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Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Pollutant Load Scenarios for Stormwater Management in Addington Catchment

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Executive Summary

Addington Brook is a stormwater-affected urban stream in western Christchurch that is a priority catchment for stormwater management improvements, due to adverse impacts seen on the aquatic ecosystem of the Brook and downstream receiving environment. In order to better understand where and what contaminants are being generated in stormwater runoff from the catchment's impermeable (roof, road and carpark) surfaces, an event-based contaminant load model, Modelled Estimates of Discharges for Urban Stormwater Assessment (MEDUSA), was applied to the Addington catchment to estimate the amount of total suspended solids (TSS), total zinc (Zn) and total copper (Cu) being generated by these surfaces (Charters 2016). The modelling identified large carparks and highly trafficked roads as primary contributors of TSS, galvanised roofs as primary contributors of Zn and highly trafficked roads and industrial carparks as primary contributors of Cu.

In this current study, stormwater management scenarios that target primary contributors for each contaminant were simulated with MEDUSA, as follows:

- S1 – Replacement of all zinc-based roofs with new Coloursteel®
- S2 – Replacement of all zinc-based roofs with inert material
- S3 – Replacement of only old galvanised roof with new Coloursteel®
- S4 – Treatment of old galvanised roof runoff with on-site treatment
- S5 – Treatment of a representative large commercial site with large-scale on-site treatment
- S6 – Treatment of road runoff from highly trafficked roads
- S7 – Treatment of the highest load generating carparks
- S8 – Effect of removing copper generation from road via implementation of Cu-free brake pads

The predicted annual loads for these scenarios have been compared against the 'baseline' annual load for current catchment conditions. For TSS management, the most significant reduction is achieved by targeting minor and major arterial roads and treating their runoff in a system such as a raingarden (12% TSS reduction in catchment). For zinc, targeting zinc-based roofs (i.e. Scenarios 1 and 2) is predicted to achieve the greatest reduction from baseline conditions (Zn reductions of 52-70%). Targeting only old galvanised roofs (Scenario 3; i.e. targeting a limited surface area) is predicted to achieve 15% Zn reduction. For TCu management, the removal of copper contributions onto roads and carparks via implementation of Cu-free brake pads is predicted to have a significant reduction on catchment copper loads (78%).

There are several recommendations for future research to address limitations observed in this current study:

Alternative treatment solutions are required that can provide greater zinc removal efficiencies than current treatment systems. The effectiveness of scenarios that are based on treatment (as opposed to source reduction) is limited by the level of zinc reduction that can be achieved in such systems. Roof runoff in particular has a high proportion of dissolved metals, which are poorly removed in typical sediment-removal focused treatment systems.

There is a knowledge gap to be addressed in quantifying the proportional contributions from non-brake pad sources to better predict the effects of the Cu-free brake pad scenario. As the uptake of Cu-free brake pads will be phased in over a period of time, there is opportunity to monitor the change this brings to untreated runoff quality. This can then be compared to the data being collected in other international programmes.

Street sweeping remains a valuable management method for reducing sediment and heavy metal pollution in road runoff, however a lack of good data on the effectiveness of street sweeping meant such a scenario was not modelled in this study. Further research is needed to quantify the amount of pollutants removed per frequency of sweeping, how widely this varies and what influences Christchurch's local climate has on the removal rates, in order to be able to make effective decisions on sweeping frequency.

Percent reductions in at-source pollutant loads predicted by this modelling may not result in an immediate equivalent reduction being observed in the receiving waterway. Resuspension of settled sediment within the stormwater network and within the Brook may result in higher TSS and metal loads instream. Pollutant transformations within the stormwater network and in stream are not well understood and further research is needed in both settings to better link the at-source runoff quality with the receiving waterway quality (and resultant impacts on the aquatic ecosystem).

Contents

1 Introduction

Addington Brook is a stormwater-influenced waterway in western Christchurch that joins the Avon River/Ōtākaro near Christchurch Hospital, in the city centre. Elevated sediment and heavy metal concentrations observed in both instream water quality sampling and at-source untreated stormwater sampling indicate that stormwater is a key contributor of these pollutants and the Brook is in turn transporting these pollutants downstream into the Avon River/Ōtākaro. Accordingly, Environment Canterbury (ECan) is undertaking various targeted projects in the catchment to reduce the contribution of pollutant to the Brook from stormwater, with the overarching aim of improving the water quality in the Brook and downstream receiving environments.

The University of Canterbury have previously applied an event-based contaminant load model, Modelled Estimates of Discharges for Urban Stormwater Assessment (MEDUSA), to the Addington catchment to estimate the amount of total suspended solids (TSS), total and dissolved zinc (Zn) and total and dissolved copper (Cu) being generated by individual impervious surfaces (i.e. roofs, roads and carparks) within the catchment (Charters 2016). These pollutants have been found to be elevated in urban waterways and are of particular concern due to their adverse effects on waterway health; however there are other pollutants (nutrients, pathogens, other metals) also of concern for urban waterway management. MEDUSA's assessment of where and what amount of TSS, Zn and Cu is being generated by individual surfaces is important for development of targeted strategies that will address the pollutant 'hotspots' in the catchment. MEDUSA identified the following key characteristics of pollutant generation in this catchment:

1. TSS is the major contaminant (i.e. highest annual load amount), with the majority being contributed from carpark runoff, followed by road runoff. Therefore, large carparks and high-traffic roads should be targeted for TSS reduction strategies.
2. Zinc is the next highest contaminant load and is primarily sourced from galvanised roofs (with old galvanised roof showing particularly high per area loads). The majority of these roof zinc loads are in dissolved form, so any targeted management strategy needs to address galvanised roofs and the dissolved form of zinc.
3. Copper is primarily contributed by roads (in particular, major arterial roads) and industrial carparks (in particular, where heavy vehicles are manoeuvring at the site). Therefore, large industrial carparks and high-traffic roads should be targeted for copper reduction strategies.

4. Given the amount of dissolved metals (which are poorly removed in typical sediment-removal focused treatment systems), source reduction strategies that limit the generation of these pollutants should be implemented, coupled with targeted dissolved metals treatment where polluted runoff generation cannot be avoided.

This current study reports on the modelling of several stormwater management scenarios that aim to address these characteristics, using MEDUSA to predict the reduction in contaminant loads for each scenario.

2 Methodology

2.1 Contributing impermeable areas by surface type

The Addington Brook catchment comprises 243 ha of mixed industrial, commercial and residential land use. 117 ha of the catchment is covered by impermeable roofs, roads and carparks that drain to the stormwater network, with the remaining 126 ha comprised of surfaces such as pervious grassed areas (including sections of South Hagley Park), unsealed carparks, residential backyards and small areas of paving that drain their runoff to adjacent pervious areas. The vast majority of its roof surfaces are galvanized, many unpainted in the industrial/commercial areas, although some newer roofs in both the industrial/commercial and residential areas are painted or powder-coated (e.g. Coloursteel®) (Table 2-1). Over half the roads passing through the catchment are either minor or major arterial roads (typical total daily traffic flows of 3,000-15,000 and >12,000, respectively) (Table 2-1). Most carpark surfaces in the catchment are commercial; of the remaining industrial carparks, the majority is used by slow-moving, manoeuvring heavy vehicle traffic.

Table 2-1: Current composition of impermeable surfaces by surface type in Addington catchment

Surface Type	Subcategory	Description	Area (m^2)
Roof	Butynol All	Inert butynol	656
	Concrete All	Concrete tiles	20,855
	Decramastic All	Decramastic tiles	4,702
	Fibreglass All	Inert fibreglass corrugate	436
	Galvanised New	Includes coated, painted galv. roofs that look to be in near new condition	55,214
	Galvanised Moderate	Unpainted galv. roofs (even if new), or painted galv. roofs that look to be in reasonable but not new condition.	361,998
	Galvanised Old	Galv roofs painted or unpainted that look to be in poor condition (e.g. rust)	12,479

Surface Type	Subcategory	Description	Area (m^2)
Road	Private	As identified from CCC GIS files of Christchurch roads	365
	Local Road		93,042
	Collector		16,943
	Minor arterial		52,000
	Major arterial		74,323
Carpark	Commercial	Retail and commercial carpark with limited heavy vehicle use	316,352
	Industrial Manoeuvring	Industrial site carpark with obvious heavy vehicle stop-start and turning activity	114,510
	Industrial Standard	All other industrial site carparks	42,563
Total			**1,166,439**

2.2 Overview of MEDUSA and development of baseline model

A modelling process was followed using the MEDUSA model to predict annual TSS, zinc and copper loads (Figure 2-1). The process involved recalibration of MEDUSA with the latest available field data for untreated runoff quality, simulation of multiple management scenarios to predict the resultant reduction in pollutant loads, and evaluation of the different scenarios against the current 'baseline' annual loads.

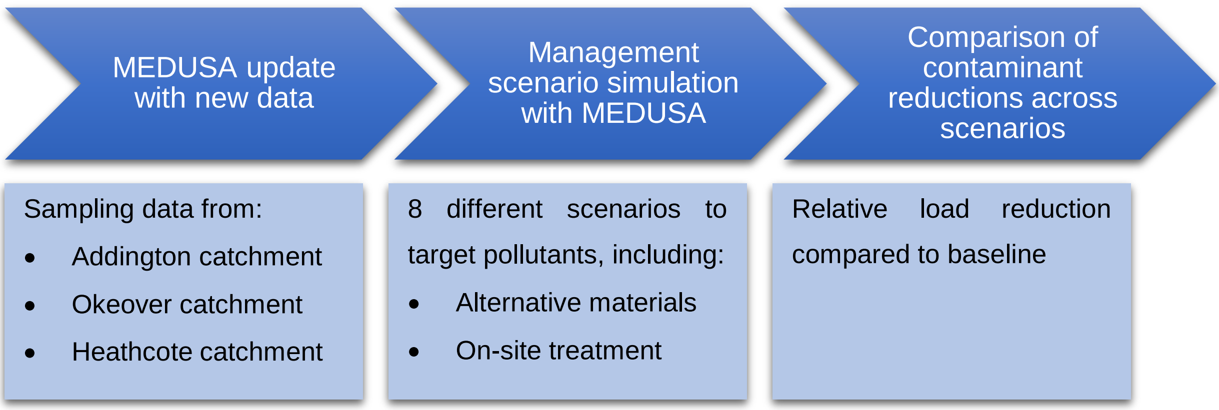


Figure 2-1: Modelling process used in this study to quantify relative contaminant reduction from implementation of different stormwater management scenarios

The MEDUSA model uses rainfall characteristics (average intensity, length of antecedent dry period, rainfall pH and event duration) to predict the amount of TSS, and total and dissolved Cu and Zn that is generated from each roof, road and carpark surfaces in the Addington catchment. The surfaces have been delineated in GIS using a combination of Christchurch City Council-provided GIS data, aerial image analysis and field verification. Each surface type is categorised by its material or usage characteristics.

MEDUSA has been calibrated using untreated runoff quality data from the Addington, Okeover and Heathcote catchments in Christchurch. At the time of the original MEDUSA modelling of the Addington catchment in 2015/16, only Okeover and Addington sampling data was available. However, Heathcote data is now available and has been incorporated into the model calibration for this scenario modelling, enabling more surface types to be calibrated with actual data, rather than based on assumptions where no data was available. Details on the comparison of the updated calibration with the calibration used previously in the 2015/16 original Addington modelling are provided in Appendix A.

Following calibration, MEDUSA was run for a full year of events, using event rainfall data for the year 2012 as a representative year. Researchers at the University of Canterbury had characterised rainfall pH for several events in 2012 and therefore there was a relatively complete set of characterised rainfall events for these year, with minimal assumptions required for rainfall pH. Furthermore, 2012 had a relatively typical annual rainfall amount for Christchurch (Christchurch Botanic Weather Station recorded 631 mm annual rainfall for 2012 (NIWA 2013b); Christchurch's mean annual rainfall is 647 mm (NIWA 2013a)). A 'Baseline' model was generated from the average event load produced from modelling the 88 events of the year 2012, and this was used as a comparative benchmark for the stormwater management scenarios, to assess their relative reduction in contaminant loads.

2.3 Scenarios modelled in MEDUSA

Eight management scenarios were explored in this study to quantify the range in reduction in pollutant loads that could be achieved by contrasting approaches. For example, larger- and smaller-scope strategies were compared (i.e. addressing all galvanised roofs versus only old galvanised roofs), as were scenarios which targeted roof versus road or carpark runoff, and source reduction techniques were compared with treatment systems. Some management scenarios targeted zinc, while others targeted TSS or copper. Table 2-2 summarises the modelled scenarios and explains the objectives behind each scenario.

Table 2-2: Description of modelled stormwater management scenarios

Scenario	Target Contaminant(s)	Details
Baseline	TSS, Total and dissolved Zn, Total and dissolved Cu	Predicted pollutant loads using the latest model version, to provide baseline loads (i.e. current catchment conditions) for comparison with the various management scenarios.
S1 - Replacement of all zinc-based roofs with new Coloursteel®	Total and dissolved Zn	The concentration of released zinc increases with age, so replacement of zinc-based roofs over time with newer material will reduce the overall zinc load.
S2 - Replacement of all zinc-based roofs with inert material	Total and dissolved Zn	As any zinc-based material has been observed to release elevated zinc (including new, coated products such as Coloursteel®), an alternative strategy is to replace zinc-based roofs over time with inert material. Examples of inert materials include butynol, plastic tiles, clay and concrete tiles (though less favourable due to weight) and fibreglass.
S3 – Replacement of only old galvanised roof with new Coloursteel®	Total and dissolved Zn	Old galvanised roofs produced very high zinc loads (well above any other surface type). This scenario represents a smaller-scale strategy of targeting only the very highest zinc producing surfaces.
S4 – Treatment of old galvanised roof runoff with on-site treatment	Total and dissolved Zn	If roof replacement is not feasible, on-site treatment (e.g. raingardens, proprietary filter devices with enhanced media for metal removal) may be an effective approach to reducing zinc loads.
S5 – Treatment of a representative large commercial site with large-scale on-site treatment	TSS, Total and dissolved Zn, Total and dissolved Cu	Treatment of all carpark and roof runoff from multiple surfaces (all under common property ownership) in a centralised treatment facility such as a constructed wetland.
S6 – Treatment of road runoff from highly trafficked roads	TSS, Total and dissolved Zn, Total and dissolved Cu	Interception and treatment of road runoff using linear treatment systems such as raingardens. This strategy targets the highest trafficked roads, as pollutant concentrations have been observed to increase with traffic intensity and presence of heavier vehicles.
S7 – Treatment of the highest load generating carparks	TSS, Total and dissolved Zn, Total and dissolved Cu	Treatment of carpark runoff using a multi-function treatment system such as a raingarden. This strategy targets the highest load producing carparks as identified using the MEDUSA model for each pollutant.
S8 – Effect of removing copper generation from road via implementation of Cu-free brake pads	Total and dissolved Cu	The availability of copper-free brake pads is increasing, and this scenario represents a material replacement strategy that reduces the generation of copper pollution from vehicles at source.

Notes on Scenario 7: Method of selection of highest load producing carparks

Annual pollutant loads were modelled in MEDUSA for TSS, total Zn and total Cu for individual carpark surfaces in the Addington catchment, using the Baseline scenario. Carparks were then ranked from highest to lowest load for each pollutant (i.e. as pollutant load per area varies by carpark type (i.e. commercial vs industrial), the order of ranking may change between TSS, Zn and Cu). The three highest TSS-producing carparks each produced 1.7-3 times the next highest ranking carpark, and these same three carparks each produced 1.9-3.4 times the total Cu load of the next highest ranking carpark, representing a natural breakpoint for targeting the highest TSS and total Cu loads. The total Zn rankings were less differentiated; however the six highest total Zn-producing carparks each produced 1.2-3.3 times the next highest ranking carpark and also represented a natural breakpoint in total Zn loads.

As there is some overlap in the rankings across the different pollutants, the three highest TSS- and total Cu-producing carparks and six highest total Zn-producing carparks can be addressed by targeting a total of seven particular carparks in the catchment (Table 2-3) (these carparks are typically the largest of their types in the catchment). Therefore, for Scenario 7, treatment was applied to the combined loads produced by these seven carparks for each pollutant.

Table 2-3: Highest load producing carparks in Addington

Carpark Code	Classification	Area (m^2)	TSS		Total Zn		Total Cu	
			Annual load (kg)	Rank	Annual load (g)	Rank	Annual load (g)	Rank
CP260	Industrial Mnv	26,466	1345	1	3496	1	874	1
CP259	Industrial Mnv	19,968	1015	2	2638	2	659	2
CP265	Industrial Mnv	14,816	753	3	1957	3	489	3
CP1	Industrial Mnv	13,055	445	4	1735	5	258	5
CP270	Commercial	7,801	396	5	1031	8	214	4
CP100	Industrial Mnv	6,075	393	6	1848	4	200	13
CP198	Industrial Std	9,662	329	7	1284	6	171	9

Notes on Scenario 8: Implementation of Cu-free brake pads

The percentage of Cu in brake pads has been decreasing in the past decade (TDL Environmental 2016), with 44% of available brake pad achieving the <0.5% copper levels to be considered “Cu-free” or “no intentionally added Cu”. In New Zealand, Cu-free brake pad technology is increasing in availability and uptake, and this scenario aimed to assess the expected reduction in Cu from universal uptake of Cu-free brake pads. Modelling of copper reductions for the California Stormwater Quality Association (TDL Environmental 2016) estimated Cu reductions in brake pad content ranging from 81 to 99%, with Cu comprising between 1.4% down to 0.05% of brake pads, respectively. Accordingly, Scenario 8 in this modelling report represents the Cu-free scenario assuming a future of 0.05% Cu in brake pads (i.e. negligible levels). The modelling also assumes that brake pads are the principle source of copper on these surfaces and therefore does not account for any atmospheric deposition or other sources of copper nor the legacy of copper bound in road and carpark surfaces that can be remobilised during rain and ultimately still enter the Brook from the stormwater system.

Consideration of street sweeping

A further scenario was initially proposed to simulate the impacts of increased street sweeping within the catchment, however this was assessed as infeasible for several reasons. Firstly, there is a lack of quantified removal efficiencies on which to base the modelling assumptions. Furthermore, the effectiveness of street sweeping is highly variable and dependent on several factors (Amato et al. 2010), including:

- The particle size of the sediment on the road surface, as studies have shown street sweeping to generally be more effective at capturing coarser particles
- The techniques used (mechanical broom, vacuum assisted broom, water flushing etc.) result in differing efficiencies
- The number of passes made (Sartor and Boyd (1972) found efficiency increased with number of passes)
- Environmental conditions such as season and climate

The untreated road runoff quality data collected in the Addington, Okeover and Heathcote catchments were taken from roads that undergo regular street sweeping (see Charters (2016) for further details on scheduled frequencies) (i.e. the MEDUSA calibration used in this modelling incorporates the effects of the current street sweeping programme). There is no comparative data from a local unswept road from which the effect of this sweeping could be quantified on sediment and metal removal.

Use of percent reduction for modelling of treatment systems

Where the scenarios involve stormwater treatment systems to treat the runoff (e.g. in raingardens or constructed wetlands; Scenarios 4 to 7), a percent reduction has been applied based on the Auckland Contaminant Load Model (CLM) reduction factors (Auckland Regional Council 2010a). The Auckland CLM developed the load reduction values on the "…*basis of professional judgement after reviewing the literature. The LRFs represent the maximum degree of contaminant retention that could be expected for well designed, installed and maintained devices…"* (Auckland Regional Council 2010b). Due to the lack of sufficient recent treatment performance data that could justify updating these load reduction factors, the Auckland CLM values have been used in this modelling.

The Auckland CLM reduction factors are specific for the surface type (i.e. roof runoff factors may differ from paved surface factors, in recognition of the fine TSS and dominant dissolved form of metals found in roof runoff (Auckland Regional Council 2010b)). Therefore, where the treatment is applied to roof runoff using a roof-runoff reduction factor from the CLM, this reduction factor has been applied to both total and dissolved zinc loads, as zinc has been found to be primarily in dissolved form in roof runoff in local Christchurch studies (Charters 2016, Charters et al. 2016, O'Sullivan et al. 2017). Where treatment is applied to road and carpark areas, only the reduction in total metals are reported here. As particulate metals are more readily captured in treatment systems, it is likely that the load reduction factor for the total metal is based primarily on removal of the particulate metals and therefore the expected removal factor for dissolved metals only cannot be assumed.

3 Results

Results are reported for only the contaminants that are being targeted by each specific management scenario.

A comparative summary of the relative reduction in contaminants across all scenarios is provided in Section 3.9.

3.1 Scenario S1 – Replacement of all zinc-based roofs with new Coloursteel®

Notes

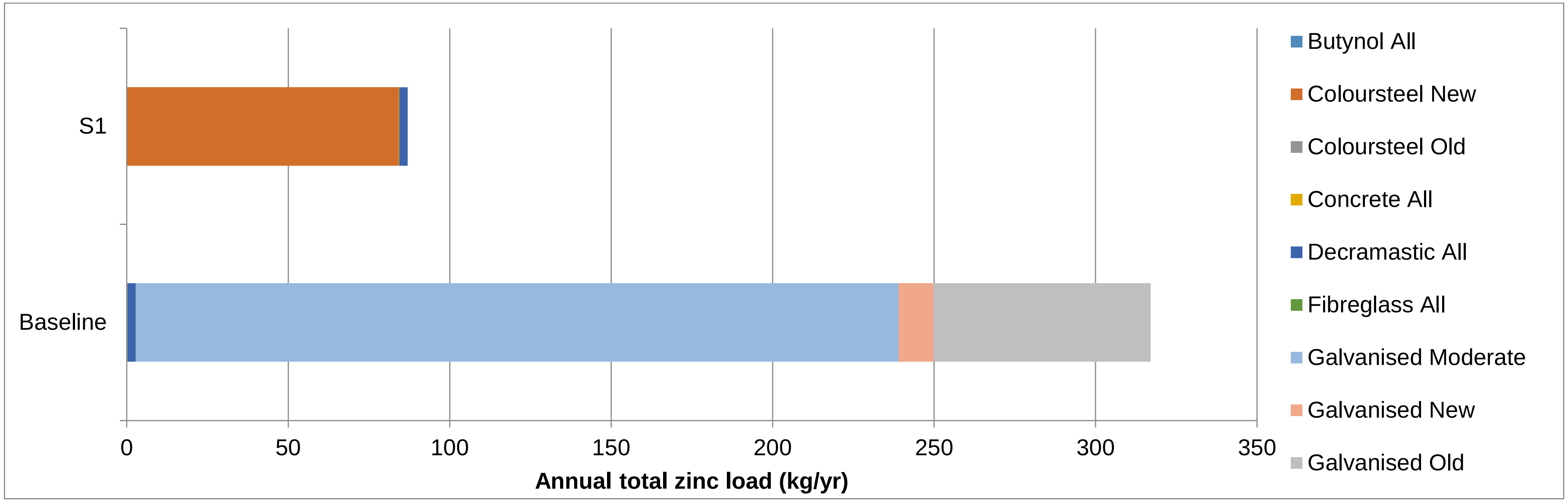
Modelled by reassigning all zinc-based roofs as 'Coloursteel New' (Note: Decramastic already assigned properties of 'Coloursteel New' in Baseline model, so not reassigned here)

Results only comparing total and dissolved zinc loads as these are the targeted contaminants for this scenario.

Only roof surface categories are shown in the graph for visual clarity. The right hand table shows the relative load contribution from roads and carparks compared to roofs (note that the contributing roof surface area is unchanged between baseline and S1).

Surface Category	Percent change in annual load	
	Total Zn	Dissolved Zn
Roofs	-73%	-79%
Roads	0%	0%
Carparks	0%	0%
TOTAL	***-52%***	***-64%***

Surface Category	Annual total zinc load (kg/yr)	
	Baseline	S1
Roofs	317 (71%)	87 (40%)
Roads	58 (13%)	58 (27%)
Carparks	70 (16%)	70 (33%)
TOTAL	***445***	***215***



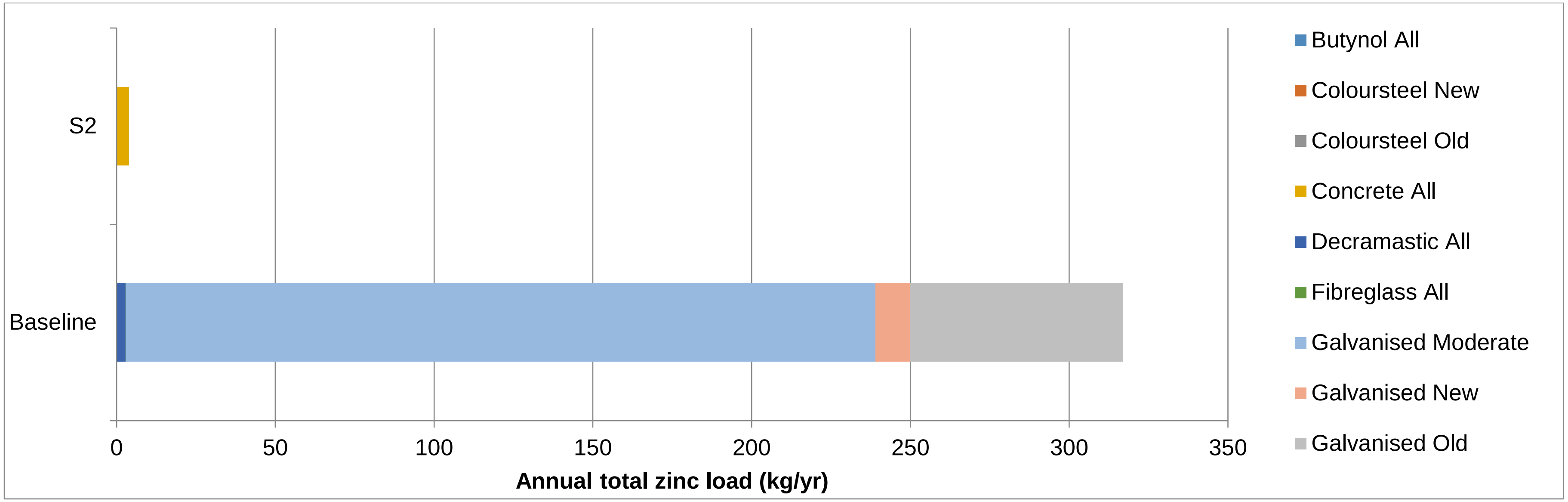
3.2 Scenario S2 – Replacement of all zinc-based roofs with inert material

Notes

Modelled by reassigning all zinc-based roofs (galvanised and decramastic categories) as 'Concrete All'. However, the 'Concrete All' category represents a wide range of inert materials that could be used, including butynol, fibreglass and non-metallic tiles.
Results only comparing total and dissolved zinc loads as these are the targeted contaminants for this scenario.
Only roof surface categories are shown in the graph for visual clarity. The right hand table shows the relative load contribution from roads and carparks compared to roofs (note that the contributing roof surface area is unchanged between baseline and S2).

Surface Category	Percent change in annual load	
	Total Zn	Dissolved Zn
Roofs	-99%	-99%
Roads	0%	0%
Carparks	0%	0%
TOTAL	***-70%***	***-81%***

Surface Category	Annual total zinc load (kg/yr)	
	Baseline	S2
Roofs	317 (71%)	4 (3%)
Roads	58 (13%)	58 (44%)
Carparks	70 (16%)	70 (53%)
TOTAL	***445***	***132***



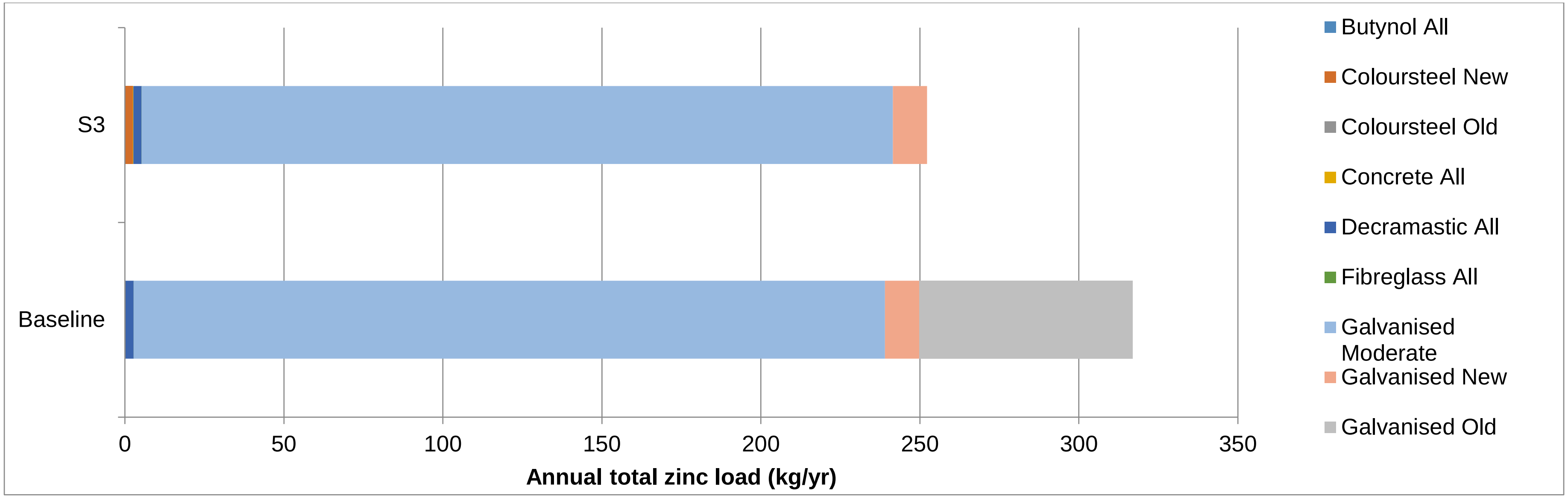
3.3 Scenario S3 – Replacement of old galvanised roofs only with new Coloursteel®

Notes

Modelled by reassigning only 'Galvanised Old' roofs as 'Coloursteel New'.
Results only comparing total and dissolved zinc loads as these are the targeted contaminants for this scenario.
Only roof surface categories are shown in the graph for visual clarity. The right hand table shows the relative load contribution from roads and carparks compared to roofs (note that the contributing roof surface area is unchanged between baseline and S3).

Surface Category	Percent change in annual load	
	Total Zn	Dissolved Zn
Roofs	-20%	-19%
Roads	0%	0%
Carparks	0%	0%
TOTAL	***-15%***	***-15%***

Surface Category	Annual total zinc load (kg/yr)	
	Baseline	S3
Roofs	317 (71%)	252 (66%)
Roads	58 (13%)	58 (15%)
Carparks	70 (16%)	70 (18%)
TOTAL	***445***	***380***



3.4 Scenario S4 – Onsite treatment of old galvanised roofs only

Notes

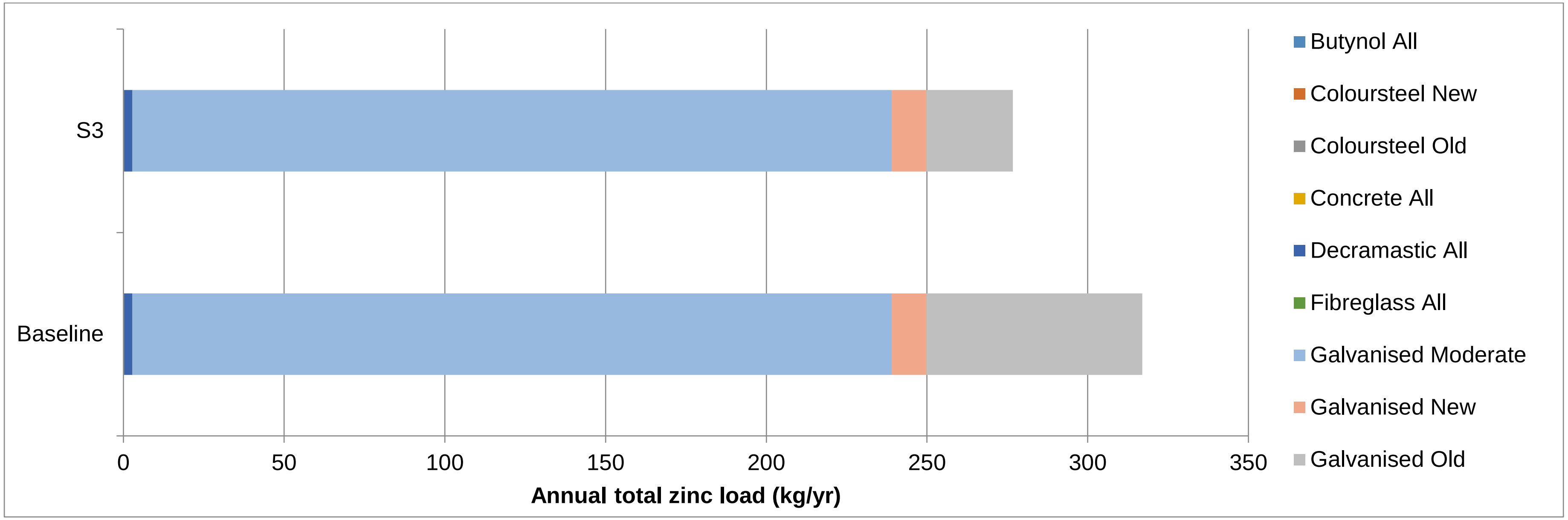
Modelled by applying a 60% removal to all old galvanised roof zinc loads. Percent removal based on Auckland Contaminant Load model reduction factors for TZn in a raingarden (roof runoff) (Auckland Regional Council 2010a). Same load reduction factor assumed for dissolved zinc, as zinc in roof runoff is primarily in dissolved form.

Results only comparing total and dissolved zinc loads as these are the targeted contaminants for this scenario.

Only roof surface categories are shown in the graph for visual clarity. The right hand table shows the relative load contribution from roads and carparks compared to roofs (note that the contributing roof surface area is unchanged between baseline and S4).

Surface Category	Percent change in annual load	
	Total Zn	Dissolved Zn
Roofs	-13%	-12%
Roads	0%	0%
Carparks	0%	0%
TOTAL	***-9%***	***-9%***

Surface Category	Annual total zinc load (kg/yr)	
	Baseline	S4
Roofs	317 (71%)	277 (68%)
Roads	58 (13%)	58 (14%)
Carparks	70 (16%)	70 (17%)
TOTAL	***445***	***405***



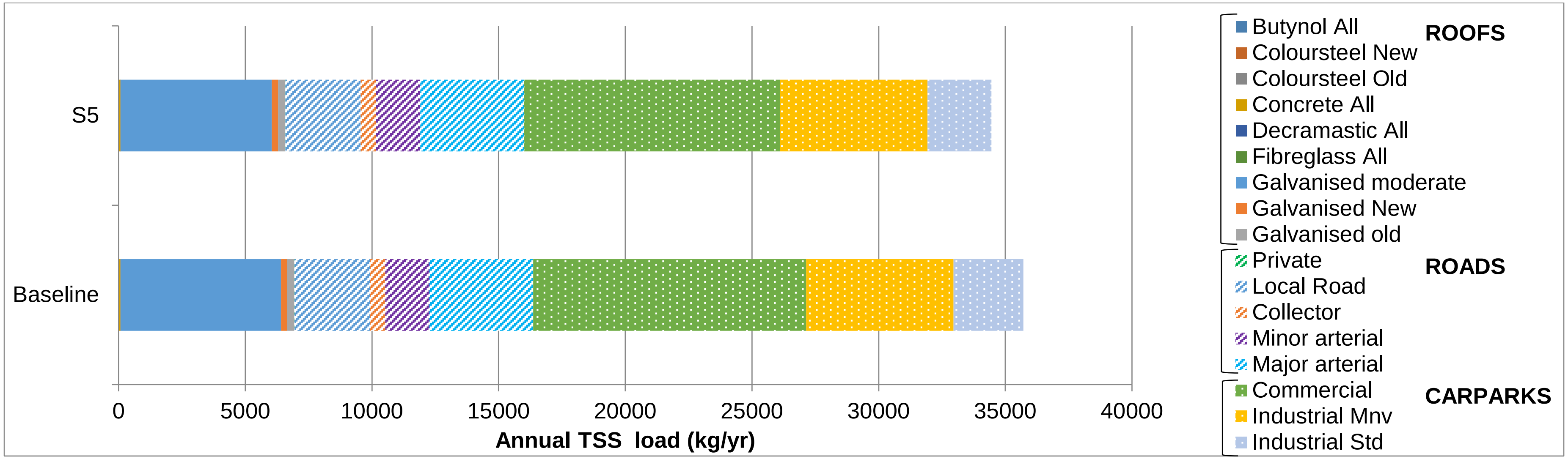
3.5 Scenario S5 – Treatment of runoff from all roofs and carparks at a representative large commercial site

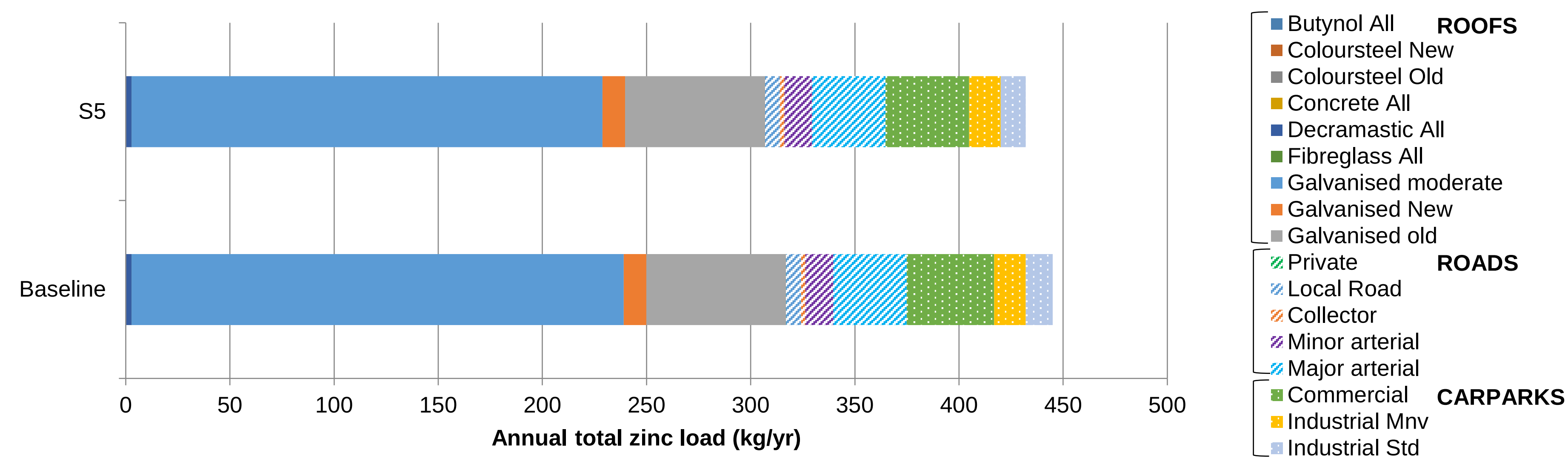
Notes

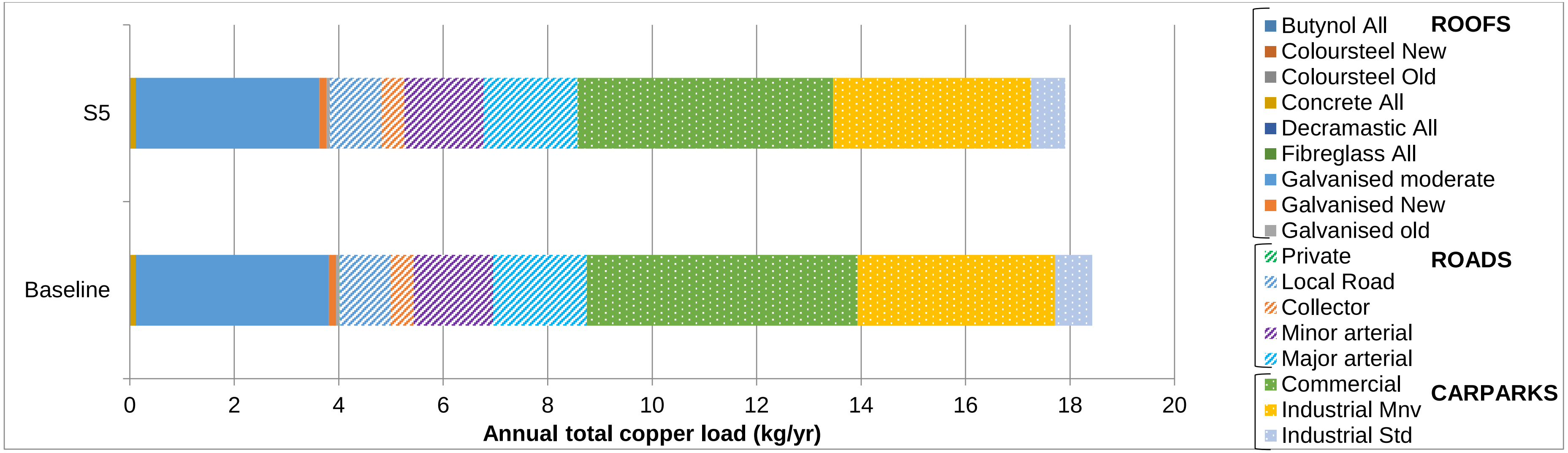
Modelled by applying percent removals of 80% TSS removal, 60% TZn removal and 70% TCu removal to all roofs and carparks at a representative large commercial site in the catchment. Percent removal based on Auckland Contaminant Load Model (CLM) load reduction factor for a constructed wetland (road and other paved surfaces runoff) (Auckland Regional Council 2010a).

Results comparing TSS, total zinc and total copper loads as these are all targeted contaminants for this scenario. Dissolved metals have not been modelled as their removal in constructed wetland is likely to differ (hence the lower percentage load reduction factor applied in the Auckland CLM for roof runoff compared to road runoff into a constructed wetland, as more metals in dissolved form in roof runoff).

Surface Category	Percent change in annual load			Treated area as percentage of Addington impermeable area
	TSS	Total Zn	Total Cu	
Roofs	-5.1%	-3.2%	-4.5%	5.7%
Roads	0%	0%	0%	0%
Carparks	-4.7%	-4.0%	-3.4%	6.1%
TOTAL	***-3.5%***	***-2.9%***	***-2.8%***	***4.7%***



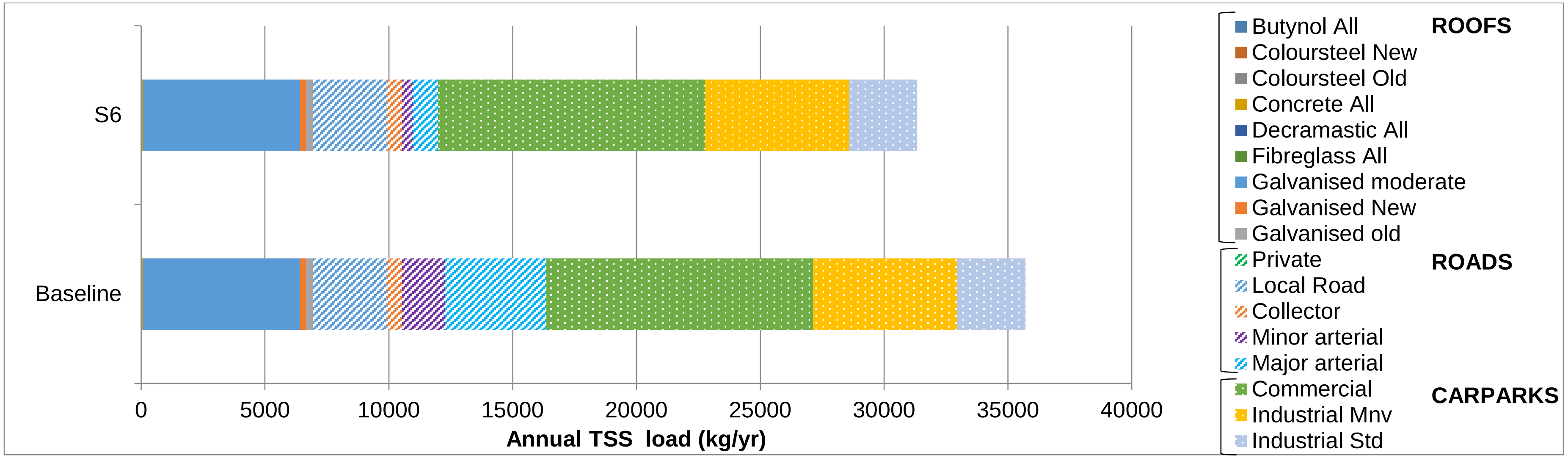

S5
Baseline
0
50
100
150
200
250
300
350
400
450
500
Annual total zinc load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std

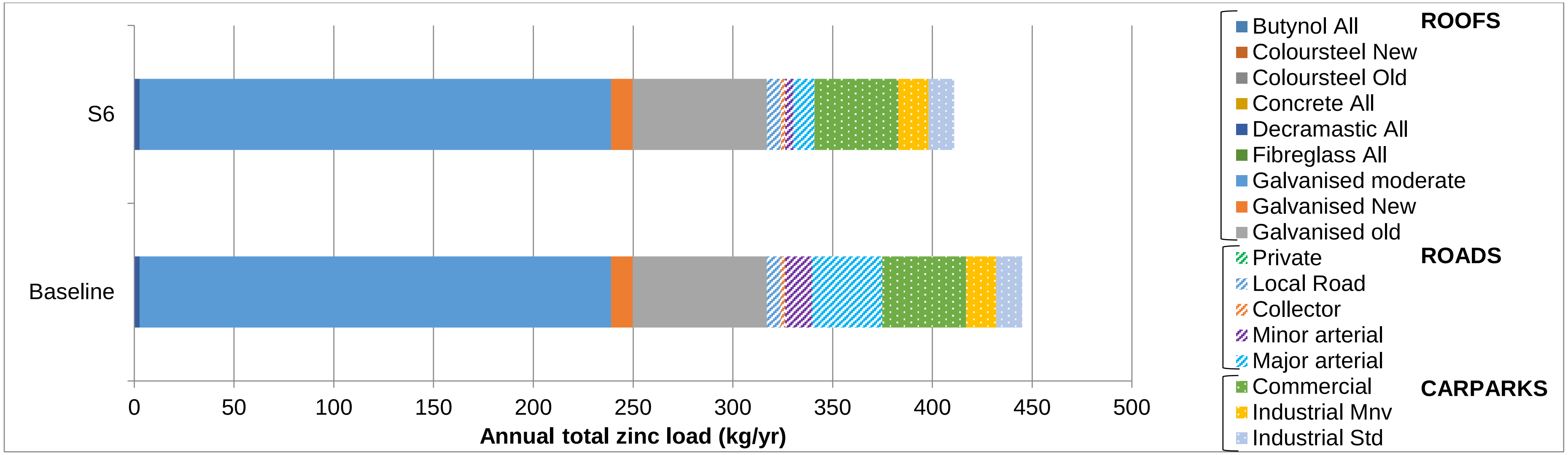

S5
Baseline
0
2
4
6
8
10
12
14
16
18
20
Annual total copper load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std

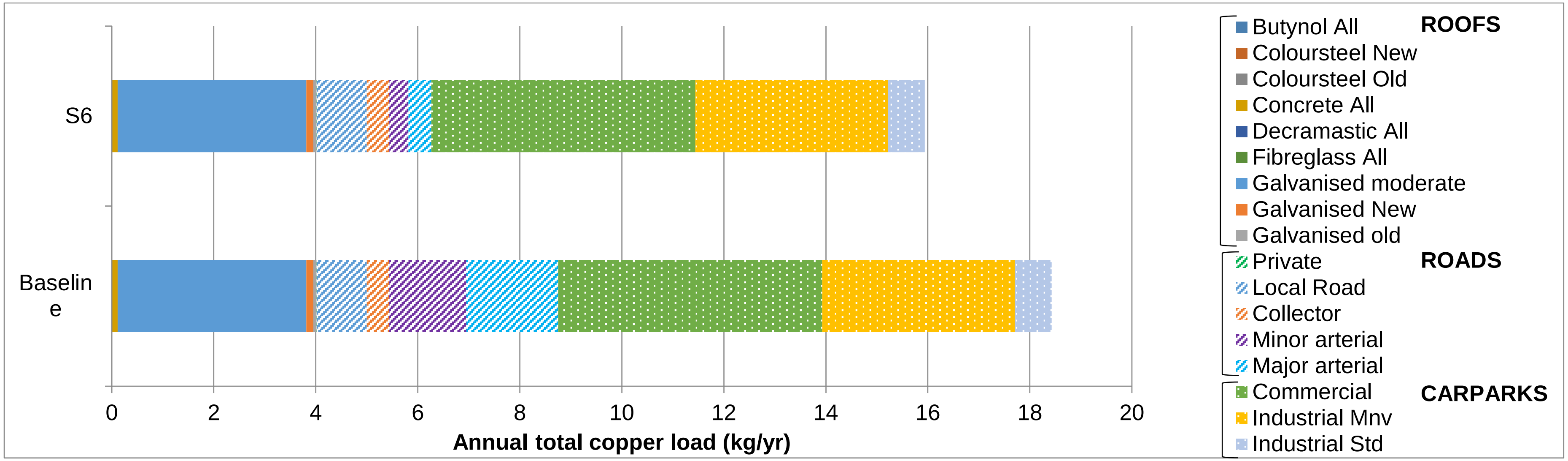
3.6 Scenario S6 – Treatment of runoff from highly trafficked roads

Notes
Modelled by applying percent removals of 75% TSS removal, 70% TZn removal and 75% TCu removal to all 'Major arterial' and 'Minor arterial' roads in the catchment. Percent removal based on Auckland Contaminant Load model reduction factors for TSS, TZn and TCu in a raingarden (road runoff) (Auckland Regional Council 2010a), as this represents a likely linear treatment system that could be implemented.
Results comparing TSS, total zinc and total copper loads as these are all targeted contaminants for this scenario. Dissolved metals have not been modelled for this scenario as load reduction factor may differ from particulate metals.

Surface Category	**Percent change in annual load**		
	TSS	**Total Zn**	**Total Cu**
Roofs	0%	0%	0%
Roads	-46%	-59%	-53%
Carparks	0%	0%	0%
TOTAL	***-12%***	***-8%***	***-13%***




S6
Baseline
0
50
100
150
200
250
300
350
400
450
500
Annual total zinc load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std


S6
Baselin
e
0
2
4
6
8
10
12
14
16
18
20
Annual total copper load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std

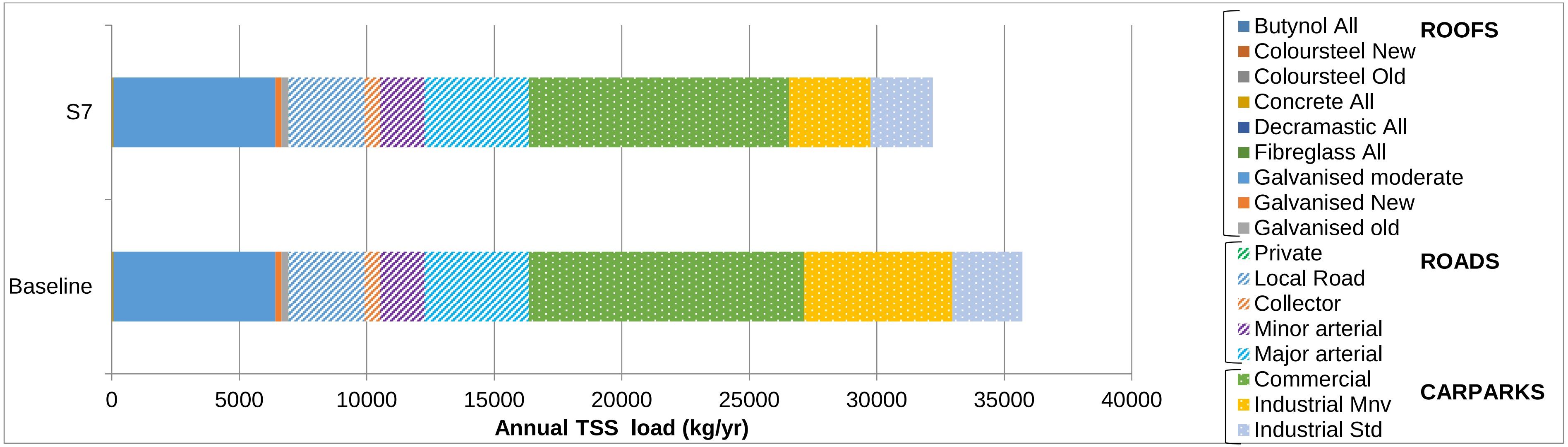
3.7 Scenario S7 – Treatment of runoff from highest load-producing carparks

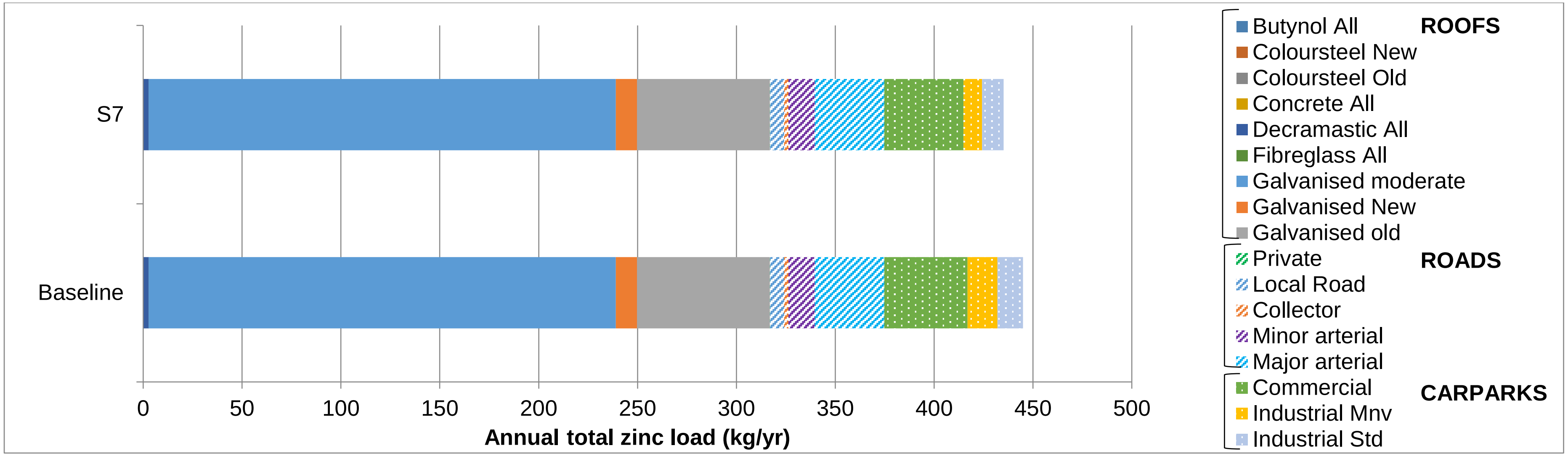
Notes

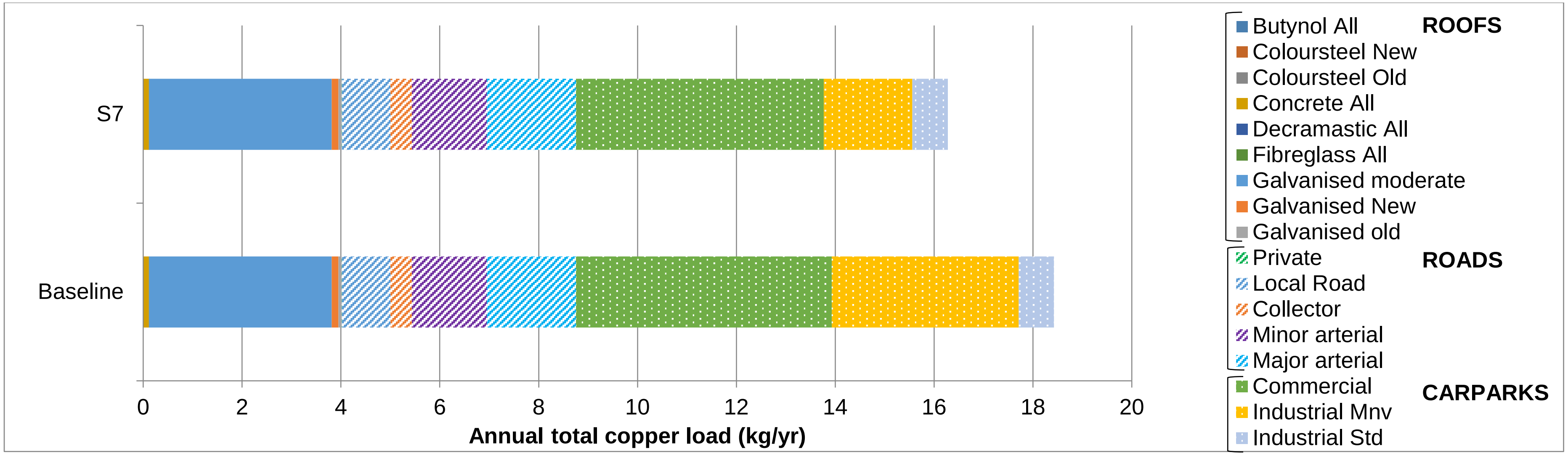
Modelled by applying percent removals of 75% TSS removal, 70% TZn removal and 75% TCu to the top 7 load-producing carparks in the catchment (refer to Section 2.3 for carpark selection details). Percent removal based on Auckland Contaminant Load model reduction factors for TSS, TZn and TCu in a raingarden (road and other paved surfaces runoff) (Auckland Regional Council 2010a), as this represents a likely multi-functional treatment system that could be implemented.

Results comparing TSS, total zinc and total copper loads as these are all targeted contaminants for this scenario. Dissolved metals have not been modelled for this scenario as load reduction factor may differ from particulate metals.

Surface Category	Percent change in annual load		
	TSS	**Total Zn**	**Total Cu**
Roofs	0%	0%	0%
Roads	0%	0%	0%
Carparks	-18%	-14%	-22%
TOTAL	***-10%***	***-2%***	***-12%***




S7
Baseline
0
50
100
150
200
250
300
350
400
450
500
Annual total zinc load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std


S7
Baseline
0
2
4
6
8
10
12
14
16
18
20
Annual total copper load (kg/yr)
ROOFS
Butynol All
Coloursteel New
Coloursteel Old
Concrete All
Decramastic All
Fibreglass All
Galvanised moderate
Galvanised New
Galvanised old
ROADS
Private
Local Road
Collector
Minor arterial
Major arterial
CARPARKS
Commercial
Industrial Mnv
Industrial Std

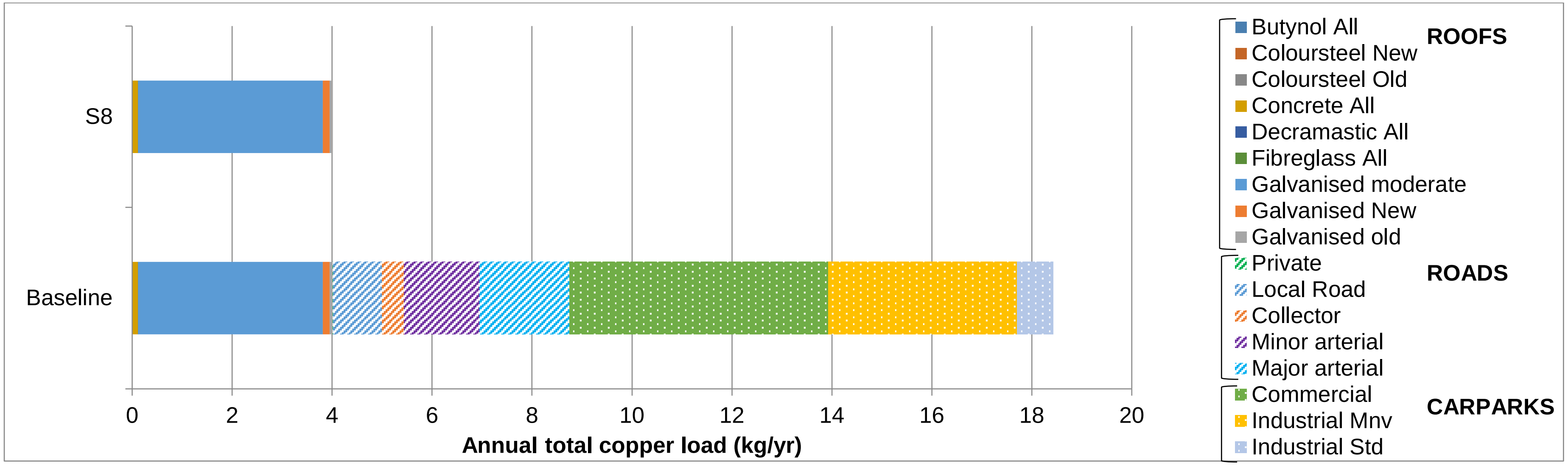
3.8 Scenario S8 – Implementation of Cu-free brake pads

Notes

Modelled by discounting any copper loads from roads and carparks. However, there is likely to still be some copper contributions from these surface types; further research is needed to understand the copper contribution from atmospheric deposition, other sources, and legacy copper bound in road and carpark surfaces.

Results comparing only total and dissolved copper loads as these are targeted contaminants for this scenario.

Surface Category	**Percent change in annual load**	
	Total Cu	**Dissolved Cu**
Roofs	0%	0%
Roads	-100%	-100%
Carparks	-100%	-100%
TOTAL	***-78%***	***-86%***



3.9 Comparative summary of the relative reduction in contaminant load across all scenarios

Comparative annual loads

Table 3-1: Annual TSS load (kg/yr)

Surface Type	Baseline	S5	S6	S7
	Current	Large commercial site tmt.	Arterial roads tmt	Large CP tmt.
Roofs	6,936	6,574	6,936	6,936
Roads	9,424	9,424	4,760	9,424
Carparks	19,355	18,454	19,355	15,614

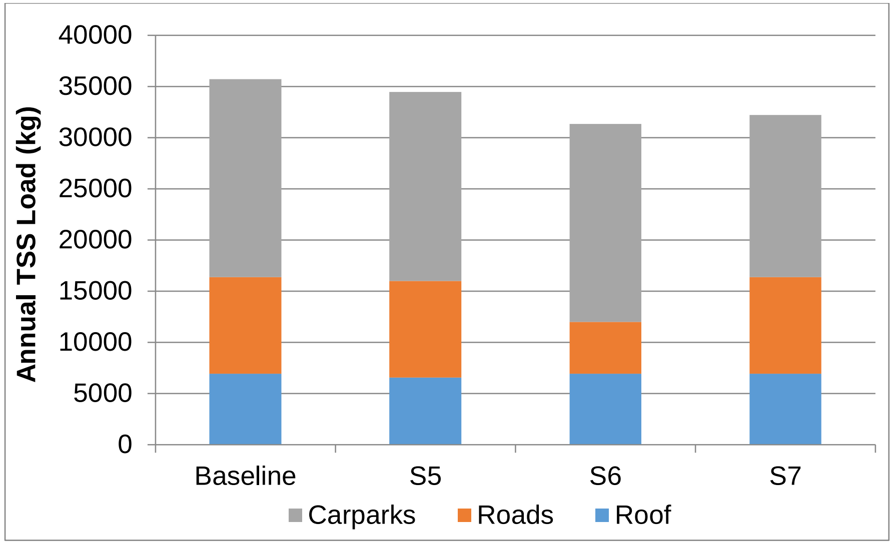
Table 3-2: Annual total zinc load (g/yr)

Surface Type	Baseline	S1	S2	S3	S4	S5	S6	S7
	Current	All galv to CS new	All galv to inert	Old galv to CS new	Old galv onsite tmt.	Large commercial site tmt.	Arterial roads tmt	Large CP tmt.
Roofs	316,983	86,976	3,839	252,286	269,983	306,854	316,983	316,983
Roads	57,874	57,874	57,874	57,874	57,874	57,874	23,872	57,874
Carparks	70,125	70,125	70,125	70,125	70,125	67,347	70,125	60,307

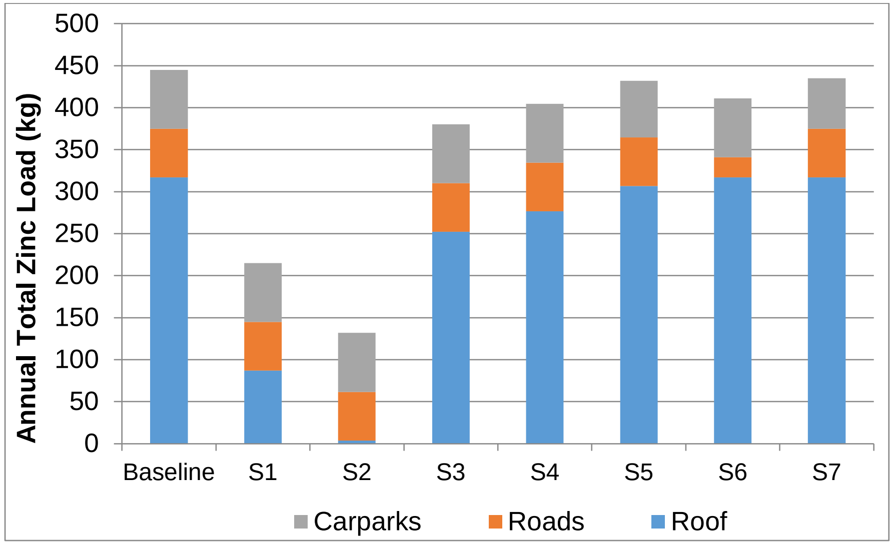
Table 3-3: Annual total copper load (g/yr)

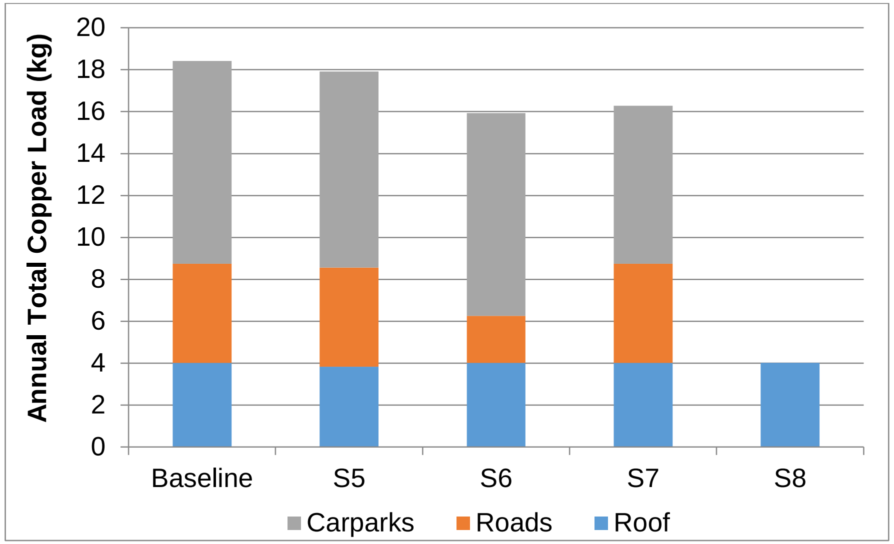
Surface Type	Baseline	S5	S6	S7	S8
	Current	Large commercial site tmt.	Arterial roads tmt.	Large CP tmt.	Cu-free brakes
Roofs	4,017	3,832	4,017	4,017	4,017
Roads	4,735	4,735	2,248	4,735	0 [1]
Carparks	9,673	9,341	9,673	7,525	0 [1]

[1] Note that there will likely still be some copper contributions from atmospheric deposition, other sources, and legacy copper bound in road and carpark surfaces



Code	Scenario Description
Baseline	Current situation
S1	All galvanised roofs to new Coloursteel®
S2	All galvanised roofs to inert roofing material
S3	Old galvanised roofs only to new Coloursteel®
S4	Onsite treatment of old galvanised roof runoff
S5	Treatment of large commercial site roof and CP runoff
S6	Treatment of highly trafficked roads' runoff
S7	Treatment of highest load-producing carparks' runoff
S8	Implementation of Cu-free brake pads





S8: Note that there will likely still be some copper contributions from atmospheric deposition, other sources, and legacy copper bound in road and carpark surfaces

Comparative percent reduction in annual loads

Table 3-4: Percent reduction in TSS annual load, comparative to baseline load

Surface Type	S5 Large commercial site tmt.	S6 Arterial roads tmt	S7 Large CP tmt.
Roofs	-5%	0%	0%
Roads	0%	-46%	0%
Carparks	-5%	0%	-18%
Total	**-3 %**	**-12%**	**-10%**

Table 3-5: Percent reduction in total zinc annual load, comparative to baseline load

Surface Type	S1 All galv to CS new	S2 All galv to inert	S3 Old galv to CS new	S4 Old galv onsite tmt.	S5 Large commercial site tmt.	S6 Arterial roads tmt	S7 Large CP tmt.
Roofs	-73%	-99%	-20%	-13%	-3%	0%	0%
Roads	0%	0%	0%	0%	0%	-59%	0%
Carparks	0%	0%	0%	0%	-4%	0%	-14%
Total	**-52%**	**-70%**	**-15%**	**-9%**	**-3%**	**-8%**	**-2%**

Table 3-6: Percent reduction in total copper annual load, comparative to baseline load

Surface Type	S5 Large commercial site tmt.	S6 Arterial roads tmt.	S7 Large CP tmt.	S8 Cu-free brakes
Roofs	-5%	0%	0%	0%
Roads	0%	-53%	0%	-100%
Carparks	-3%	0%	-22%	-100%
Total	**-3%**	**-13%**	**-12%**	**-78%**

4 Key findings and recommendations for future research

The scenarios modelled using MEDUSA demonstrated that:

- For TSS management: The most significant reduction is predicted to be achieved by targeting minor and major arterial roads and treating their runoff in a system such as a raingarden (Scenario 6). This approach targets a limited surface area but achieves a 12% TSS reduction at a catchment scale.
- For TZn management: Targeting zinc-based roofs (i.e. Scenarios 1 and 2) is predicted to achieve significantly greater reduction (52-70%) than other approaches that do not target zinc-based roofs; these other approaches (Scenarios 4-8) were not predicted to be very helpful at addressing zinc, with only 2-9% reduction. Targeting only old galvanised roofs (Scenario 3) is predicted to achieve a localised reduction but achieves only 15% reduction at catchment scale in comparison to the higher reduction opportunities that Scenarios 1 and 2 offer for zinc management.
- For TCu management: the removal of copper contributions onto roads and carparks via implementation of Cu-free brake pads is predicted to have a significant reduction on catchment copper loads (78%). However, the modelling currently assumes that brake pads are the principle source of copper on these surfaces and does not account for any atmospheric deposition or other sources of copper nor the legacy of copper bound in road and carpark surfaces that can be remobilised during rain and ultimately still enter the Brook.

Recommendation for future research: treatment systems with improved zinc removal efficiencies

For zinc, the reduction benefits of undertaking roof replacement programmes compared to treating zinc in roof runoff were clearly shown. However, costs of such a replacement programme need to be considered and may not be economically feasible. However, if treatment is then to be implemented to address zinc in roof runoff, the modelling identifies that the effectiveness of the treatment approach is limited by the level of zinc reduction that can be achieved in such systems. This suggests that alternative treatment solutions are required that can provide greater zinc removal efficiencies than is expected from current systems. Compared to surface replacement strategies, a key benefit provided by treatment systems is their ability to address the pollutants in mixed runoff (e.g. used in Scenario 5 for a combination of roof and carpark runoff).

The long term effectiveness of any treatment approach is also dependent on ongoing maintenance and monitoring. Therefore any costing evaluation (whether comparing it to source reduction or to other treatment options) needs to consider the full life-cycle costs of the system (i.e. capital construction costs, as well as operations and maintenance costs).

Recommendation for future research: relative contributions from different copper sources in road and carpark runoff

There is a knowledge gap to be addressed in quantifying the proportional contributions from non-brake pad sources to better predict the effects of the Cu-free brake pad scenario. As the uptake of Cu-free brake pads will be phased in over a period of time, there is opportunity to monitor the change this brings to untreated runoff quality at sites where fleets of vehicles are collectively managed (i.e. at industrial manoeuvring carparks with truck and bus fleets, where the fleet is changed to Cu-free brake pads). This can then be compared to the data being collected in other international programmes, such as the Brake Pad Partnership in San Francisco and the by the Washington Department of Ecology, both in the US (TDL Environmental 2016).

Recommendation for future research: quantification of street sweeping efficiencies for pollutant removal

Street sweeping remains a valuable management method for reducing sediment and heavy metal pollution in road runoff – if the equipment and operational staff are available and there is an existing contract for this work. Untreated runoff analysis by (Charters et al. 2016) found evidence of sediment carryover in the interstitial spaces of asphalt surfacing between rain events, due to the typically low intensity rainfall dynamics; this suggests street sweeping may be a helpful mechanism for freeing and capturing this trapped material. However, further research is needed to quantify the amount of pollutants removed per frequency of sweeping, how widely this varies and what influences Christchurch's local climate has on the removal rates, in order to be able to make effective decisions on sweeping frequency.

Recommendation for future research: connecting at-source quality to instream quality and effects

In general, the percent reductions in at-source pollutant loads predicted in this modelling may not result in an immediate equivalent reduction being observed in the receiving waterway. Resuspension of settled sediment within the stormwater network and within the Brook may result in higher TSS and metal loads instream. Pollutant transformations within the stormwater network and in stream are not well understood and further research is needed in both settings to better link the at-source runoff quality with the receiving waterway quality (and resultant impacts on the aquatic ecosystem).

5 References

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TDL Environmental (2016) Estimated urban runoff copper reductions resulting from brake pad copper use restrictions, Prepared for California Stormwater Quality Association, 39 pp.

Appendix

A1 MEDUSA recalibration based on new sampling data

Since the original MEDUSA modelling of the Addington catchment in 2015/16, new sampling data has been gathered from a programme of untreated runoff quality sampling in the adjacent Heathcote catchment (Figure A1) (note the original calibration of the Addington MEDUSA model used both Addington and Okeover catchments' sampling data). The new sampling in the Heathcote catchment had characterised the untreated runoff quality of different impermeable surface types that had not been previously characterised in the Addington or Okeover sampling programmes. Therefore, the Heathcote data enabled more surface types to be calibrated using actual data, where general assumptions had been made previously based on the limited range of characterised surface types.

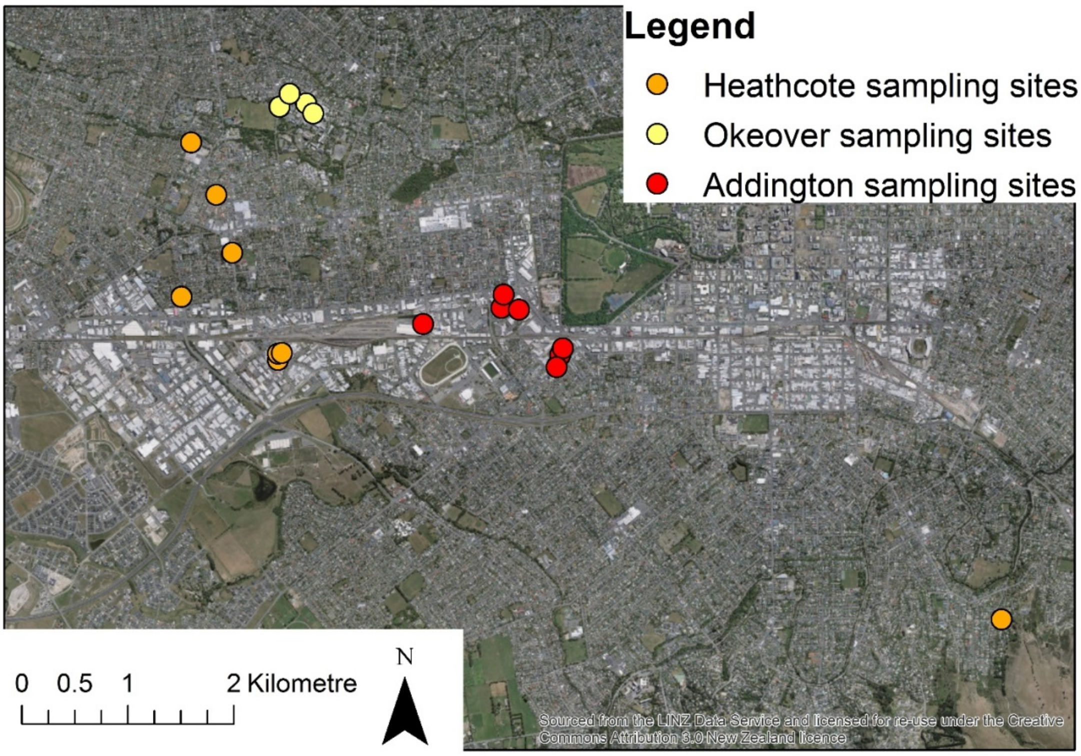

Figure A1: Untreated runoff quality sampling sites used to inform calibration of MEDUSA model for scenario simulations

As the original application of MEDUSA to the Addington catchment was the first time the newly developed model had been applied outside the original catchment (Okeover, which had informed the development of the model relationships with rainfall characteristics and surface characteristics), a simplified method of recalibration had been used at the time of the Addington study. Further model development has since occurred and so the opportunity has been taken in this study to use an advanced calibration process as it provides a better representation of the relationships between rainfall, surface characteristics and the resultant contaminant load.

Table A1 summarises the basis of calibration used for each surface type category – the study and sampling site that provided the data for calibration, and the changes, if any, between the 2015/16 Addington study and this current study. Table A2 summarises the relative change in predicted annual pollutant loads.

Table A1: Summary of surface types and basis of calibration

Surface Type	Category	Former basis of calibration	New basis of calibration
Roof	Butynol All	Based on 'Okeover Concrete roof' sampling data	No change to input data, but improved calibration process
	Coloursteel New	Not used	Based on 'Heathcote Coloursteel New' sampling data
	Coloursteel Old	Not used	Based on 'Heathcote Coloursteel Old' sampling data
	Concrete All	Based on 'Okeover Concrete roof' sampling data	No change to input data, but improved calibration process
	Decramastic All	Based on 'Okeover Concrete roof' sampling data	Based on 'Heathcote Coloursteel New' sampling data as Decramastic roofs have potential to contribute zinc compared to an inert roof material. Assume Decramastic coating limits metal dissolution, similar to coated Coloursteel®.
	Fibreglass All	Based on 'Okeover Concrete roof' sampling data	No change to input data, but improved calibration process
	Galvanised New	Based on 'Addington Tower Junction' (unpainted new galvanised roof) sampling data	Based on 'Heathcote Coloursteel New' sampling data as likely new galvanised roofs are coated (i.e. Coloursteel® or similar)
	Galvanised Moderate	Based on 'Addington Tower Junction' (unpainted new galvanised roof) sampling data	No change to input data, but improved calibration process
	Galvanised Old	Based on 'Addington GoBus' (old galvanised roof) sampling data	No change to input data, but improved calibration process
Road	Private	Based on 'Okeover Ilam (collector) Road' sampling data	Based on 'Heathcote Brodie Street (local road)' sampling data
	Local	Based on 'Okeover Ilam (collector) Road' sampling data	Based on 'Heathcote Brodie Street (local road)' sampling data
	Collector	Based on 'Okeover Ilam (collector) Road' sampling data	Based on 'Heathcote Hansons Lane (collector road)' sampling data, as more heavy vehicle traffic on Hansons Lane (like Addington roads) compared to Ilam Road
	Minor arterial	Based on 'Addington Lincoln Road' sampling data	No change to input data, but improved calibration process
	Major arterial	Based on 'Addington Picton Ave'[1] sampling data	No change to input data, but improved calibration process
Carpark	Commercial	Based on 'Addington Tower Junction carpark' sampling data	No change to input data, but improved calibration process
	Industrial Standard	Based on 'Addington Kiwirail carpark' sampling data	No change to input data, but improved calibration process
	Industrial Manoeuvring	Based on 'Addington GoBus carpark' sampling data	No change to input data, but improved calibration process

[1] The 'Addington Picton Ave' sampling site collected runoff from Blenheim Road, a major arterial road.

Table A2: Comparison of updated 'Baseline' model with 2015/16 study version

Surface Category	2015/16 Study Annual Loads (kg/yr)			This study (updated calibration as per Table 2-1) Annual Loads (kg/yr)			Percent change			Comment
	TSS	TCu	TZn	TSS	TCu	TZn	TSS	TCu	TZn	
Roofs	7,043	3.0	224	6,936	4.0	317.0	-2%	33%	41%	Increase in TCu: The recalibration of old galvanised roofs resulted in greater generation rates of Cu, however, although the % change is large, the loading is relatively low. Increase in TZn: Primary increase is from decramastic roofs now being assigned values based on a zinc-based material (Coloursteel® New) rather than an inert material, and recalibration of old galvanised roof.
Roads	8,753	5.1	53.3	9,424	4.7	57.9	8%	-7%	9%	There were relatively small changes in loadings from roads. Reduction in TSS, TCu and TZn for recalibrated local roads (using Heathcote data) was balanced by increase in TSS for recalibrated major arterial roads, and increase in TZn and TCu for the recalibrated collector roads (using Heathcote data)
Carparks	14,595	8.6	63.6	19,355	9.7	70.1	33%	12%	10%	Recalibration of each carpark category resulted greater generation rates of TSS and increases in TZn and TCu loads.
Total	30,391	16.8	341.3	35,715	18.4	445.0	18%	10%	30%	Annual loads in general are increased in this new model version, although changes are within the expected uncertainties in the model and do not change the order of magnitude of the loads being predicted.