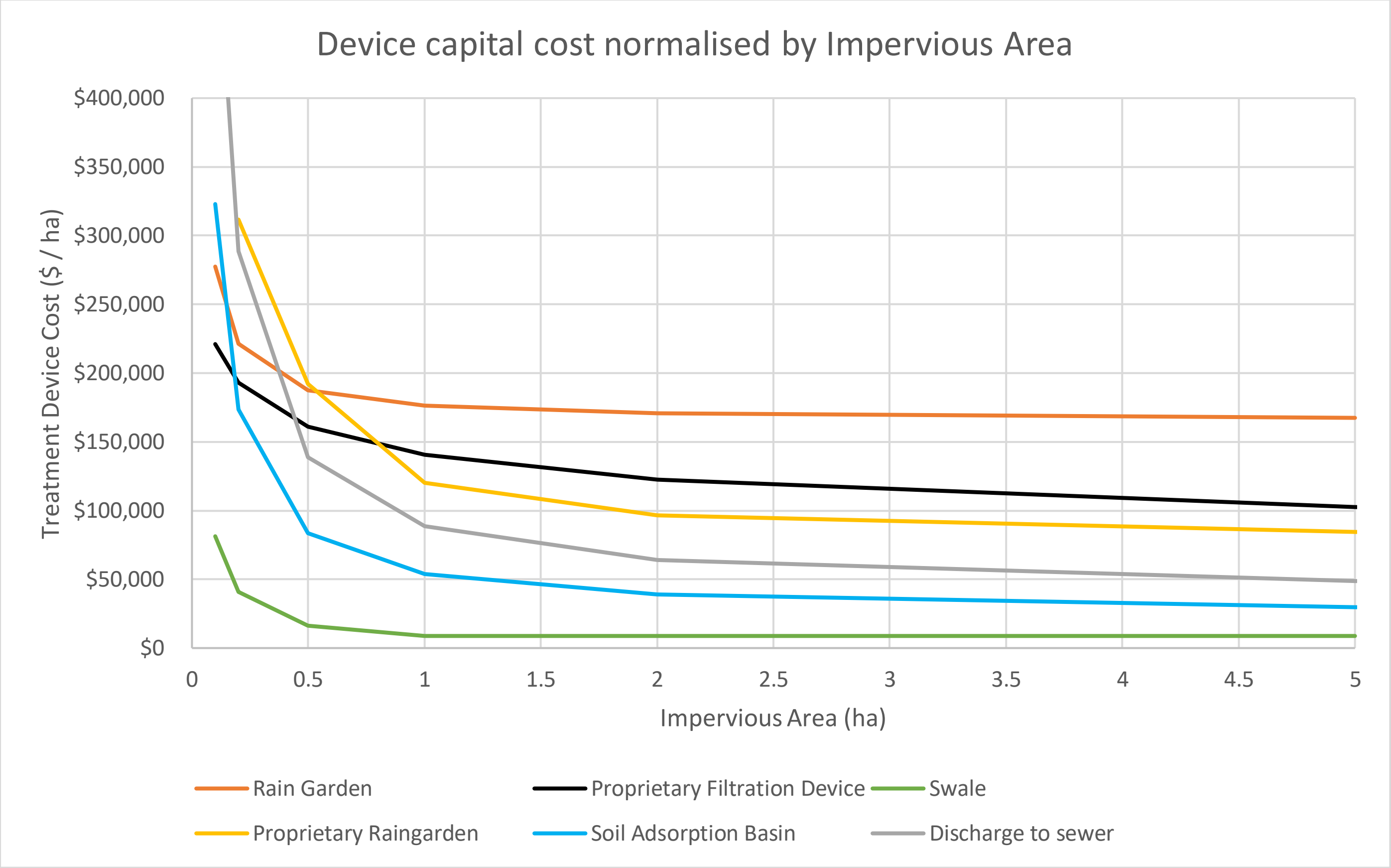

Figure 1 Device capital cost normalised by Impervious Area for small catchments

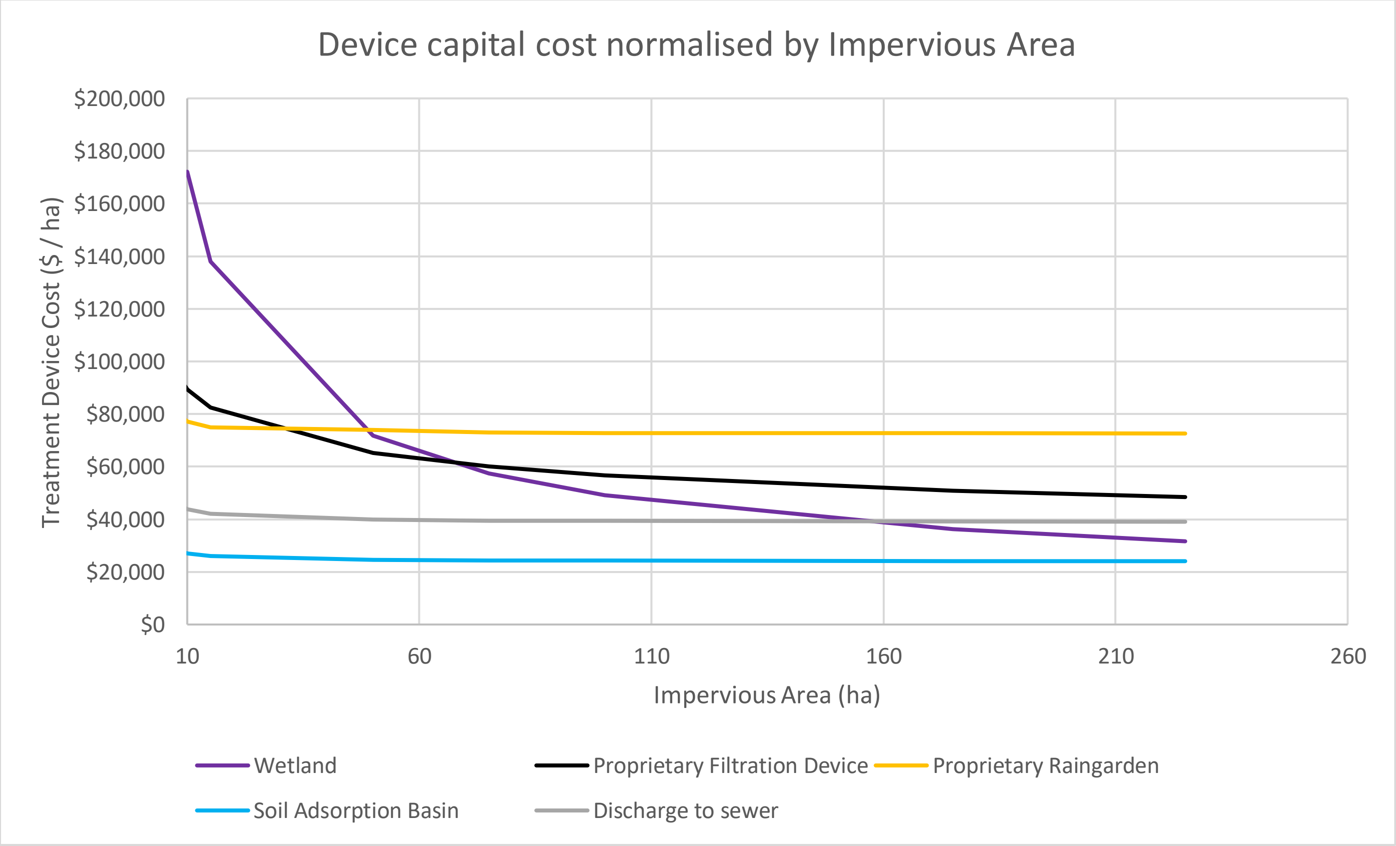

Figure 2 Device capital cost normalised by Impervious Area for large catchments

NPV cost curves

The NPV of the whole of life costs by impervious area are provided in Figure 3 and Figure 4 for both small and large catchments. Due to the way that the costs are built up, these show a relatively linear increase in cost with an increasing impervious catchment area.

For small catchments (Figure 3), swales have the cheapest whole of life cost, but as discussed previously, these are typically only accepted as pre-treatment in Christchurch. This is due to the difficulty in obtaining sufficient grade, and problems with maintenance to ensure adequate performance. For an improved performance, soil adsorption basins are the next most cost effective, followed by proprietary rain gardens and discharge to sewer. Proprietary filtration devices and rain gardens are the most expensive based on the information used. However, where land purchase is required, then small footprint devices (such as PFDs) or devices that can be installed in the street (such as rain gardens) may prove more cost effective than soil adsorption basins.

For large catchments (Figure 4), soil adsorption basins are the most cost effective followed by wetlands, although at the smaller end of the scale (an impervious area of 10 Ha or wetland size of 9,000 m²) wetlands are more expensive than many devices. Discharge to sewer is the next most expensive, followed by proprietary rain gardens and then PFDs.

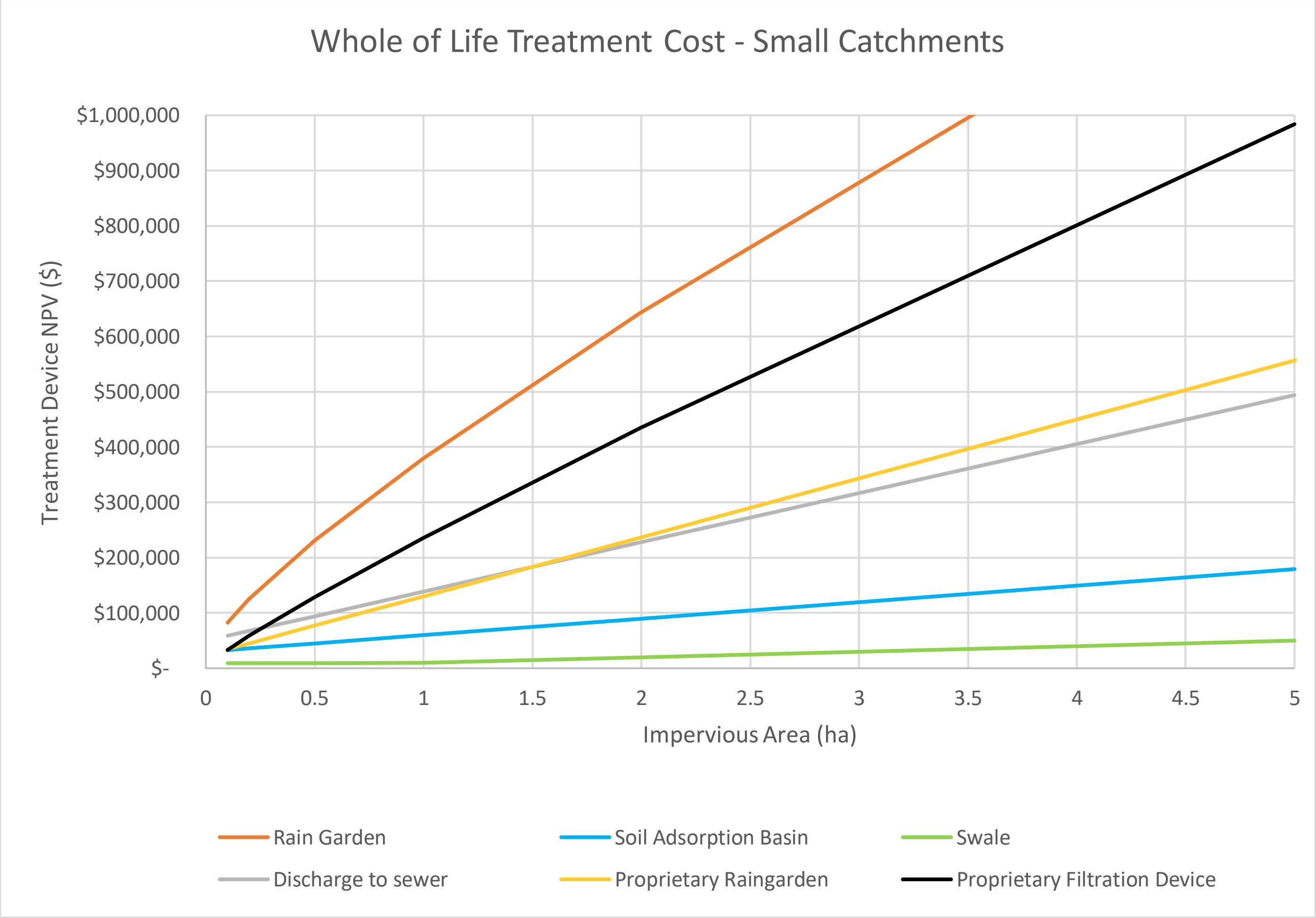

Figure 3 Treatment device NPV for small catchments

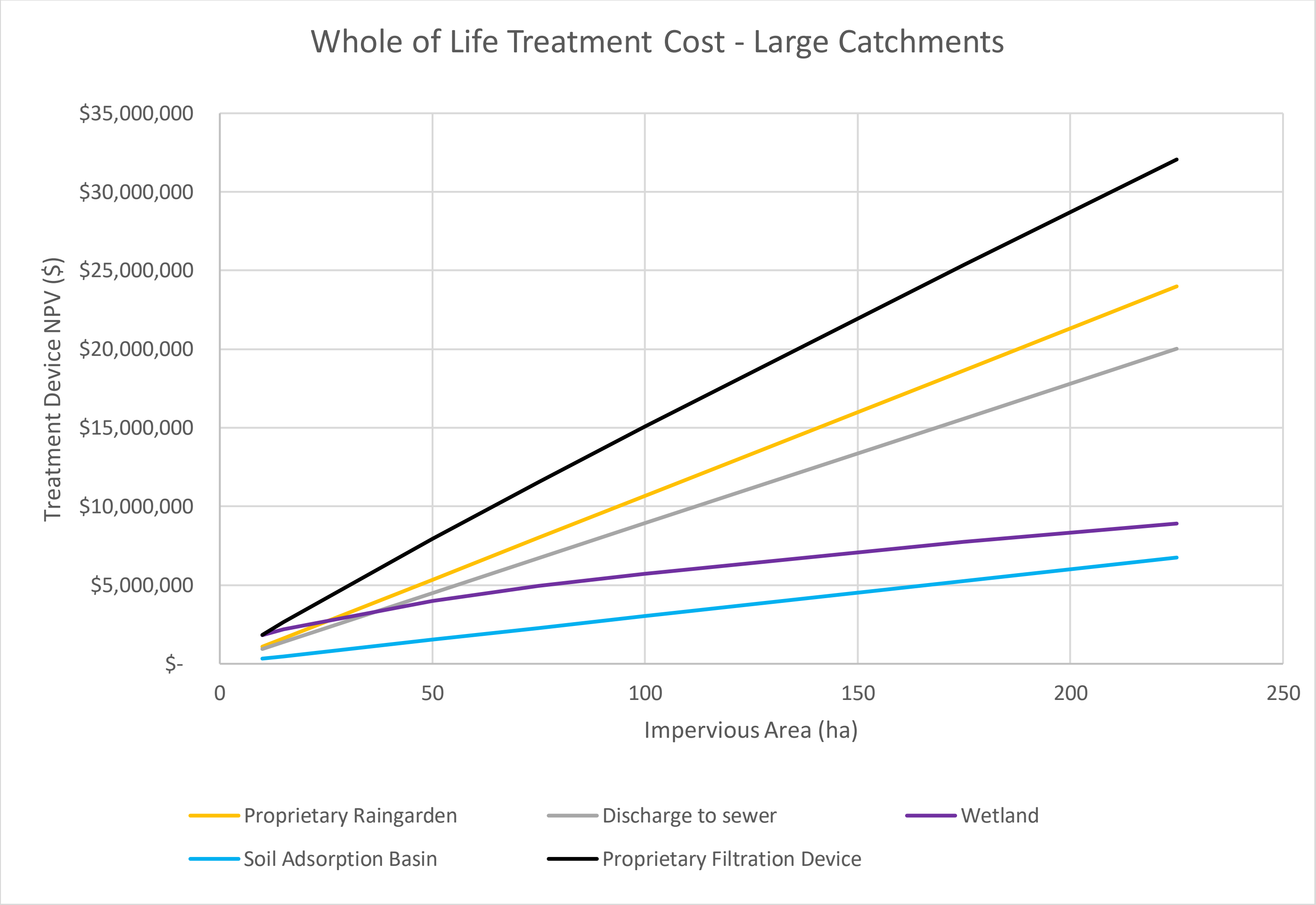

Figure 4 Treatment device NPV for large catchments

Contaminant load generation and treatment efficiency

To maintain consistency, the contaminant load model (C-CLM) developed for the CSNDC (Golder, 2018) was used as a basis for establishing base contaminant generation rates for residential areas and commercial / industrial areas. Total suspended solids (TSS) and zinc (Zn) were selected as indicator contaminants because they are persistent in stormwater and affected by each of the stormwater treatment methods considered in this CBA. There are also reduction targets specified for them in the CSNDC. While copper could have been included in the analysis as well, the removal rates (and therefore benefits) are similar to those of zinc and it was not considered that including copper would provide additional insight into the benefits.

The C-CLM was peer reviewed for CCC as part of the CSNDC process (Kennedy, 2018). This report noted the limitations of the model, principally that:

- *"The reduction estimates are based on contaminant yields and treatment efficiencies that are general estimates based on best available data.*
- *Both the yield estimates and the treatment reductions have large confidence limits around the reduction estimates produced from scenarios developed. The predictions therefore must be regarded as informed reductions not absolute predictions."*

The review concluded that,

> *Overall, the C-CLM is a suitable tool for providing estimates of the relative reduction of stormwater contaminant loads over time as a result of treatment facilities and devices bring proposed and implemented by CCC. As such, bearing in mind the limitations of the model noted above and in ARC (2011), it is therefore suitable for use as a performance indicator in the CSNDC.*

Therefore, while it is acknowledged that there are limitations in the C-CLM and that better tools exist (e.g. MEDUSA), it is considered suitable to use as a comparative tool.

To determine whether land use had an impact, contaminant generation rates for residential areas and commercial / industrial areas were developed. To determine the contaminant generation rates for a typical residential area, the rates for two modelled residential catchments (Avonside and Ilam) were averaged and used in the analysis. The Curletts catchment was used to derive similar figures for commercial / industrial areas (Table 7). These rates were compared to new residential and new commercial / industrial areas from the same report (Table 8).

Table 7 Modelled C-CLM contaminant generation rates (extracted from Appendix B, Golder (2018))

Typical catchments	Area (ha)	TSS (tonne/yr)	Zinc (kg/yr)	Classification	TSS ($g/m^2/yr$)	Zinc ($g/m^2/yr$)
Avonside	293	79	418	Residential	26.96	0.143
Ilam	310	63	319	Residential	20.32	0.103
				Assumed Residential Average	23.64	0.123
Curletts	356	91	1074	Commercial / industrial	25.56	0.302

Table 8 Modelled C-CLM contaminant generation rates by surface type replicated from Table 2, Golder (2018)

Surface Type	Sub-Type	TSS (g/m²/yr)	Zinc (g/m²/yr)	New Residential (%)	Commercial / industrial (%)
Grass	Urban	27	0.0016	51.9	20
	Rural	12.6	0.0007		
Roofs	Concrete	9.6	0.02		5
	Galvanised unpainted	3	2.24		
	Galvanised poor paint	3	1.34		
	Galvanised well painted	3	0.2		
	Decramastic	7.2	0.28		
	Coloursteel	3	0.02	17	
	ZincAlume	3	0.2		20
	Unknown	6	0.02	2.1	5
Roads	Private Road	12.6	0.0044	9	2
	Local Road	16.8	0.0266	4.6	6
	Collector	31.8	0.1108	1.9	10
	Minor arterial	57.6	0.2574	0.5	2
	Major arterial	94.8	0.4711		
Paved	Residential	19.2	0.195	12.6	
	Commercial	19.2	0		15
	Industrial	13.2	0.59		15
Construction		1500	0.088	51.9	20
Total %				100	100
Weighted Generation TSS (g/m²/yr)				24.3672	17.232
Weighted Generation Zinc (g/m²/yr)				0.0344962	0.148732

The combination of the generation rates by area produced catchment loadings for various catchment areas (Table 9) for both typical catchment types: residential and commercial / industrial.

Table 9 Contaminant load by development type

Impervious catchment area (ha)	TSS (Residential) (kg / yr)	TSS (Commercial / industrial) (kg / yr)	Zinc (Residential) (kg / yr)	Zinc (Commercial / industrial) (kg / yr)
0.1	24	26	0.1	0.1
0.2	47	51	0.2	0.2
0.5	118	128	0.6	0.6
1	236	256	1.2	1.2
2	473	511	2.5	2.5
5	1,182	1,278	6.1	6.1
10	2,364	2,556	12.3	12.3
50	11,821	12,781	61.4	61.4
100	23,643	25,562	122.8	122.8

As the resultant difference between contaminant generation from residential and commercial/industrial impervious areas in Table 9 is relatively small , an averaged contaminant load has been used to compare the devices for simplicity.

Capture rates were extracted from the Golder report[3] to indicate the potential efficacy of the treatment devices (Table 10 and Table 11). These rates do not express the potential variability in capture rates due to varied levels of maintenance and catchment conditions. It is assumed that the devices are maintained to the high standard necessary to achieve the removal rates below, and this is reflected in the operational costs above. They also provide consistency with those used in the C-CLM and therefore the CSNDC.

Table 10 TSS removal rates (%) for treatment devices replicated from Table 6, Golder (2018)

Treatment System	Roofs	Roads	Paved	Grass
First flush basin & wetland	50	80	80	80
Rain garden and proprietary rain garden[4]	70	80	80	80
Proprietary filtration devices (PFD, e.g. StormFilter)	50	75	75	75
Soil adsorption basins	89	89	89	89
Swale	30	30	75	75
Discharge to sewer[5]	89	89	89	89

Table 11 Total zinc removal rates (%) for treatment devices replicated from Table 6, Golder (2018)

Treatment System	Roofs	Roads	Paved	Grass
First flush basin & wetland	25	60	60	60
Rain garden and proprietary rain garden	60	70	70	70
PFD	15	40	40	40
Soil adsorption basins	71	71	71	71
Swale	15	40	40	40
Discharge to sewer	71	71	71	71

Combining the contributing areas from Table 8 with the removal rates from Table 10 and Table 11 gives indicative removal rates (%) for devices by land use (Table 12).

Table 12 Removal rates (%) for treatment devices by land use

Treatment System	TSS Residential	TSS Commercial	TSS Average	Total Zinc Residential	Total Zinc Commercial	Total Zinc Average
First flush basin & wetland	74	71	72	53	50	51
Rain garden and proprietary rain garden	78	77	77	68	67	67
PFD	70	68	69	35	33	34
Soil adsorption basins	89	89	89	71	71	71
Swale	59	53	56	35	33	34
Discharge to sewer	89	89	89	71	71	71

As there was little difference in the removal rates between the residential and commercial catchments, only the average removal rate was used in the analysis (Figure 5).

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[3] The C-CLM report states that, “the load reduction factors used in the C-CLM model are the largest reductions that could be expected for well designed, installed and maintained devices.” (Golder, 2018).

[4] Conventional and proprietary rain gardens were assumed to have the same contaminant removal rates.

[5] Assumed to be similar to soil adsorption basins as it is primarily based on bypass.

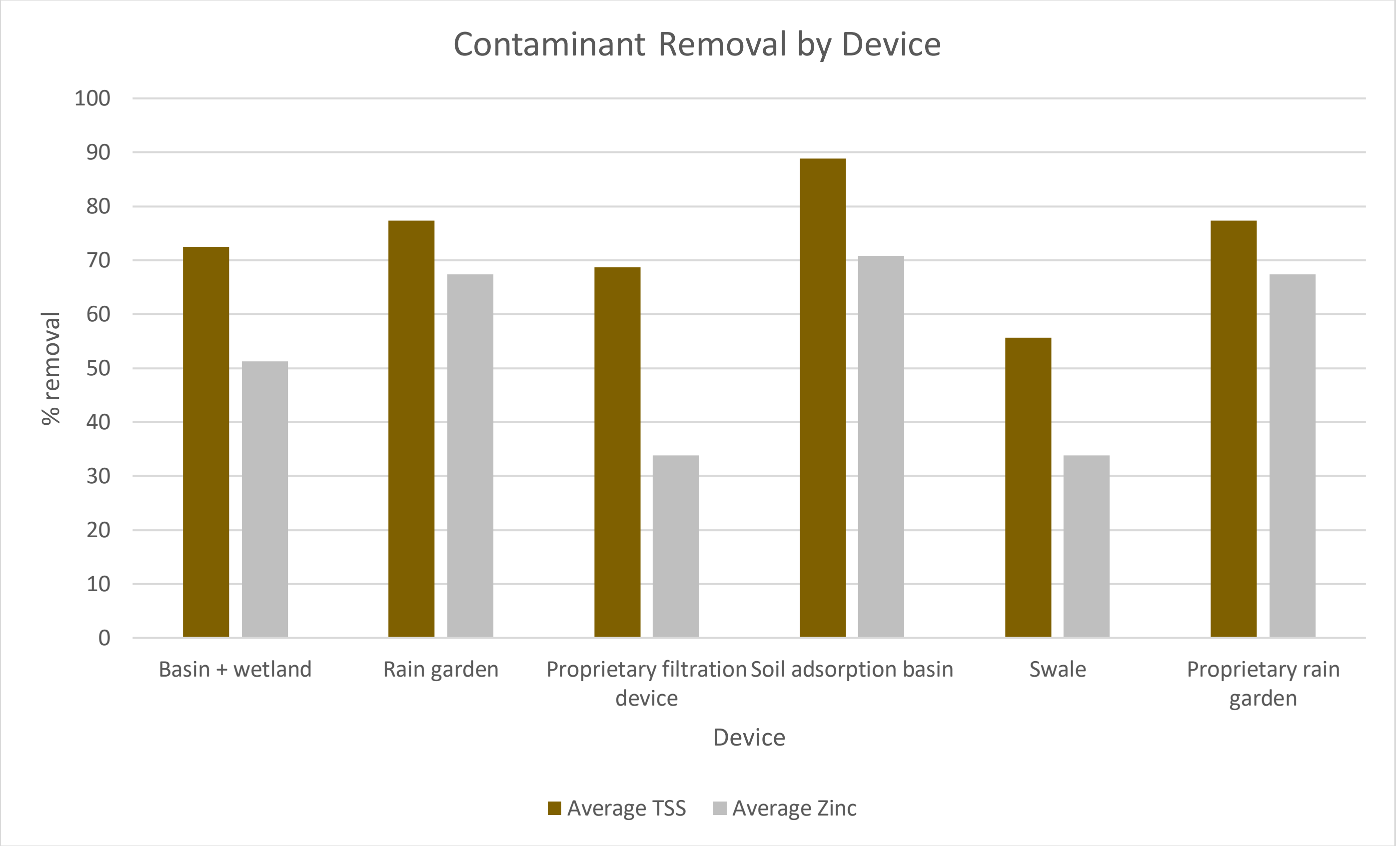

Figure 5 Contaminant removal rate by device type

The costs by treated impervious area were then compared to the estimated contaminant removal as described in the next section.

Assumptions

The following key assumptions were made in assessing treatment efficiency:

1. The treatment efficiencies in the C-CLM are appropriate for use in this comparison.
2. Treatment devices were maintained to a sufficient standard to achieve the stated capture rates.
3. Treatment efficiencies are uniform throughout the event and for all concentrations. This is a simplification with differing impacts across the different devices.
4. Bypass is excluded from the analysis on the assumption that all devices have the same amount of bypass. In reality the different devices will have differing amounts of bypass depending on the design assumptions made, and this could have a large impact on treatment efficiency.
5. All devices have a similar operational life (i.e. fifty years).

Benefit analysis

For this analysis, the benefits have been assessed in terms of contaminant removal only. CCC has a six-values approach to stormwater management, where not only is drainage considered, but also culture, ecology, landscape, heritage and recreation. There are also other methods to assess the benefits of stormwater management devices which take into account a wider range of environmental and social co-benefits (e.g. Moore and Batstone, 2019). However, in order to simplify the analysis the benefits have been assessed only in terms of modelled contaminant removal: the different benefits provided by alternative devices is included in the discussion.

The first step of the process was to calculate the removal rates by device for different contributing impervious areas (Table 13 and

Table 14). This was followed by assessing the cost to remove the contaminant by device type and size.

Table 13 TSS removal by catchment area and treatment device type (kg/yr)

Impervious catchment area (ha)	Contaminant Load (kg/yr)	TSS Removal (kg/yr)						
		Wetland	Rain Garden	PFD	Swale	Proprietary Rain Garden	Soil Adsorption Basin	Discharge to sewer
0.1	**24**	18	19	17	14	19	22	22
0.2	**49**	35	38	33	27	38	43	43
0.5	**121**	88	94	83	68	94	108	108
1	**243**	176	188	167	135	188	216	216
2	**486**	352	376	334	271	376	432	432
5	**1,215**	880	940	835	677	940	1,079	1,079
10	**2,430**	1,761	1,880	1,669	1,353	1,880	2,158	2,158
15	**3,644**	2,641	2,820	2,504	2,030	2,820	3,237	3,237
50	**12,148**	8,804	9,401	8,347	6,767	9,401	10,790	10,790
75	**18,222**	13,206	14,101	12,521	10,150	14,101	16,185	16,185
100	**24,296**	17,609	18,802	16,694	13,534	18,802	21,580	21,580
175	**42,518**	30,815	32,903	29,215	23,684	32,903	37,766	37,766
225	**54,666**	39,619	42,304	37,563	30,451	42,304	48,556	48,556

Table 14 Total zinc removal by catchment area and treatment device type (kg/yr)

Impervious catchment area (ha)	Contaminant Load (kg/yr)	Total Zinc Removal (kg/yr)						
		Wetland	**Rain Garden**	**PFD**	**Swale**	**Proprietary Rain Garden**	**Soil Adsorption Basin**	**Discharge to sewer**
0.1	**0.2**	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.2	**0.4**	0.2	0.3	0.1	0.1	0.3	0.3	0.3
0.5	**0.9**	0.5	0.6	0.3	0.3	0.6	0.7	0.7
1	**1.9**	1.0	1.3	0.6	0.6	1.3	1.3	1.3
2	**3.8**	1.9	2.5	1.3	1.3	2.5	2.7	2.7
5	**9.4**	4.8	6.4	3.2	3.2	6.4	6.7	6.7
10	**18.9**	9.7	12.7	6.4	6.4	12.7	13.4	13.4
15	**28.3**	14.5	19.1	9.6	9.6	19.1	20.1	20.1
50	**94.4**	48.4	63.6	31.9	31.9	63.6	66.9	66.9
75	**141.6**	72.6	95.5	47.8	47.8	95.5	100.4	100.4
100	**188.8**	96.9	127.3	63.8	63.8	127.3	133.8	133.8
175	**330.5**	169.5	222.8	111.6	111.6	222.8	234.2	234.2
225	**424.9**	217.9	286.4	143.5	143.5	286.4	301.1	301.1

Present day cost (NPV) per kg contaminant removed

In order to compare the cost efficiency of contaminant removal between different devices, the NPV[6] device cost has been converted to an annual cost (by dividing the NPV by 50) and then divided by the mass of contaminant removed. This is shown below for TSS and zinc to demonstrate how the cost of removal per unit of contaminant varies by device and by catchment size.

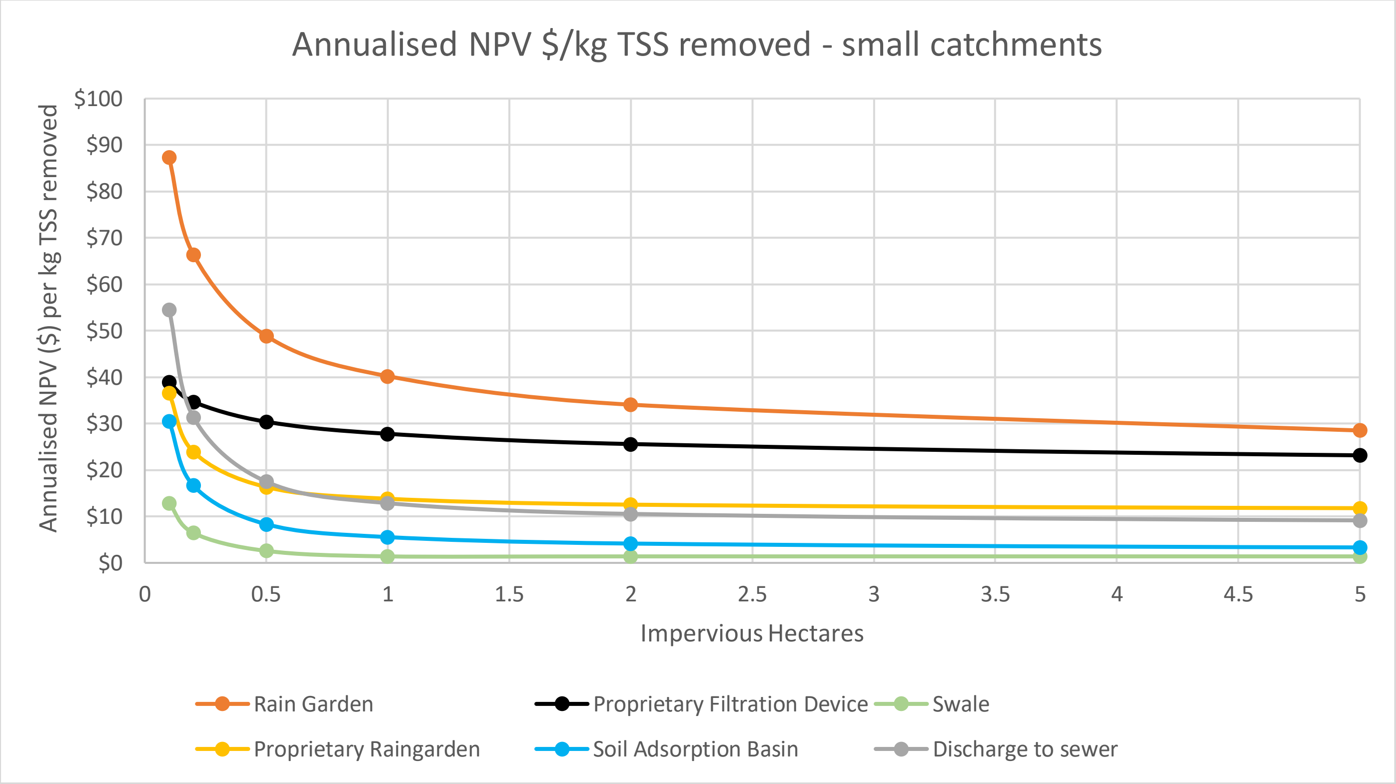

Figure 6 Annualised present day cost (NPV) per unit of TSS removed - small catchments

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[6] All NPV figures are calculated assuming a 50 year period and 5% discount rate.

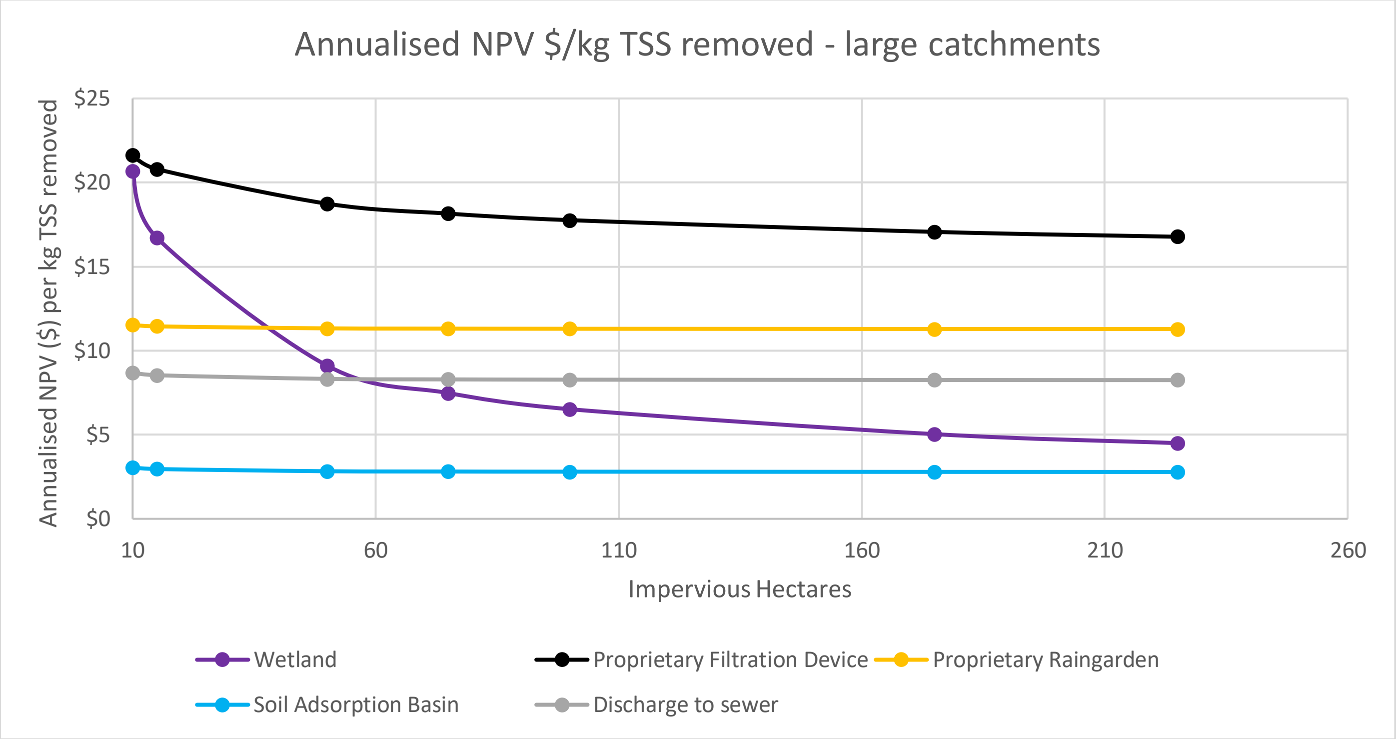

Figure 7 Annualised present day cost (NPV) per unit of TSS removed - large catchments

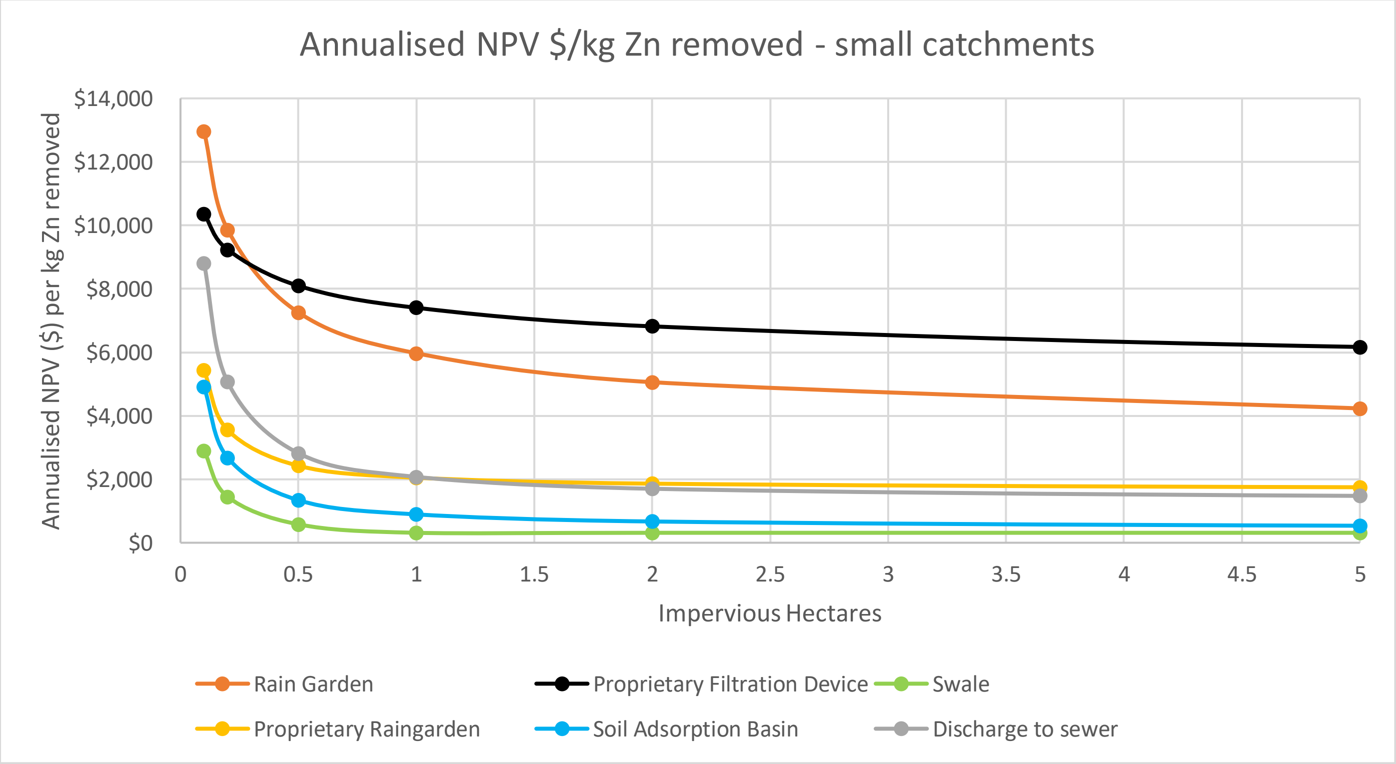

Figure 8 Annualised present day cost (NPV) per unit of zinc removed - small catchments

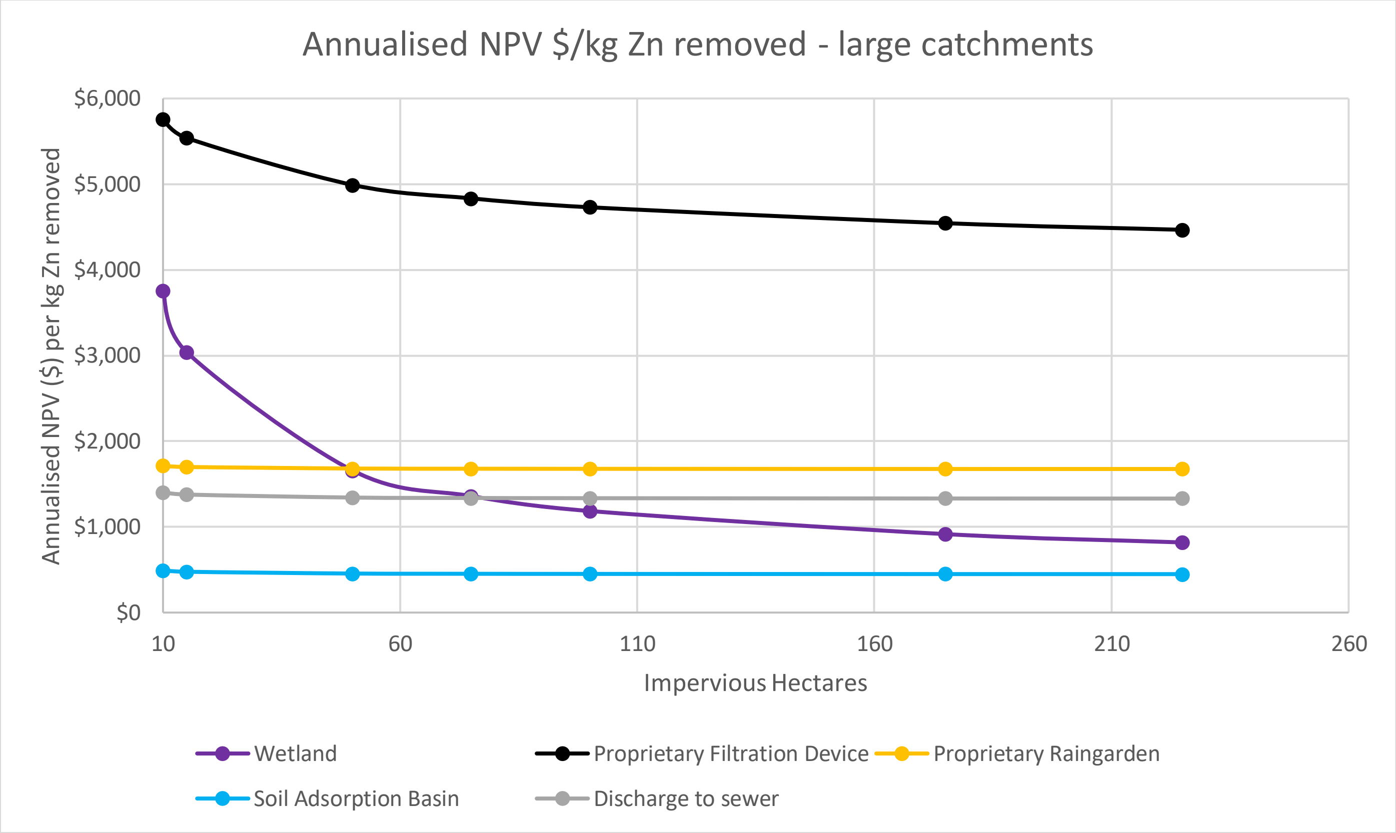

Figure 9 Annualised present day cost (NPV) per unit of zinc removed - large catchments

The figures above have been averaged by catchment size to allow easier comparison between devices.

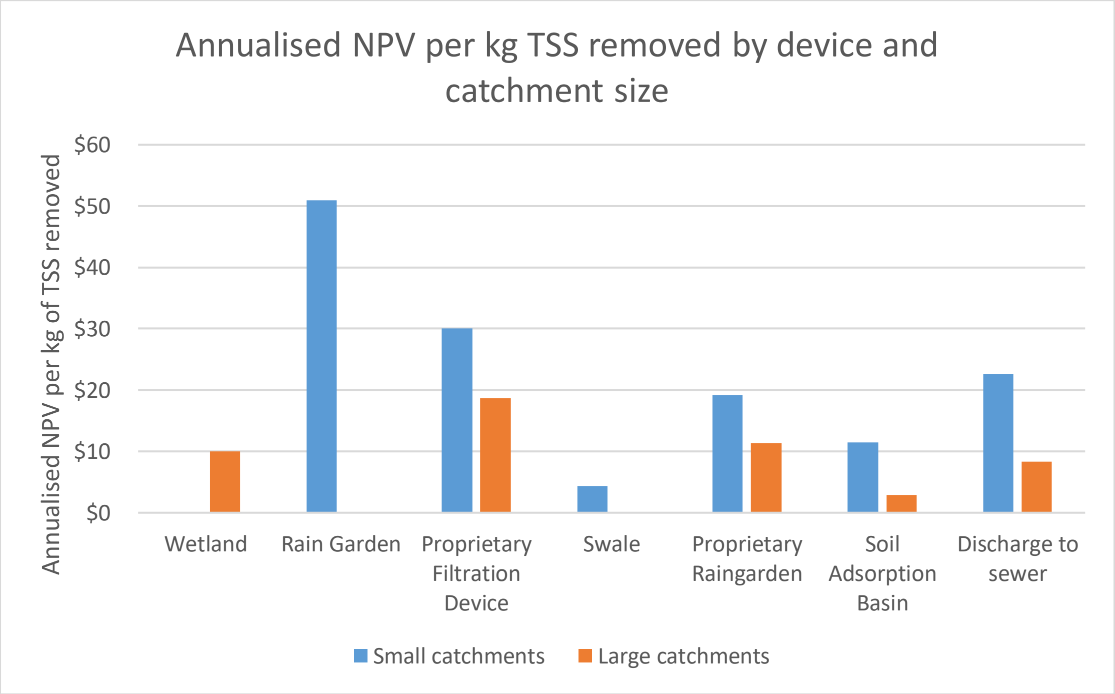

Figure 10 Annualised present day cost (NPV) per unit of TSS removed averaged by catchment size

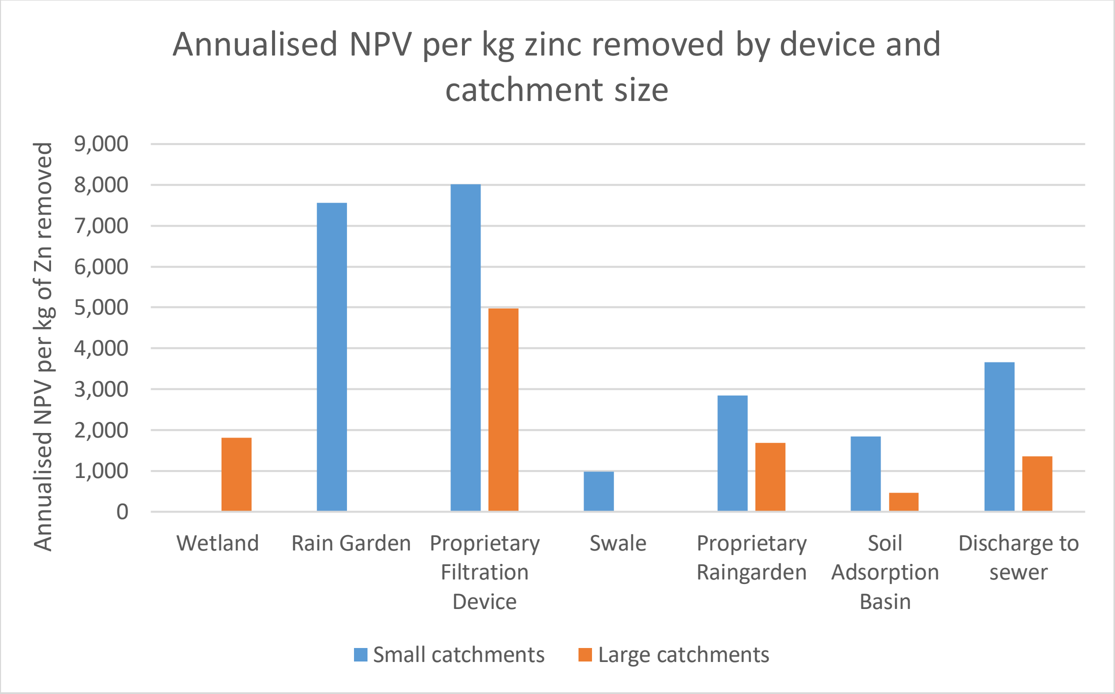

Figure 11 Annualised present day cost (NPV) per unit of zinc removed averaged by catchment size

Another way of looking at this is to consider the NPV for a given removal of zinc in kg per year. This is shown below for TSS (Figure 12) and zinc (Figure 13). For example, the NPV cost to remove 10,000 kg of TSS per year varies from approximately $1.5M for a soil adsorption basin up to almost $9M for a PFD.

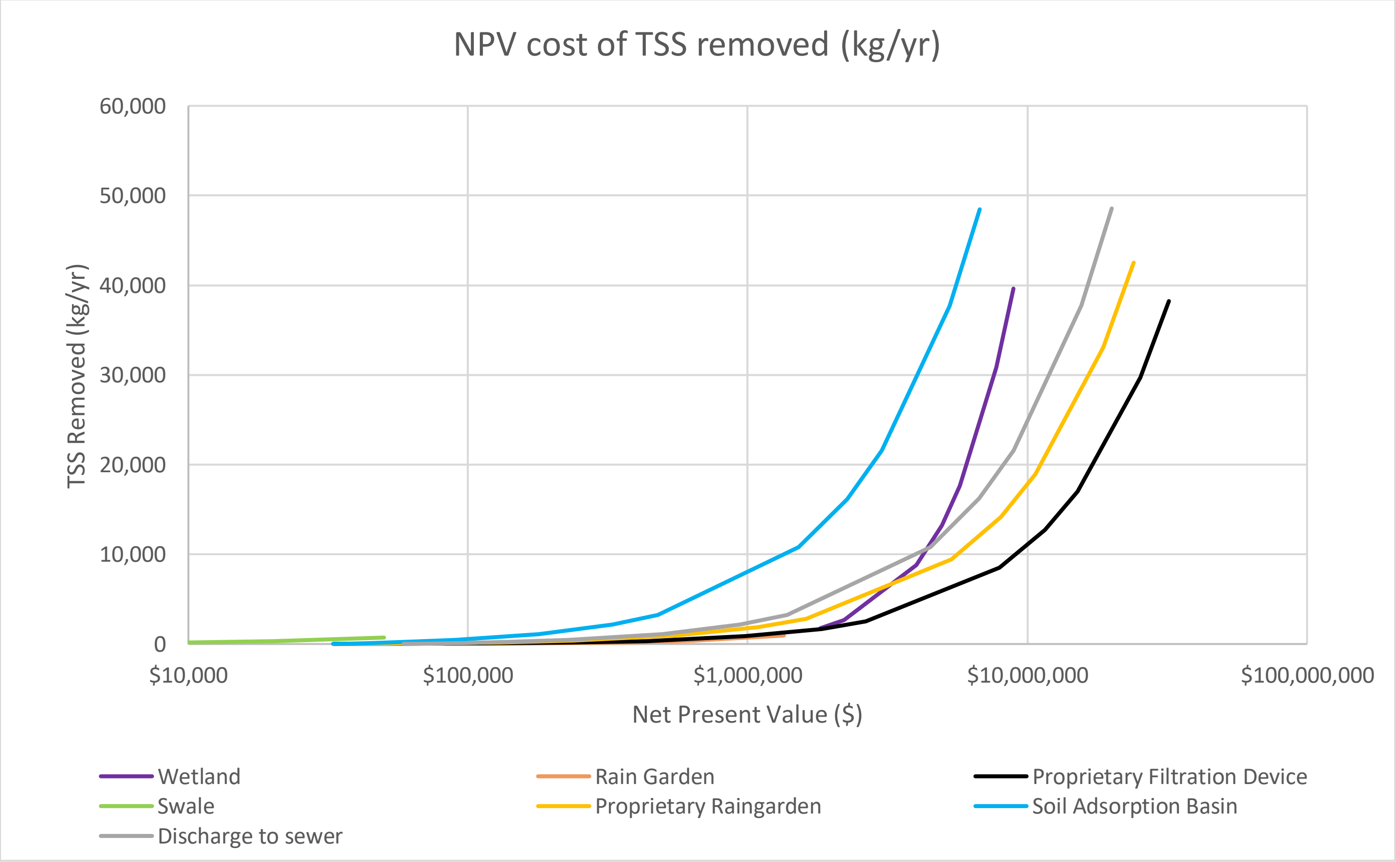

Figure 12 NPV cost per amount of TSS removed annually

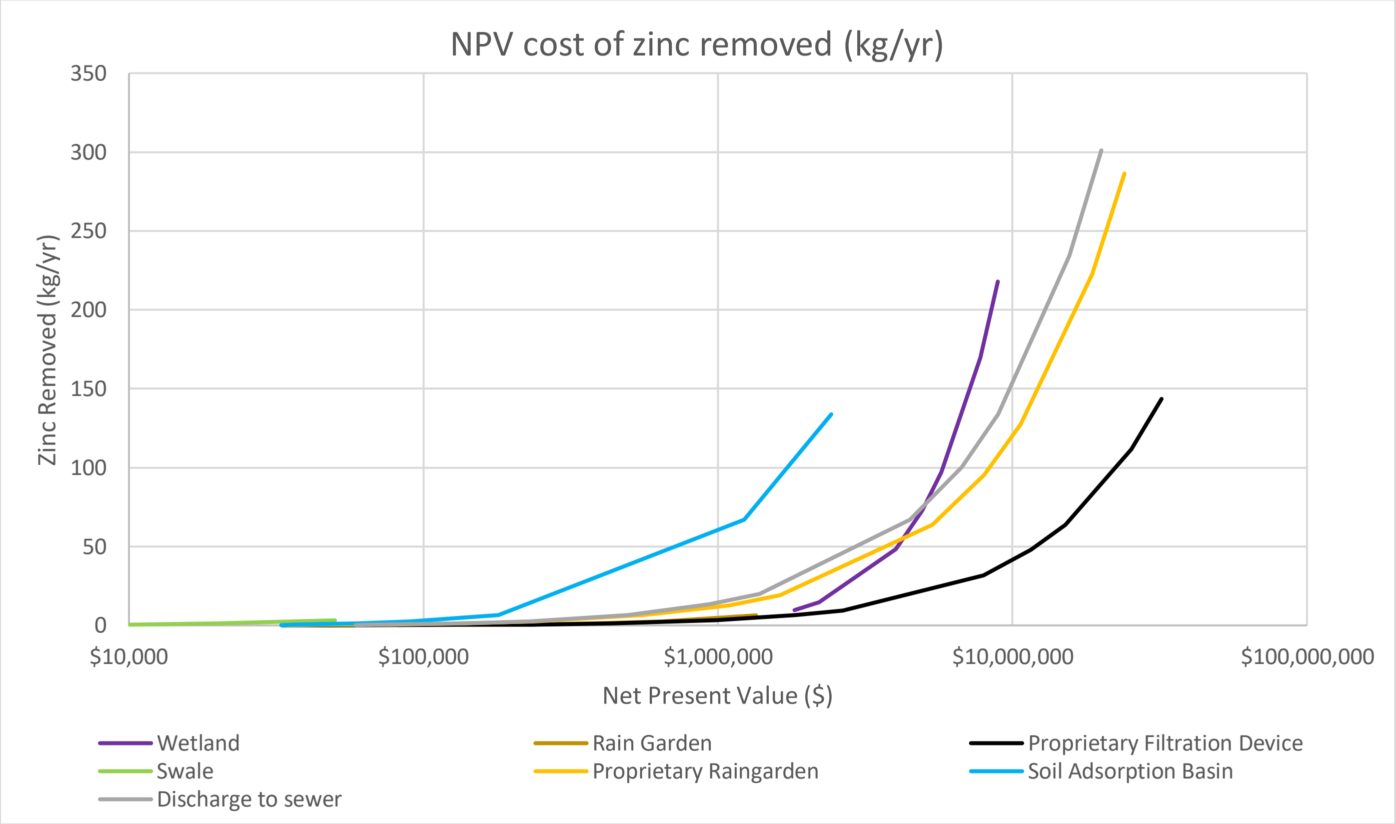

Figure 13 NPV cost per amount of zinc removed annually

Discussion

The analysis has considered the costs (capital and operational only) and benefits (in modelled contaminant removal) of treatment devices which are applicable in the Christchurch context. In general, the list of devices from the highest cost-benefit ratio to the lowest is shown in the table below.

Table 15 Treatment devices from highest to lowest cost-benefit ratio based on contaminant and catchment size

Rank	TSS – small catchment	TSS – large catchment	TSS – all catchments	Zinc – small catchment	Zinc – large catchment	Zinc – all catchments
1	Swale	Soil adsorption basin (MAR)	Swale	Swale	Soil adsorption basin (MAR)	Swale
2	Soil adsorption basin (MAR)	Discharge to sewer	Soil adsorption basin (MAR)	Soil adsorption basin (MAR)	Wetland	Soil adsorption basin (MAR)
3	Proprietary rain garden	Wetland	Wetland	Proprietary rain garden	Discharge to sewer	Wetland
4	Discharge to sewer	Proprietary rain garden	Discharge to sewer	Discharge to sewer	Proprietary rain garden	Proprietary rain garden
5	PFD	PFD	Proprietary rain garden	Rain garden	PFD	Discharge to sewer
6	Rain garden		PFD	PFD		Rain garden
7			Rain garden			PFD

Based on this assessment, and recognising the limitations of swales and discharge to sewer, the generalised rank of devices from highest to lowest cost-benefit ratio is:

- Soil adsorption basin (MAR)
- First flush basin and wetland
- Proprietary rain garden
- Proprietary filtration device / rain garden (depending on contaminant)

This largely matches the general device selection preference currently practiced by CCC. If swales were able to be consistently designed and installed to allow for easy maintenance and consistent contaminant removal, then for small catchments these may provide a better cost-benefit ratio than other devices.

There are a number of limitations and gaps in the study, some of which have been discussed previously. One of the main limitations is that the benefits are assessed solely in terms of contaminant removal, ignoring the environmental and social co-benefits that may result from different devices. As CCC has a six-values approach to stormwater management, these co-benefits are important to acknowledge. For instance, wetlands provide an opportunity to include all six benefits in both terrestrial and aquatic habitats, whereas proprietary in-ground devices provide water quality benefits only to the waterway. Likewise soil adsorption basins typically provide less terrestrial ecological benefit as they are typically grassed, although the wide spaces are often used for recreation.

As well as cost and benefits, there are other strong drivers in the selection of devices for stormwater management (refer CCC 2012, chapter 6). The soil and groundwater conditions of a site, along with topography, dictate what devices are suitable. While soil adsorption basins provide a cost-effective means of stormwater treatment where the spoils are suitable and the depth to groundwater is sufficiently deep, they are limited in their application where groundwater is high, which is true in many places in Christchurch. Space constraints and the cost of land often limit the choice of retrofitted stormwater devices, meaning that soil adsorption basins and wetlands may not be feasible in those areas. While rain gardens and PFDs may be more expensive when there are no space constraints, the small footprint of these devices often makes them more suitable for retrofit.

Recommendations

Schedule 4D required that CCC “conduct a cost/benefit analysis of options of alternate methods of stormwater treatment and discharge including consideration of redirection to the sewer and Managed Aquifer Recharge/Discharge (For consideration as part of Council Annual Planning process).” The analysis has confirmed that the current device selection process utilised by CCC provides the optimum cost to benefit outcome in most situations. As such, no change to the current planning process is recommended, with the caveat that it is acknowledged that there are many situations where this generalised analysis may not be applicable.

Areas for further development which may improve this analysis include:

- Refining contaminant load modelling to better understand the contaminant generation for different sites
- Undertaking continuous simulation modelling (e.g. MUSIC) for a range of catchment types and sizes for each device to allow for inclusion of bypass assessment
- Refining the contaminant removal efficiencies of each device across the particulate and dissolved fractions and for different contaminant concentrations
- Including renewal costs
- Further investigation of large-scale corrective maintenance costs which may fall outside of renewal costs. For example, rectifying blockages and/or cleaning sediment out of soil adsorption basins
- Include land costs
- Improved understanding of lifecycle costs across all devices

While the improvements listed above would improve the analysis, it is unlikely that the device selection process would change significantly.

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Appendix A - Technical Review of Scope of Cost/Benefit Analysis for CSNDC Schedule 4D

Prepared by	Sue Ira, Koru Environmental Consultants Ltd, on behalf of Technical Peer Review Panel (TPRP)
Prepared for	Christchurch City Council (CCC)
Dated	14 April 2021

Purpose

This technical peer review panel (TPRP) scope review is prepared on behalf of Christchurch City Council (CCC) to fulfil the requirements of Condition 14c of the Comprehensive Stormwater Network Discharge Consent (CSNDC aka CRC190445).

Scope

A scope for the cost/benefit analysis for CSNDC Schedule 4D has been developed by CCC for TPRP review. The review is to be undertaken by the appointed expert(s), and should focus on each panel member's area of expertise.

The following items should form part of this review:

- CSNDC and associated schedules to be familiar with the consent requirements.
- CBA to ensure it meets the relevant requirements of Condition 40 and Schedule 4D.
- This document to ensure it meets the relevant requirements of Condition 14c.

Review Format: Collective ☐ Individual ☒

Peer Review Collaborators (if Collective)

N/A

Documents Provided

- Comprehensive Stormwater Network Discharge Consent (CSNDC)
- Scope for Cost/Benefit Analysis for CSNDC Schedule 4D

Peer Reviewer Methodology/Response

A life cycle costing (LCC) approach is currently used nationally and internationally as a key method for estimating costs associated with stormwater interventions. The use of LCCs within this scope of works to inform a Cost Benefit Analysis (CBA) would therefore be considered best practice. The assessment of benefits has been restricted to contaminant removal benefits of the different interventions.

Taking account of the comments provided within this review (below), it is considered that the proposed scope of works and methodology generally meets the intent of Condition 40 and Schedule 4D.

In this regard, it is recommended that the authors give consideration to the following comments:

1. Whilst I generally agree with CCC's interpretation of Schedule 4d, I do believe that the scope should also include methods of treatment which are currently best practice internationally but which are not 'existing devices' being used by CCC at present, such as swales, tree pits and green roofs. Schedule 4d references the requirements for a CBA of "alternative" treatment methods <u>in addition to</u> methods of disposal. In this case, I believe "alternative" to mean more than just existing devices. As such it may be wise to include a few treatment methods which are currently not being used by CCC in order to fully meet the intent of Schedule 4d.
2. For clarity it would be helpful to list the types of proprietary filtration devices which will be included in the CBA.
3. Methodology: Costs – it is noted that the Auckland Council FWMT work primarily provides LCCs based on the surface area of a device. As such, the authors may wish to review/ decide upon the unit of the LCC

data once the literature review has been completed. Alternatively, an additional step would be needed to convert the $/m2/yr LCCs to a water quality volume cost.

4. Methodology: Benefits – it appears that the benefit assessment focusses solely on water quality benefits (i.e. contaminant removal). Given the scope of the CSNDC, this is likely to meet the intent of Condition 40 and Schedule 4d. It should be noted that many of the stormwater treatment methods have social, economic, cultural and environmental benefits which are beyond water quality. It may be worth acknowledging this in the CBA assessments (potentially additional benefits of each method, over and above water quality benefits, could be listed)
5. Optional comparison of benefits for different landuse types: This sounds like a good approach, but would require some careful thought to implement. Maintenance levels or requirements for high traffic roads/ industrial vs residential would be quite different, which affects the LCC. The authors may wish to use high LCC estimates for commercial areas vs low LCC estimates for residential areas. I don't think it would be correct to use the same LCCs to do this comparison.

These individual comments on the proposed scope of works and methodology are also included on the scope of works document itself (as track changes/ comments).

Appendix B - Technical Review of Cost/Benefit Analysis for CSNDC Schedule 4D

Prepared by	Technical Peer Review Panel (TPRP)
Prepared for	Christchurch City Council (CCC)
Dated	8 July 2021

Purpose

This technical peer review panel (TPRP) review is prepared on behalf of Christchurch City Council (CCC) to fulfil the requirements of Condition 15c of the Comprehensive Stormwater Network Discharge Consent (CSNDC, CRC190445).

Scope

A cost/benefit analysis for CSNDC Schedule D has been developed by CCC for TPRP review. The review is to be undertaken by the appointed expert(s) and should focus on each panel member's area of expertise.

The following items should form part of this review:
- CSNDC and associated schedules to be familiar with the consent requirements.
- CBA to ensure it meets the relevant requirements of Condition 40 and Schedule 4D.
- This document to ensure it meets the relevant requirements of Condition 15c.

Review Format: Collective ☐ Individual ☒

Peer Review Collaborators (if Collective)

Documents Provided

- Comprehensive Stormwater Network Discharge Consent (CSNDC)
- Cost/Benefit Analysis for CSNDC Schedule 4D

Peer Reviewer Methodology/Response

Thank you for providing the Cost/ Benefit Analysis (CBA) for CSNDC Schedule 4D to me for review. I found the document very interesting and informative to read. The costs presented provide a good mix of local cost data from CCC's own records and national cost data. The contaminant removal benefits are generated from a previously peer reviewed report and C-CLM model by Golder (2018). Overall, it is considered that the CBA provides a "fit-for-purpose" assessment of the relative difference in costs and contaminant removal benefits of the selected stormwater treatment devices. Some detailed comments have been provided below for your consideration.

- Table 4: Without seeing the detailed workings which have contributed to the development of the cost equations, I cannot fully review this aspect of the analysis. As a general comment, I wonder whether all of the maintenance costs/ formulas provided in Table 4 account for large scale corrective maintenance activities and associated costs, For example, rectifying blockages and/ or cleaning sediment out of soil adsorption basins. Generally, the maintenance costs are also not reflective of the inverse relationship between surface area size and the maintenance cost of a device. Having said that, the overall NPV $ values are reasonably consistent with what has been found in the literature and it is unlikely that further investigation into these aspects would change the general relative difference of the CBA between the devices.
- It is interesting that first flush basins and wetlands are not included in the <5ha category. They could potentially be included for 2-5ha if this was needed.
- Future CBA's could further refine the capital cost of Proprietary RGs by requesting costs from suppliers.
- It is likely that the shape of the NPV cost curves (Figures 3 – 4) is dominated by the maintenance costs (as these provide a mostly linear relationship between surface area of the device and maintenance cost).

- The contaminant load generation and treatment efficiency data has not been reviewed and is "taken as read" given that this data emanates from a previously reviewed report by Golders (2018). My only query relates to Tables 10 and 11 where I'm interested to know if the Golder report TSS and zinc removal efficiencies equate to/ are consistent with the rainfall parameters shown in Table 3 and the device design parameters used for the development of the capital cost equations.
- Tables 13 and 14 make for really interesting reading. Please just double check some of the numbers – I only undertook a few spot checks, but noticed one or two potential errors in the first row of Table 13.
- Please check the axes on the graphs in Figures 12 and 13 – the y-axis includes $ values yet references kg/yr, x-axis has no $ sign next to the numbers. Makes it slightly confusing to read. Also please check the cost of the PFD referenced in the text: PFD in Figure 12 looks to be around $20 million? Is it perhaps supposed to reference discharge to sewer, which is closer to $9 million?
- For all graphs which relate to cost, I recommend referencing the discount rate (5%) and analysis period (50 years) for clarity purposes.
- I wonder if a discussion point and recommendation for CCC coming out of this study could be around further design/ construction guidance being provided for swales to facilitate future use in areas which have sufficient grade to allow for swales (relates to the first paragraph after the bullet points in the discussion session).
- Recommendations: potentially the recommendation to include renewal costs could also include further investigation of large scale corrective maintenance costs (for completeness sake).

Taking account of the comments provided above, it is considered that the CBA meets the intent of the scope of works and of Condition 40 and Schedule 4D. This review has been undertaken based on good faith and the information presented to me within this document.

Sue Ira
Director, Koru Environmental Consultants Ltd.

19 July 2021:
A revised document, taking my comments above into account has been provided to me for review. Taking account of the revisions, it is considered that the CBA meets the intent of the scope of works and of Condition 40 and Schedule 4D. This review has been undertaken based on good faith and the information presented to me within this document.

Sue Ira
Director, Koru Environmental Consultants Ltd.