Stormwater Contaminant Load Monitoring (2016) and Modelling of the Heathcote Catchment and Six Representative Subcatchments

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ABSTRACT

Adverse effects from sediment and heavy metals have been observed in the Heathcote catchment, which is diverse in its land use activities. Stormwater management improvements are planned for the catchment through the Heathcote Stormwater Management Plan. Contaminant load monitoring and modelling for subcatchments in the Heathcote were undertaken to help inform the stormwater management policies and planning. The UC's event-based contaminant load model, MEDUSA (Modelled Estimates of Discharges for Urban Stormwater Assessments), that predicts the amount of total suspended solids (TSS), and total and dissolved copper and zinc generated by individual roof, road and carpark surfaces, was employed for the modelling. Stormwater monitoring of key impermeable surfaces was used to calibrate the model and also quantify the chemical speciation of the contaminants (i.e. particulate or dissolved form), important for assessing appropriate future treatment or mitigation strategies.

Stormwater runoff monitoring and predictive modelling (using MEDUSA) was previously conducted in the Okeover and Addington subcatchments of the Avon Catchment. In those studies, four roof types, three road types and three carpark classifications were monitored and modelled. In this study, stormwater runoff quality was monitored from eight different impermeable surfaces in the Heathcote catchment over 9 rainfall events from July to November 2016. These sites represented typical surfaces in the catchment: a new Coloursteel® roof, an older Coloursteel® roof, a concrete roof, a galvanized painted roof, three roads (local, collector, minor arterial) and a commercial/light industrial carpark.

First flush (first 1 L of runoff) and steady state samples were analysed for TSS and total and dissolved zinc and copper. Data from the monitoring campaign was analyzed and then used to refine MEDUSA to Heathcote conditions. The model was applied to estimate zinc loads from roofs for the Heathcote catchment as a whole, as well as from six individual subcatchments representing industrial areas (Curries and Jardens Drains; Awatea), mixed use areas (Curletts Drain; Waltham) and mostly residential areas (Jacksons Creek; Wilderness Drain). Predictions of contaminant loads were obtained for each rainfall event sampled in 2016. Additionally, predictive simulations were conducted for all events for years between 2011-2016 to ascertain differences as a function of variable weather conditions.

The galvanized roof surfaces produced significantly more zinc than other surfaces. Coloursteel® Old and Galvanised Painted first flush runoff contributed some of the highest zinc concentrations measured in recent Christchurch untreated stormwater sampling. First flush concentrations from the

new Coloursteel® roof were consistently lower than the steady state concentrations from the old Coloursteel® roof. Similarly, zinc concentrations from the galvanised painted roof were higher than the new Coloursteel® roof, but lower than the old Coloursteel® roof. The data also clearly show that the majority of zinc from the four roof types is in the dissolved form, substantiating previous monitored data in Christchurch. These data confirm that the key mechanism for zinc generation from roofs is direct dissolution of the roof material, enhanced and sustained by the exposure and breakdown of the galvanizing layer through weathering. Zinc measured in concrete roof runoff is believed to originate from galvanised components in the guttering and downpipes rather than from atmospheric deposition alone. Therefore, while concrete and other non-metallic roofs may not contribute large zinc loads to stormwater runoff, some zinc is dissolved from their galvanised drainage components, which may be something to consider in management decisions about roof replacements along with roof condition.

Because zinc was defined as the focus of the study, total zinc loads were predicted using MEDUSA. Modelling results revealed that there is a clear difference in the rate at which total zinc is derived from each roof type, with concrete and Coloursteel® roofs yielding the least amount of zinc (per area) in roof runoff. Zincalume® and painted Galvanised roofs released more than double the amount (per area) of concrete and Coloursteel® roofs, but not as much as unpainted galvanised roofs. The data highlight the availability of zinc from roofs (with metallic surfaces) to stormwater runoff and the positive effect of painting these surfaces to immobilize some of the zinc. The yearly scenario results reveal the influence of variable wet weather conditions (including rainfall pH, antecedent dry days, rainfall intensity and duration) on zinc runoff from roofs.

Despite the relatively low proportion (7 %) of roofs within the Heathcote Catchment that are defined as poorly painted or unpainted, they consistently contribute more than 30 % of the total zinc load from roofs in each year. Waltham (mixed landuse) roofs, which make up 29 % of the catchment and comprise the highest proportion (16 ha) of unpainted galvanized roofs, contribute between 2.2 and 7.6 net kg TZn/event to stormwater runoff. Similarly, Wilderness Drain (residential landuse) roofs, which make up 26 % of the catchment and comprise 12 ha of unpainted galvanized roofs, 34 ha of painted galvanized roofs and 27 ha of Coloursteel® roofs, produces nearly the same net zinc loads (2.0 -7.9 TZn kg) per rain event as Waltham. These disaggregated data are important because they highlight that the proportional area of specific roof types (e.g. unpainted galvanized) is a clear determinant of how much total zinc can be expected in roof runoff rather than assuming greater contributions from a more industrial/commercial area alone. Furthermore, depending on the condition of that roof material, a range of lower or higher zinc loads can be expected from roof runoff during rain events.

Changes (as modelled scenarios) in proportional roof areas from the current status would result in significant reductions of total zinc runoff from roofs in the Heathcote subcatchments across all the modelled years, with some variability between years due to the influence of rainfall parameters. This reduction is more pronounced at the higher ranges for each scenario. A change in proportional zinc loads in different subcatchments results from the change in their proportional areas (and condition), highlighting the value in examining specific subcatchment responses to variable modelling scenarios.

Contents

1 Introduction

The Heathcote Catchment is diverse in its land use activities. There are large industrial and commercial subcatchments such as Haytons Stream and Curletts Drain at its western end and Woolston in its eastern section. Residential areas are a mix of flat land suburbs as well as the majority of Christchurch's hill suburbs. Stormwater runoff from impervious surfaces in the catchment, such as roofs, roads and carparks, is one of the key sources of heavy metals (and sediment). TSS is contributed via atmospheric deposition of particles (dry and wet deposition) (Murphy et al., 2014), breakdown and degradation of surface materials and direct deposition from vehicular sources (e.g. tyre and brake pad wear, dust wash off from vehicle bodies) (Zanders, 2005). Copper is contributed from brake pads (it is used as a heat dissipater), industrial uses of copper (released into the airshed and settled with atmospherically deposited particles) and direct dissolution of copper materials (Davis et al., 2001; O'Sullivan et al. 2012 and Wicke et al., 2012). Zinc is contributed from tyres (it is used as a vulcanizing agent in tyre rubber), industrial uses of zinc and especially from direct dissolution of zinc materials, such as galvanised roofs and cladding (Charters et al., 2017). Adverse effects from sediment and heavy metals have been observed in the Heathcote catchment (e.g. O'Sullivan and Charters, 2014, Margetts and Marshall, 2016) and the Christchurch City Council (CCC) is required under the Land and Water Regional Plan to manage stormwater discharges to meet water quality guidelines in the waterways.

Improved stormwater management was identified as a key priority to reduce the contaminant loads, however a deeper understanding of where and how stormwater pollution is being generated within the catchment is needed to guide the development of targeted stormwater management options for water quality improvements. Accordingly, the Christchurch City Council engaged the University of Canterbury to measure and model specific contaminant loads generated by impervious surfaces within Heathcote representative subcatchments.

A targeted monitoring campaign measured stormwater runoff from specific impermeable surfaces from July-November 2016. This revealed the chemical speciation of the contaminants (i.e. particulate or dissolved forms), important for assessing appropriate treatment or mitigation strategies. Subsequently, an event-based contaminant load model, Modelled Estimates of Discharges for Urban Stormwater Assessment (MEDUSA) (Charters *et al*., in review) was used to predict the amount (load) of key contaminants (TSS, Zn, Cu) contributed by individual impervious surfaces within the representative (typical industrial/commercial, flat land residential and hill residential) subcatchments. The model accounts for rainfall characteristics such as rainfall pH, length of antecedent dry period, average intensity and event duration, and thereby incorporates local climate characteristics into its predictions.

2 Materials and Methods

2.1 Sampling Site Characteristics

In 2016, runoff was sampled from eight selected impermeable surfaces within the Heathcote subcatchments (Figure 2-1) during 9 rainfall events (Table 2-1).

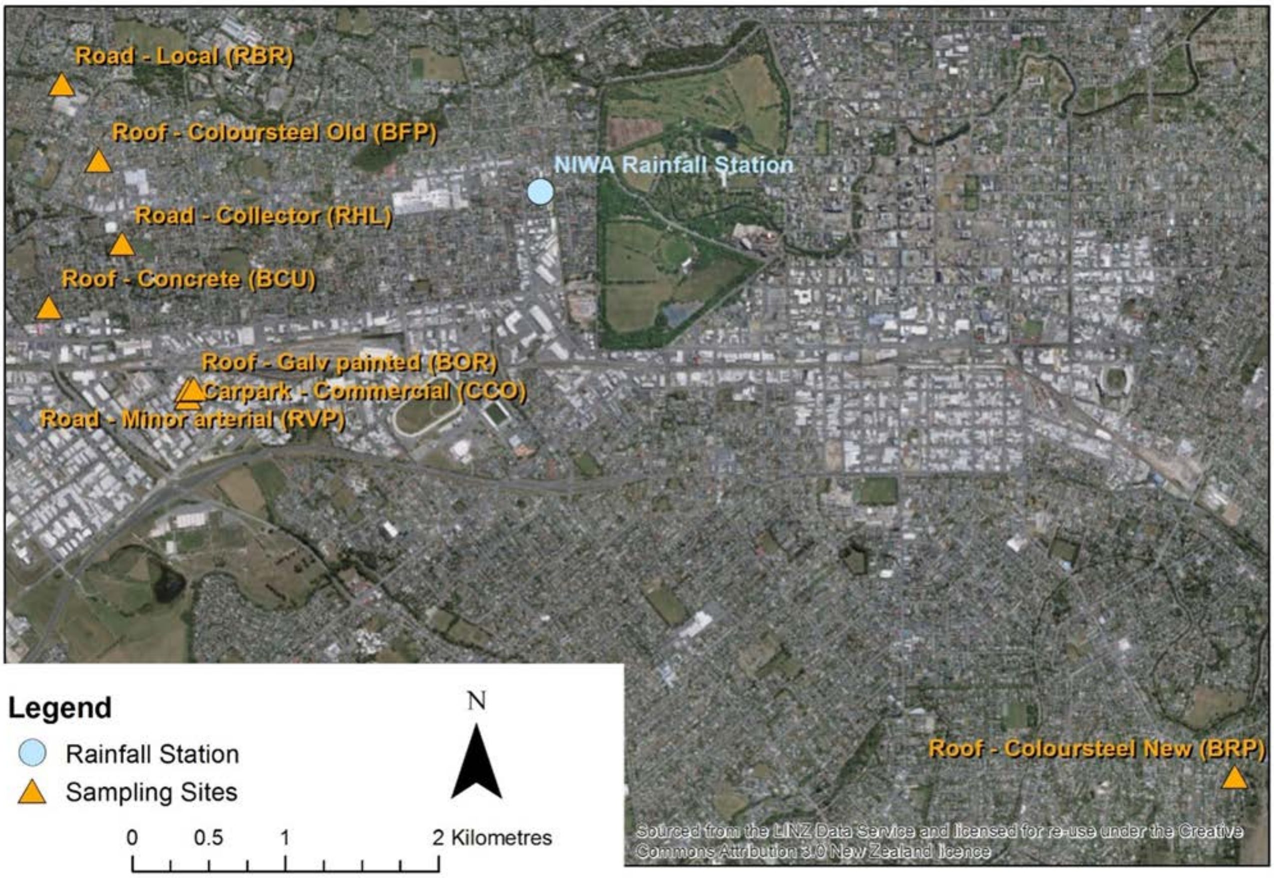


Figure 2-1. Sampled impermeable surfaces within the Heathcote subcatchments

Table 2-1 Sampled rainfall event characteristics

Event No.	Start Date	Rainfall pH (S.U.)	Average intensity (mm/hr)	Peak 15-min intensity (mm/hr)	Antecedent dry period (days)	Duration (hrs)	Depth (mm)	Depth of preceding event (mm)
1	8 Jul 2016	6.29	0.81	2.12	9.66	4.0	3.2	0.4
2	3 Aug 2016	6.60	0.16	1.44	3.23	8.8	1.4	2.0
3	4 Aug 2016	6.02	0.43	2.40	0.71	6.8	2.9	1.4
4	13 Aug 2016	6.64	0.49	2.48	4.24	18.0	8.8	0.2
5	26 Aug 2016	6.79	1.76	3.84	1.29	8.0	14.0	0.9
6	7 Sep 2016	6.53	0.79	7.00	1.45	24.8	19.5	0.8
7	14 Oct 2016	6.74	0.47	2.60	2.01	5.8	2.7	3.3
8	20 Oct 2016	6.17	1.70	14.04	5.60	22.3	37.8	2.7
9	11 Nov 2016	--[1]	0.40	1.80	2.22	17.5	7.0	0.7
Median		***6.57***	***0.49***	***2.48***	***2.22***	***8.8***	***7.0***	***0.9***
Minimum		***6.02***	***0.16***	***1.44***	***0.71***	***4.0***	***1.4***	***0.4***
Maximum		***6.79***	***1.76***	***14.04***	***9.66***	***24.8***	***37.8***	***3.3***

[1] Rainfall pH not recorded for Event 9.

Average and 15-minute peak rainfall intensity, duration and length of the antecedent dry period were recorded for each event using meteorological data from the nearby National Institute of Water and Atmosphere's (NIWA) Weather Station. Rainfall was collected and pH measured during sample collection. All sites were monitored for first flush (FF; for the purposes of this study defined as the first 1 L of runoff) and steady state (SS) runoff quality. Thermo Scientific™ Nalgene™ Storm Water Sampler bottles (1 L HDPE) were used to collect FF samples. For carpark and road runoff sites, they were deployed by suspending the bottle from the sump grate with a cable tie, in the corner of the sump where the initial runoff would flow in. For the roofs, the bottle was fitted within a Thermo Scientific™ Nalgene™ Storm Water Mounting Kit and fixed under the downpipe. Grab sampling (1 L HDPE) was used for all SS samples. Samples were delivered to Hill Laboratories within 24 hours and analyzed following appropriate APHA methods with robust quality control procedures (as detailed in Charters, 2016 for the Addington catchment).

Table 2-2 summarises details of the monitored locations. The sites were considered representative of either the most common surfaces types in the catchment or specific surface materials and conditions (e.g. residential, industrial, mixed land use) that were of interest from an environmental impact point-of-view. Figure A2-1 shows these locations along with previously monitored impermeable surfaces within the Okeover and Addington subcatchments of the Avon Catchment.

Table 2-2 Sampling site characteristics and events

Site	Site Code	Surface type	Description	Estimated Drainage Area (m^2)	FF samples	SS samples	No. of events where FF and SS sampled
Curletts Road, Upper Riccarton	BCU	Roof	Concrete roof (installation date unknown)	30	4	4	4
Fletcher Place, Upper Riccarton	BFP	Roof	Old Colorsteel™ roof (installed 1994; 22 years old)	37	6	5	5
Orange Homes, Middleton	BOR	Roof	Old painted galvanised roof (installation date unknown)	105	7	6	6
Rapaki Road, Hillsborough	BRP	Roof	New Colorsteel™ roof (installed 2016; <1 year old)	52	6	5	5
NZ Couriers, Middleton	CCO	Carpark	Commercial/light industrial	356	7	6	6
Brodie Street, Upper Riccarton	RBR	Road	Local road (4,200 AADT) [1]	280	6	5	5
Hansons Lane, Upper Riccarton	RHL	Road	Collector road (6,600 AADT)	670	4	3	3
Venture Place, Middleton	RVP	Road	Runoff from Annex Road, a minor arterial road (14,300 AADT) [1]	750	7	6	6

1 AADT: Annual Average Daily Traffic (CCC, 2012 cited in Charters, F. (2016))

2.2 Measured Contaminant Loads

Event Mean Concentration (EMC) was derived in order to calculate the contaminant load. In the absence of flow monitoring, EMC was based on proportional first flush (FF) and steady state (SS) concentrations for each event (as shown in as shown in Figure A2 2) in the appendices). Zinc per event loads were calculated on a per area basis (e.g. mg/m^2) based on EMC multiplied by the event rainfall depth.

2.3 Comparison of Measured and Modelled Contaminant Loads

Predictions of contaminant loads were modelled for all (9) water quality rainfall events sampled in 2016 and then compared to the same measured events. This enabled new calibration coefficients to be derived for the Heathcote Catchment. Along with the previous calibrated coefficients derived for the Okeover and Addington subcatchments within the wider Avon Catchment, the updated coefficients were used to calibrate the model to the Heathcote conditions.

Model predictive performance was measured using the Nash-Sutcliffe Model Efficiency (NSE) statistic (Nash and Sutcliffe, 1970), which has been employed for modelling sediment and nutrient loadings (Moriasi et al., 2007). It describes the predictive accuracy of the model in comparison to the observed data (e.g. Charters et al., 2017). Values close to 1 indicate a perfect fit between the modelled and observed loads, while values $0<NSE<1$ show the model is a better predictor than the observed mean. The NSE values represent log-transformed load values (as detailed in Charters et al., in review). The calibrated MEDUSA model showed a very good fit to the measured (observed) data across all roof sites (Figure 2-2). The model produced high (≥ 0.88) NSE values for total zinc (TZn) for all metal roofs, and a lower NSE value of 0.73 for the concrete roof, confirming the applicability of MEDUSA to the Heathcote.

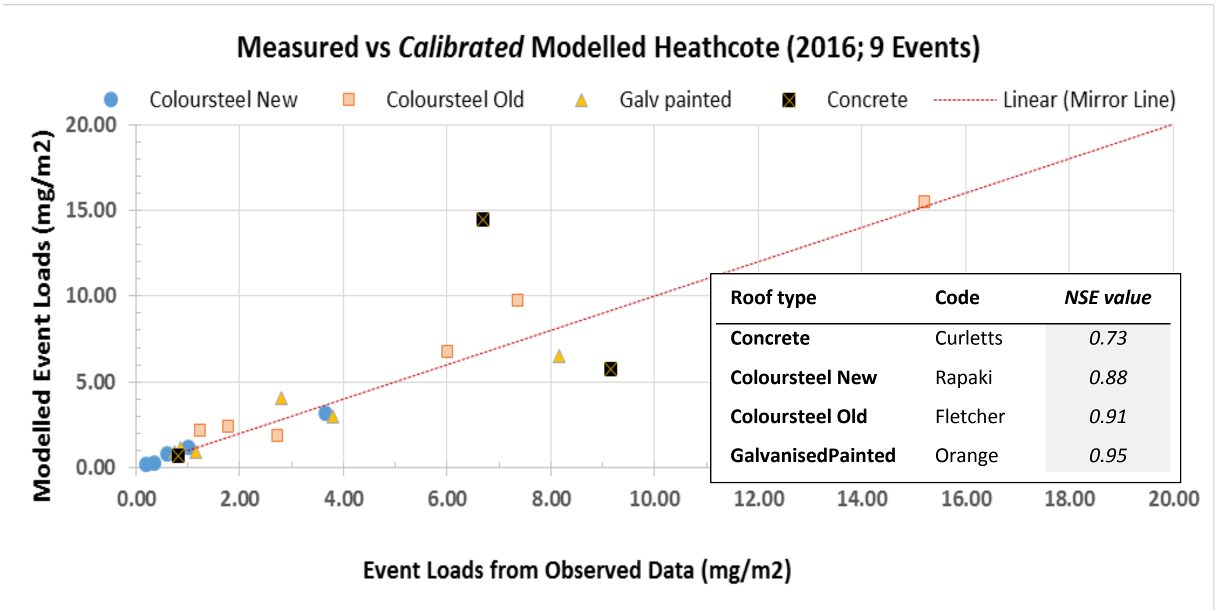


Figure 2- 1 Observed zinc loads against MEDUSA predicted loads for the six Heathcote sites.

2.4 Modelled Contaminant Loads and Management Scenarios

The MEDUSA model was run for the whole Heathcote Catchment as well as six representative subcatchments (two from each **A**: established residential, **B**; industrial and **C**; a mix of residential and industrial) for zinc contributions from roofs (detailed in section 3.1). Since roofs are considered a major contributor of zinc to the Heathcote receiving waterways (i.e. during rainfall events), changing roof types were prioritized as a targeted scenario that could result in significant reductions of zinc pollution. As well as baseline (i.e. status quo) modelling of the current roof areas (**Scenario 1**), three additional scenarios were modelled to predict what change in zinc loads (mg/event) might result as a function of changing roof types. These additional scenarios stipulated that all metal roof areas within the catchment were comprised of:

- **Scenario 2**: 90 % new Coloursteel® and 10 % old Coloursteel® (& existing ‘other’ non-metal roofs)
- **Scenario 3**: 50 % new Colorsteel™ and 50 % old Colorsteel™ (& existing ‘other’ non-metal roofs)
- **Scenario 4**: all concrete, i.e. no metallic roofs.

Additionally, predictive simulations were conducted for each rainfall event for the period 2011-2016 to ascertain zinc loads as a function of variable weather conditions. Through scenario modelling, outputs can help guide management decisions for selection of appropriate stormwater policies and treatment systems, with the ultimate aim of reducing the contribution of stormwater contaminants to urban waterways.

3 Results and Discussion

3.1 Surface Area Delineation

The Heathcote catchment comprises 10,345 hectares (ha) of mixed industrial, commercial and residential land use delineated into more than 19 subcatchments (Figure 3-1). Roof surfaces constitute nearly 13 % (1328 ha) of the total catchment, roads 9 % (919 ha) and other paved areas (not including roads) 9 % (919 ha), in total comprising 31 % imperviousness as detailed in Table 3-1.

Figure 3- 1: Location map of Heathcote catchment and hydrological subcatchments in Christchurch as detailed in detailed in Table 3-1.

Table 3-1 Heathcote subcatchments and their respective areas (delineated from PDP Analysis using CCC GIS data). Highlighted subcatchments were chosen to be most representative for the scenario modelling.

	Total area (ha)	**Proportion of catchment (%)**
HEATHCOTE CATCHMENT	*10,345*	*100*
Roofs	*1328*	*13*
Roads	*919*	*9*
Paved areas/carparks (not including roads)	*927*	*9*
Non-impervious surfaces	*7,171*	*69*

Subcatchment No	***Name***	**Total area (ha)**	**Impervious (%)**	**Roof area (%)**
1	Bridle Path	6280	16	5
2	Avoca Valley and Butts Valley	530	16	6
3	Steam Wharf Stream	109	62	41
4 (Industrial)	Curries and Jardens Drains	405	48	20
5	Bells Creek	261	68	19
6 (Mixed)	Waltham	418	64	29
7	Victory Drain	497	10	4
8 (Residential)	Jacksons Creek	357	56	23
9	Sibleys and Scotts Drains	663	16	10
10 (Residential)	Wilderness Drain	481	50	26
11	Dyers / Hackthorne	105	34	18
12	Heathcote River Corridor	242	38	23
13 (Mixed)	Curletts Drain	353	65	22
14	Paparua/Haytons	1523	35	14
15 (Industrial)	Awatea	958	50	15
16	Cashmere Valley	550	7	3
17	Worsleys Valley	375	7	4
20	Hendersons Basin	280	6	2
21	Hoon Hay Valley	716	3	1
22	Sutherlands	192	9	4
18a	Hendersons Road	134	21	11
18b	Sherrings Drain	85	31	19
18c	Ballintines Drain	102	40	27
18d	Luneys Drain	65	22	13
19a	Halswell	185	27	17
19b1Aidan	Aidanfield	54	40	26
19b1OldHals	Westlake	39	43	26
19b2	Milns	42	9	3

Based on the CCC survey data provided (and in consultation with Paul Dickson of the CCC), metal roofs were stipulated to be Coloursteel® or Zincalume® if they were constructed after 1980, with all others pre 1980 or no date known defined as 'iron' (i.e. galvanized) and then sub-categorized as either unpainted or painted galvanised. Metallic roofs comprise 52 % of all roofs in the Heathcote catchment (Figure 3-2) consisting of 7 % unpainted/poorly painted galvanized, 16 % painted galvanized, 6 % Zincalume® and 24% Colorsteel™, with the remaining 48 % classified as 'other' (concrete, butynol, glass, bitumen, brick, concrete, fibrous cement or asbestos, fabric, bitumen and butyl rubber in all forms, plastic, roughcast, stone, tiles, wood and a mixture).

Proportional surface types as a function of each impervious category for the whole Heathcote Catchment are summarized in Figure 3-2. Further surface categorization as a function of each subcatchment is presented in the Appendix in Figure A3- 1 (roofs), Figure A3- 2 (roads) and Figure A3- 3 (pavement/carparks).

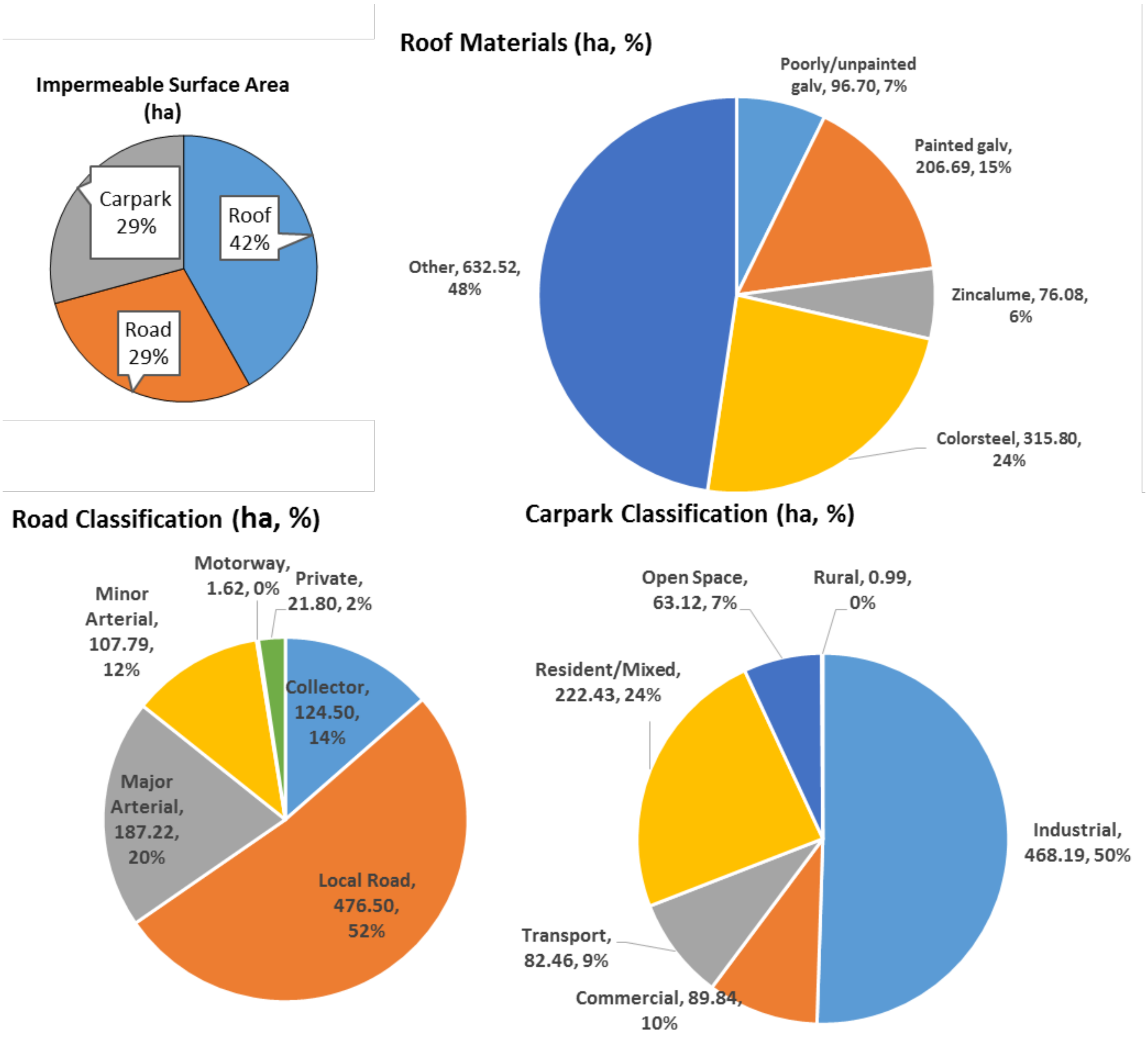


Figure 3- 2: Composition of impermeable surfaces by material type in Heathcote Catchment.

3.2 Water Quality Monitoring

3.2.1 *Monitoring of Urban Runoff in the Heathcote Catchment*

Total Suspended Solids (TSS) and the key metals (Zn, Cu) for each sampling site monitored in the Heathcote in 2016 are summarized in Table 3-2. Overall, highest concentrations were measured during the first flush (FF) period, later declining during steady-state (SS) levels. On average, the concrete roof on Curletts road had higher TSS concentrations compared with zinc metallic roofs, but much lower levels than the road (Brodie Street) or carpark (NZ Couriers) sites monitored (Table 3-2). Highest copper concentrations were measured in the carpark site and lowest levels from the older Coloursteel® roof (Fletcher Place). Average zinc concentrations from the minor arterial road (Venture Place; RVP) were the highest measured (Table 3-2), but upon secondary inspection of the area, it appeared that some roof runoff was conveyed to the collection sump, thereby representing mixed roof-road runoff, and that it was probably a weathered galvanized roof type. The galvanized roof surfaces produced significantly more zinc than other surfaces (Table 3-2).

Figure 3- 3 shows the range of total and dissolved zinc concentrations from each roof type. Both Coloursteel® Old (Fletcher Place) with 2.4 mg/L (FF) and Galvanised Painted (Orange Homes) with 1.8 mg/L (FF) contributed some of the highest zinc concentrations (Table 3-2). Of note is that the new Coloursteel® roof (Rapaki Road) yielded some zinc with 0.50 mg/L during FF down to 0.15 mg/L during SS conditions. FF zinc concentrations from the new Coloursteel® roof were consistently lower than the SS concentrations from the old Coloursteel® roof. Similarly, zinc concentrations from the galvanised painted roof were higher than the Coloursteel® new roof but lower than Coloursteel® old roof (Figure 3- 3). These data highlight the effect of roof age on zinc concentrations in roof runoff, which substantially increase due to weathering. The results corroborate with data from other subcatchments in Christchurch (Charters, 2016, Charters *et al*., 2016, and Charters *et al*., 2017). Zinc measured in concrete roof runoff (e.g. Curletts Road) is thought to originate from galvanised components in the guttering and downpipes rather than from atmospheric deposition alone.

Table 3-2: Water quality (TSS, Cu and Zn concentrations) measured from each impermeable surface type during first flush (FF) and steady-state (SS) periods over the 9 events monitored in the Heathcote in 2016. Value are averages with ranges in parenthesis.

Site	Site Code	Condition	TSS (mg/L)	Total copper (µg/L)	Dissolved copper (µg/L)	Total zinc (µg/L)	Dissolved zinc (µg/L)
Curletts Road, Upper Riccarton	BCU (Roof)	FF	24 (<3-50)	48 (23-89)	41 (21-76)	380 (290-480)	323 (230-480)
		SS	55 (<3-39)	24 (15-32)	19 (12-29)	315 (174-470)	284 (161-400)
Fletcher Place, Upper Riccarton	BFP (Roof)	FF	13 (<3-26)	4.0 (0.8-6.3)	1.6 (0.6-3.4)	2,415 (810-4,500)	2,330 (810-4,500)
		SS	3 (<3-9)	0.8 (0.3-1.6)	0.4 (0.3-0.7)	644 (330-880)	640 (330-860)
Orange Homes, Middleton	BOR(Roof)	FF	15 (3-31)	70 (25-123)	46 (18-75)	1,879 (980-4,800)	1,827 (980-4,800)
		SS	3.8 (<3-15)	13 (6.7-20)	6.7 (4.2-8.9)	342 (153-480)	337 (153-480)
Rapaki Road, Hillsborough	BRP (Roof)	FF	32 (14-59)	14 (2-27)	5.3 (1.0-11)	503 (186-1,070)	469 (186-1,010)
		SS	8.2 (<3-29)	54 (1.2-210)	0.5 (0.3-1.0)	154 (47-290)	111 (44-250)
NZ Couriers, Middleton	CCO (Carpark)	FF	239 (31-670)	248 (76-560)	60 (29-81)	977 (330-1,890)	463 (220-780)
		SS	49 (12-82)	77 (34-176)	19 (10-32)	328 (175-540)	149 (88-178)
Brodie Street, Upper Riccarton	RBR (Road)	FF	173 (43-420)	38 (16-58)	18 (10-38)	273 (100-570)	87 (42-161)
		SS	52 (23-111)	14 (7.2-21)	5.9 (3.8-11)	104 (46-187)	37 (27-60)
Hansons Lane, Upper Riccarton	RHL (Road)	FF	161 (49-360)	71 (42-121)	47 (18-99)	272 (165-330)	148 (95-230)
		SS	68 (55-80)	35 (30-40)	22 (17-27)	271 (165-330)	92 (80-104)
Venture Place, Middleton	RVP (Road)	FF	259 (117-430)	198 (91-310)	37 (20-51)	3,257 (2,700-4,900)	2,034 (1,080-3,700)
		SS	114 (28-270)	57 (28-104)	10 (7.5-16)	1,470 (900-2,200)	935 (390-1,560)

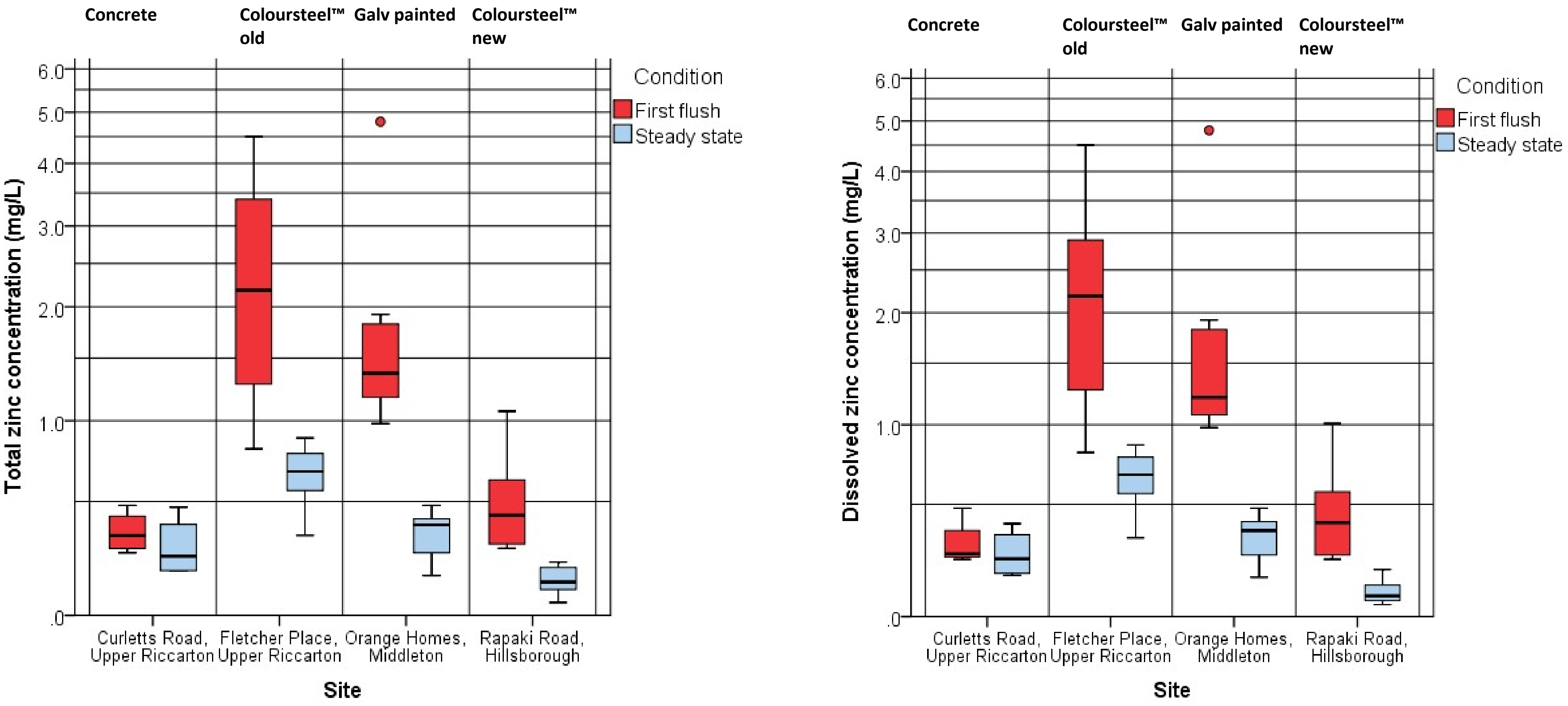


Figure 3- 3 Average total (left) and dissolved (right) Zn measured from each roof type during first flush (FF) and steady-state (SS) periods over the 9 events in 2016.

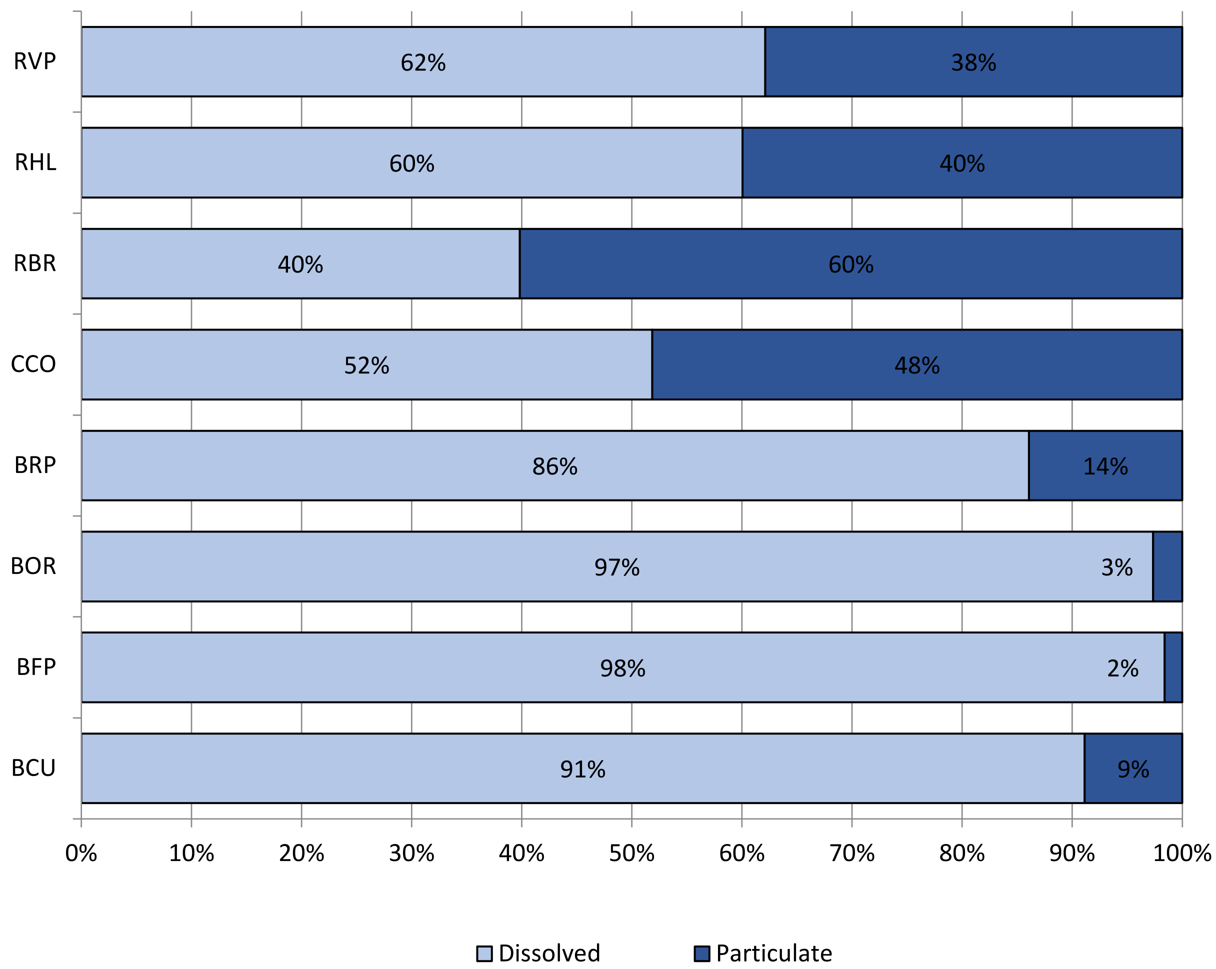


Figure 3- 4 Proportion of particulate and dissolved Zn in the monitored sites where a code starting with the letter B = Building Roof, C = Carpark and R = Road (detailed site codes are defined in Table 3-2).

The proportion of particulate and dissolved zinc (summed constituting the total amount) at each site measured in the Heathcote is summarized in Figure 3-4. The data clearly show that the majority of zinc from the four roofs is in the dissolved form, substantiating previous monitored data in Christchurch (Charters et al., 2016 and Charters et al., 2017). These data confirm that the key mechanism for zinc generation from roofs is direct dissolution of the roof material, enhanced and sustained by the exposure and breakdown of the galvanized layer through weathering. Given the elevated levels of dissolved zinc in Christchurch urban waterways, it would wise to implement source-control of this highly bioavailable metal.

3.2.2 ***International Monitoring of Roof Runoff***

Untreated runoff sampling (and concurrent contaminant load modelling) was previously conducted in Christchurch in the Okeover (Charters et al., 2016) and Addington (Charters, 2016) subcatchments of the Avon Catchment. Concentrations of zinc (and copper) from those subcatchments are included in the comparison for the Heathcote Catchment (Table 3-3). It is important to note that different catchment areas apply between the comparisons. Figure 3-5 compares the FF and SS average total zinc concentrations measured from all roofs sampled in Christchurch to national and international concentrations reported, to provide context for the data.

The three galvanised roofs in the Heathcote produced a similar order of magnitude of zinc concentrations in roof runoff compared to most other zinc roofs in Christchurch (with the exception of the old unpainted galvanised roof in Addington), and were typically one order of magnitude higher than non-metallic roofs (Figure 3-5). Steady state concentrations were also elevated, although typically they were an order of magnitude lower than the first flush concentrations. Zinc concentrations were typically in the upper range of values reported elsewhere in New Zealand, which may reflect the greater (especially more recent) monitoring data available directly from roof runoff. Overall, the data highlight the substantial contribution of bioavailable zinc derived from galvanised roofs entering stormwater runoff.

Table 3-3 Mean (and range in parenthesis) of total and dissolved Zn concentrations from each roof runoff sampled in the Heathcote, Addington and Okeover catchments in Christchurch. Colour coding is for the purpose of visual comparison between different magnitudes of Zn concentrations measured at each site.

Classification	Catchment	Site	Site Code	Condition	Total zinc (ug/L)	Dissolved zinc (ug/L)
Concrete	Heathcote	Curletts Road, Upper Riccarton	BCU	FF	380 (290-480)	323 (230-480)
				SS	315 (174-470)	284 (161-400)
Concrete	Okeover	Montana Ave roof	Cr	FF	21 (9.2-44)	17 (5.6-44)
				SS	15 (5.4-36)	9.6 (2.8-25)
Coloursteel® old	Heathcote	Fletcher Place, Upper Riccarton	BFP	FF	2,415 (810-4,500)	2,330 (810-4,500)
				SS	644 (330-880)	640 (330-860)
Coloursteel® new	Heathcote	Rapaki Road, Hillsborough	BRP	FF	503 (186-1,070)	469 (186-1,010)
				SS	154 (47-290)	111 (44-250)
Galvanised painted	Heathcote	Orange Homes, Middleton	BOR	FF	1,879 (980-4,800)	1,827 (980-4,800)
				SS	342 (153-480)	337 (153-480)
Galvanised painted	Okeover	Civil Lab Wing roof	Gv	FF	1,005 (372-2,369)	993 (372-2,369)
				SS	335 (75-1,057)	332 (75-1,057)
Galvanised unpainted new	Addington	Tower Junction downpipe	TJD	FF	4,782 (410-12,600)	4,442 (410-11,400)
				SS	1,085 (950-1,310)	1,018 (940-1,120)
Galvanised unpainted old	Addington	GoBus downpipe	GBD	FF	32,338 (11,700-56,000)	28,250 (10,700-53,000)
				SS	5,920 (2,400-8,700)	5,900 (2,300-8,700)
Copper	Okeover	E9 roof	Cu	FF	83 (36-292)	65 (16-207)
				SS	23 (5-147)	16 (4.2-44)

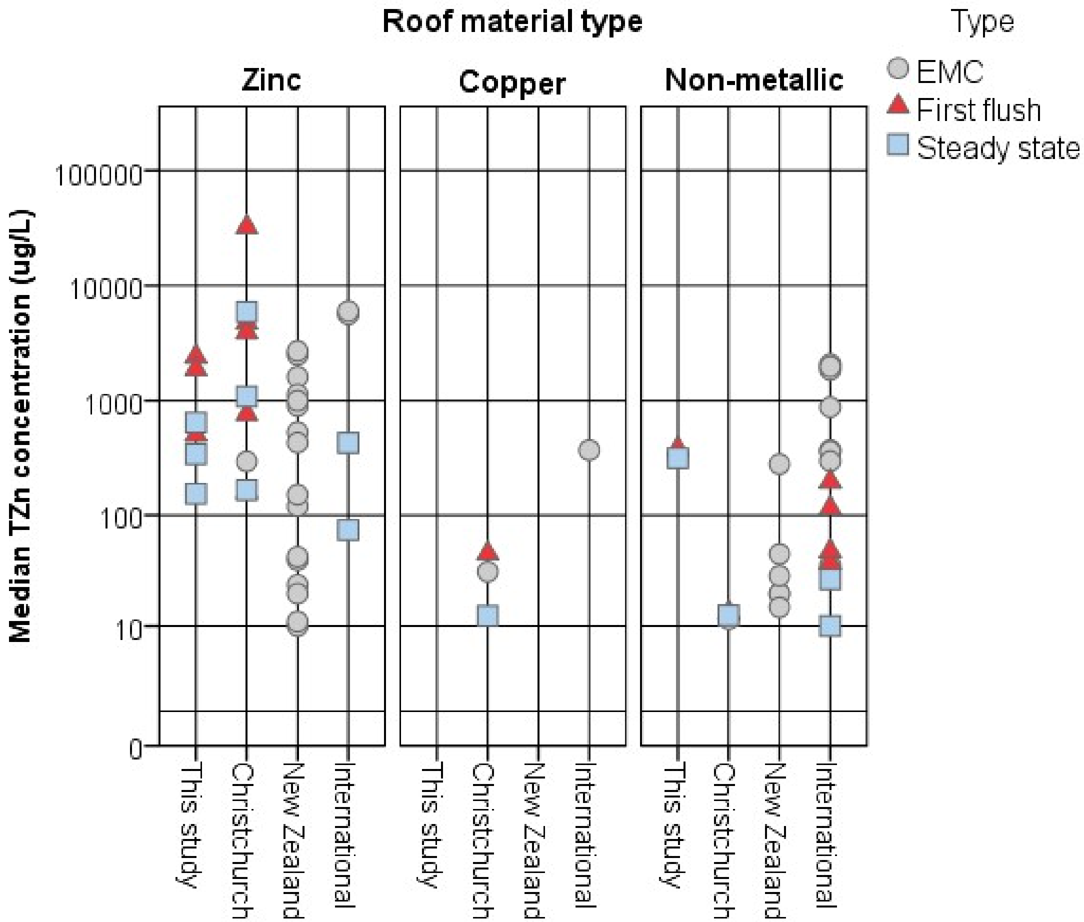


Figure 3- 5: Comparative zinc (TZn) concentrations in roof surface types sampled in the Heathcote (this study) with local (Christchurch), national (New Zealand) and international median concentrations reported elsewhere.

3.3 Modelled Results

3.3.1 *Zinc Loads from All Roof Types and Yearly Scenarios for the Whole Heathcote Catchment – Scenario 1 (Status Quo)*

Because zinc was defined as the focus of the study, total zinc loads were predicted using MEDUSA. Although dissolved zinc loads were also modelled, the detail is not reported here in the interests of reporting brevity and because the monitoring data clearly revealed that the overwhelming majority (between 86-98 %) of the total zinc from roofs is dissolved (e.g. Figure 3-4).

3.3.1.1 Average Event Rate Loads (mg/m^2/event)

For all yearly scenarios modelled, both lower and upper ranges of average event total zinc loads were derived per unit area (TZn mg/m^2). The lower and upper ranges defined for each surface type are based on the lower and higher total zinc concentrations measured, respectively, from the surface type. For instance, concrete roofs in the Okeover were designated 'low range' in the model because they yielded minimum zinc concentrations whereas concrete roofs in the Heathcote were designated 'high' range based on their higher measured TZn concentration. The sampled location for each low and high TZn concentrations used in calibrating the model coefficients are defined in Table 3-4. Because no Zincalume® roofs were sampled, the low and high concentration ranges were assigned categories of painted and unpainted galvanised, respectively, for modelling purposes.

Table 3-4 Roof location sampled for low and high TZn concentrations used in the modelling.

Roof Type	**Low range**		**High range**	
	Location	*Catchment*	*Location*	*Catchment*
Concrete	Montana Av	Okeover	Curletts Road	Heathcote
Coloursteel	Rapaki Av	Heathcote	Fletcher Place	Heathcote
Galvanised painted	Orange Homes	Heathcote	UC Engineering	Okeover
Galvanised *un*painted	Tower Junction	Addington	GoBus	Addington
Zincalume®	Orange Homes	Heathcote	Tower Junction	Addington

Average event rate loads represent the average amount of total zinc derived for each rainfall event from each square metre of each roof type currently in the Heathcote Catchment (Table 3-5). Clearly there is a difference in the *rate* at which zinc is derived from each surface type, with concrete and

Coloursteel® roofs yielding the least amount of zinc in roof runoff (Table. 3-5). While it would be expected that zinc generated from concrete roofs is minimal (mainly attributed to some atmospheric deposition) as found for the 'low' concrete amount (using measured data from the Okeover catchment), the 'high' amount found in the Heathcote is thought to be a result of galvanised guttering on the Curletts Road concrete roof as explained in section 3.2.1 earlier, so 'true' concrete (with no metal roof components) are more likely in the 'low' concrete range. Lower ranges for Zincalume® and painted Galvanised roofs (which were considered to have the same coefficients of zinc runoff in the calibrated model and therefore, the same normalized pollutant runoff rate) released more than double the amount of concrete and Coloursteel® roofs, but much less than unpainted galvanised roofs. The data highlight the availability of zinc from roofs (with metallic surfaces) entering stormwater runoff and the positive effect of painting these surfaces to immobilize some of the zinc. Differences between low and high ranges of each surface type reflect the concentration ranges measured from each of these surface types in different catchments on different occasions. The yearly scenario data reveal the influence of the number of wet weather events and their variable conditions (including rainfall pH, antecedent dry days, rainfall intensity and duration) on zinc runoff from roofs. It is possible that some of the rainfall events within each year fell outside of the calibrated MEDUSA modelled ranges, so this is something to consider in the model limitations. A deeper meta-analysis of particular (i.e. very long or high intensity) events could reveal event-specific zinc loads as a function of their key rainfall characteristics.

3.3.1.2 Total Event Loads (kg/event)

The amount of total zinc derived from each roof surface type *currently* within the Heathcote Catchment are also represented as an average event load (kg/event) for all yearly scenarios modelled. The low and high ranges are derived similarly to the mg/m^2 rate loads explained above. The kg/event values represent the average amount of total zinc derived for each rainfall event from *all* impermeable areas of each roof type currently in the Heathcote Catchment (Table 3-6). Therefore, they account for the actual roof area and provide an indication of how much total zinc is currently being derived from those roof areas in the whole Heathcote Catchment. The total rate of zinc derived for all roof surfaces per event within the whole Heathcote Catchment is also provided, which represents the sum of each roof type and their proportional areas within the catchment.

The greatest proportion of roof area type within the Heathcote Catchment is defined as 'other' (see section 3.1 (pg 15)), and is assigned the same calibrated coefficients as concrete within the model. These 'other' account for 632 ha, followed by Coloursteel® with 316 ha, Galvanised painted at 207 ha, unpainted galvanised at 97 ha and then Zincalume® at 76 ha (e.g. Figure 3- 2). Despite the relatively low area of roofs within the Heathcote Catchment that are defined as poorly galvanised painted or unpainted (7 %), they contribute on average between 31-38 % of the total zinc load from roofs (e.g. Table 3-6). Zincalume® roofs, which make up 6 % of the Heathcote catchment roof areas, contribute an average of 8-11 % of the total zinc load. Even though the 'high' end of concrete roofs contributed elevated zinc loads thought to originate from galvanised guttering, these only contributed an average of 21 % of the total zinc load for 48 % of all roof areas within the catchment but more realistically (i.e. at the low end range assuming no galvanised guttering etc.) only contributed 2 % of the total zinc load from Heathcote roofs. Further detail about the proportional roof areas as a function of the whole Heathcote Catchment and six representative subcatchments is described in section 3.3.2.

Table 3-5 Average event *rate loads* (TZn mg/m^2/event) for zinc modelled for each roof surface type currently in the Heathcote Catchment over numerous yearly scenarios.

S1 (Status Quo)	**TZn mg/m^2/event of roof type**									
Catgeory	**Galv unpainted**		**Coloursteel®**		**Galv painted**		**Concrete**		**Zincalume®**	
Range	*low*	*high*	low	high	*low*	*high*	low	high	low	high
YEAR										
2016 (9 monitored)	10.6	30.9	2.0	8.6	3.8	6.9	0.1	3.5	3.8	10.6
2013 (66 events)	10.6	31.9	1.6	8.6	3.7	6.7	0.1	3.2	3.7	10.6
2012 (88 events)	6.7	20.2	1.0	5.4	2.4	4.3	0.1	2.1	2.4	6.7
2011 (112 events)	5.7	17.2	0.9	4.6	2.1	3.6	0.1	1.9	2.1	5.7
AVERAGE YEARS	***8.4***	***25.0***	***1.4***	***6.8***	***3.0***	***5.4***	***0.1***	***2.7***	***3.0***	***8.4***

Table 3-6 Average total event actual loads (TZn kg/event)for zinc modelled for each roof surface type currently in the Heathcote Catchment over numerous yearly scenarios.

S1 (Status Quo)	**TZn kg/event of roof type**										TZnkg/event for Heathcote	
Catgeory	**Galv unpainted**		**Coloursteel®**		**Galv painted**		**Concrete**		**Zincalume®**			
Range	*low*	*high*	low	high	*low*	*high*	low	high	low	high	low	high
YEAR												
2016 (9 monitored)	10.2	29.9	6.5	27.1	7.8	14.2	0.7	22.2	2.9	8.0	28.0	101.4
2013 (66 events)	10.3	30.8	5.2	27.0	7.7	13.9	0.7	20.1	2.8	8.1	26.7	100.0
2012 (88 events)	6.5	19.5	3.3	17.1	5.0	8.8	0.4	13.2	1.8	5.1	17.1	63.7
2011 (112 events)	5.5	16.6	2.8	14.6	4.4	7.5	0.4	11.8	1.6	4.4	14.8	54.8
AVERAGE YEARS	***8.4***	***24.7***	***4.3***	***22.0***	***6.4***	***11.4***	***0.5***	***16.6***	***2.3***	***6.6***	***21.9***	***81.8***
% Tot. Catchment load	*38*	*31*	*19*	*27*	*29*	*14*	*2*	*21*	*11*	*8*	*100*	*100*

3.3.2 *Zinc Loads from All Roof Types and Yearly Scenarios for Representative Subcatchments – Scenario 1 (Status Quo)*

As well as modelling scenarios for the whole Heathcote Catchment, six subcatchments were modelled that represented the land use types of industrial (Curries & Jardens and Awatea), residential (Jackson Creek and Wilderness Drain) and mixed (Waltham and Curletts) as delineated in Table 3-1.

The catchment roof areas, along with each zinc (average) event load predicted to originate from all the roof type areas for various yearly scenarios, are summarized in Table 3-7. This table is effectively an extrapolation of Table 3-6 (showing the whole Heathcote Catchment) but also includes scenarios modelled for each of the representative subcatchments. The pattern of overall total zinc loads derived from all the roof areas in the Heathcote Catchment (as explained earlier in section 3.3.1.2) is essentially reflected in each of the subcatchments too. However, in order to better highlight differences in zinc originating from all the different roof areas in the representative land use subcatchments, Figure 3-6 shows patterns between these subcatchments for both low and high ranges expected, where data for the year 2012 (a typical rainfall year in Christchurch) is presented. Additionally, Figure 3-7 extracts these patterns for each roof surface type between the subcatchments (representing both low and high ranges expected).

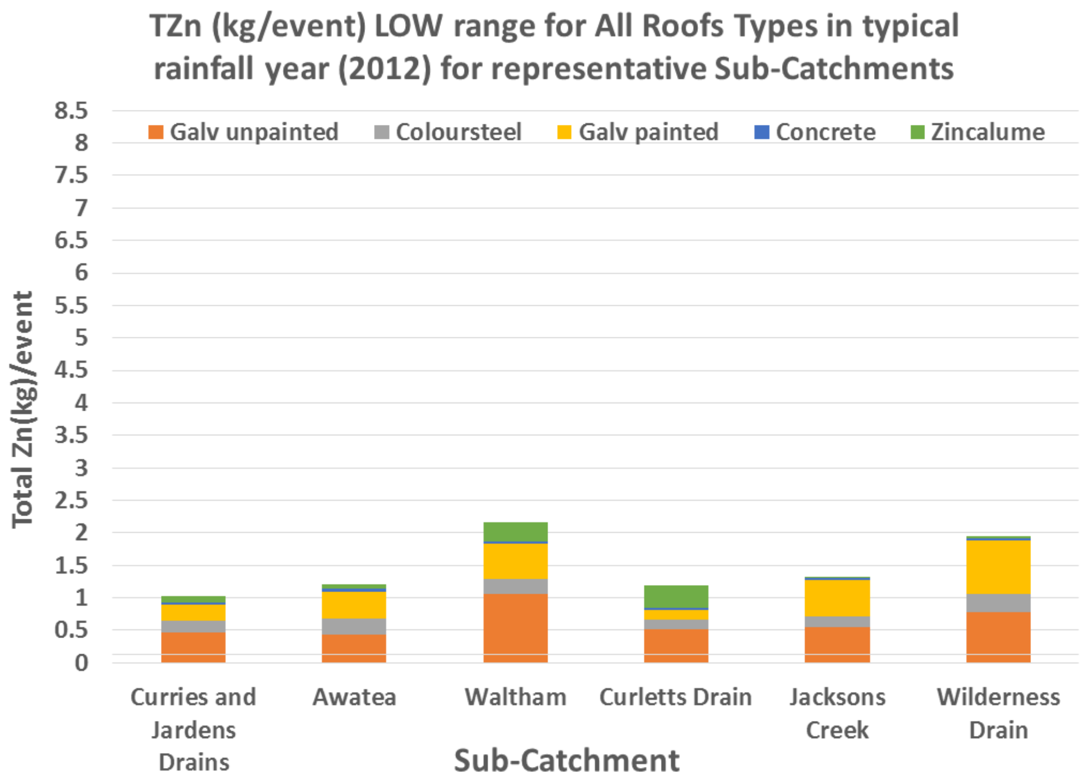
Figure 3-6 clears shows that galvanized unpainted and galvanized painted roof surfaces typically contribute the most total zinc (per event) within each subcatchment. When the (‘high’ range) values measured from concrete roofs in the Heathcote are used in the model, the amount of TZn contributed from ‘concrete’ type roofs seems quite substantial but is actually minimal when the concentrations measured from concrete roofs in the Okeover are used for modelling purposes (Figure 3-6). The higher range reflects the galvanized guttering used in many older concrete roofs, which contributes dissolution of zinc to the roof runoff and does not typically represent zinc from the concrete material itself (by contrast there were no obvious galvanized roof components in the Okeover concrete roof (contributing to the ‘low’ concrete load). Similarly, when the ‘high’ range zinc concentrations measured from an unpainted (i.e. older/poor condition) Zincalume® roof are used in the model, results suggest that Zincalume® contributes large amounts of zinc from roof runoff but these contributions are much less when painted (or newer) Zincalume® roof concentrations are used in the model. As mentioned earlier, even though unpainted galvanized roofs do not make up a large proportion of roof area within the Heathcote Catchment, they do contribute proportionally higher loads of total zinc making them a possible target for mitigating diffuse zinc runoff to urban waterways in Christchurch.

An interesting observation from the summarized data in Figure 3-6 and Figure 3-7 is that Waltham (mixed land use) roofs, which make up almost 29 % of this catchment (Table 3-1) and comprise the highest (16 ha) proportion of unpainted galvanized roofs (along with 22 ha of painted galvanized roofs and other roof types), contribute between 2.2and 7.6 net kg TZn/event from roof runoff (Table 3-7 and Figure 3-7. Similarly, Wilderness Drain (residential land use) which has 12 ha of unpainted galvanized roofs, 34 ha of painted galvanized roofs and 27 ha of Coloursteel® roofs (Table 3-7) produces comparable total zinc loads (2.0 -7.9 TZn kg) per rain event as Waltham. Figure 3-7 shows that the greatest TZn from roofs in each subcatchment depends on the surface area of each roof type. For instance, while Waltham contributes the most TZn from unpainted galvanized roofs, Wilderness Drain contributes similar amounts from Zincalume® roofs. Curletts Drain has equal proportions of zinc originating from unpainted galvanized roofs (comprising 8 ha or 10 % of all roofs in the subcatchment) and Zincalume® roofs, which make up and 14 ha (or 18 %) of the subcatchment.

These disaggregated data are important because they highlight that the proportional area of specific roof types (e.g. unpainted galvanized) is a clear determinant of how much total zinc can be expected in roof runoff rather than assuming greater contributions from a more industrial/commercial area alone. Furthermore, depending on the condition of the roof material, a range of lower or higher zinc loads can be expected from roof runoff during rain events.

Table 3-7 Average event loads for zinc modelled for each surface type currently existing in the Heathcote and representative subcatchments over numerous yearly scenarios.

S1 (Baseline)		TZn kg/event for all roof area type in EACH subcatchment																
	Catgeory	*Roof TYPE area (Ha)*	Galv unpainted		*Roof TYPE area (Ha)*	Coloursteel		*Roof TYPE area (Ha)*	Galv painted		*Roof TYPE area (Ha)*	Concrete		*Roof TYPE area (Ha)*	Zincalume		TOTAL Roofs in Cacthment	
	Range		low	high		low	high		low	high		low	high		low	high	low	high
YEAR																		
2016 (9 monitored)	**ALL HEATHCOTE**	***96.7***	**10.2**	**29.9**	***315.8***	**6.5**	**27.1**	***206.7***	**7.8**	**14.2**	***632.5***	**0.7**	**22.2**	***76.1***	**2.9**	**8.0**	**28.0**	**101.4**
	Curries and Jardens Drains	*7.0*	0.7	2.2	*17.0*	0.3	1.5	*9.9*	0.4	0.7	*42.9*	0.0	1.5	*4.5*	0.2	0.5	1.7	6.3
	Awatea	*6.5*	0.7	2.0	*23.9*	0.5	2.1	*16.4*	0.6	1.1	*95.0*	0.1	3.3	*2.3*	0.1	0.2	2.0	8.7
	Waltham	*15.8*	1.7	4.9	*21.4*	0.4	1.8	*22.3*	0.8	1.5	*48.0*	0.1	1.7	*12.3*	0.5	1.3	3.5	11.2
	Curletts Drain	*7.6*	0.8	2.3	*15.1*	0.3	1.3	*5.9*	0.2	0.4	*35.6*	0.0	1.2	*14.4*	0.5	1.5	1.9	6.8
	Jacksons Creek	*8.0*	0.8	2.5	*16.9*	0.3	1.5	*23.1*	0.9	1.6	*33.9*	0.0	1.2	*1.1*	0.0	0.1	2.1	6.8
	Wilderness Drain	*11.6*	1.2	3.6	*27.0*	0.6	2.3	*33.8*	1.3	2.3	*49.9*	0.1	1.7	*1.6*	0.1	1.7	3.2	11.7
2013 (66 events)	**ALL HEATHCOTE**	***96.7***	**10.3**	**30.8**	***315.8***	**5.2**	**27.0**	***206.7***	**7.7**	**13.9**	***632.5***	**0.7**	**20.1**	***76.1***	**2.8**	**8.1**	**26.7**	**100.0**
	Curries and Jardens Drains	*7.0*	0.7	2.2	*17.0*	0.3	1.5	*9.9*	0.4	0.7	*42.9*	0.0	1.4	*4.5*	0.2	0.5	1.6	6.2
	Awatea	*6.5*	0.7	2.1	*23.9*	0.4	2.0	*16.4*	0.6	1.1	*95.0*	0.1	3.0	*2.3*	0.1	0.2	1.9	8.5
	Waltham	*15.8*	1.7	5.0	*21.4*	0.4	1.8	*22.3*	0.8	1.5	*48.0*	0.1	1.5	*12.3*	0.5	1.3	3.4	11.2
	Curletts Drain	*7.6*	0.8	2.4	*15.1*	0.2	1.3	*5.9*	0.2	0.4	*35.6*	0.0	1.1	*14.4*	0.5	1.5	1.9	6.8
	Jacksons Creek	*8.0*	0.9	2.6	*16.9*	1.4	1.4	*23.1*	0.9	1.6	*33.9*	0.0	1.1	*1.1*	0.0	0.1	3.2	6.8
	Wilderness Drain	*11.6*	1.2	3.7	*27.0*	0.4	2.3	*33.8*	1.3	2.3	*49.9*	0.1	1.6	*1.6*	0.1	1.6	3.0	11.5
2012 (88 events)	**ALL HEATHCOTE**	***96.7***	**6.5**	**19.5**	***315.8***	**3.3**	**17.1**	***206.7***	**5.0**	**8.8**	***632.5***	**0.4**	**13.2**	***76.1***	**1.8**	**5.1**	**17.1**	**63.7**
	Curries and Jardens Drains	*7.0*	0.5	1.4	*17.0*	0.2	0.9	*9.9*	0.2	0.4	*42.9*	0.0	0.9	*4.5*	0.1	0.5	1.0	4.1
	Awatea	*6.5*	0.4	1.3	*23.9*	0.2	1.3	*16.4*	0.4	0.7	*95.0*	0.1	2.0	*2.3*	0.1	0.2	1.2	5.5
	Waltham	*15.8*	1.1	3.2	*21.4*	0.2	1.2	*22.3*	0.5	0.9	*48.0*	0.0	1.0	*12.3*	0.3	1.3	2.2	7.6
	Curletts Drain	*7.6*	0.5	1.5	*15.1*	0.2	0.8	*5.9*	0.1	0.3	*35.6*	0.0	0.7	*14.4*	0.3	1.5	1.2	4.9
	Jacksons Creek	*8.0*	0.5	1.6	*16.9*	0.2	0.9	*23.1*	0.6	1.0	*33.9*	0.0	0.7	*1.1*	0.0	0.1	1.3	4.3
	Wilderness Drain	*11.6*	0.8	2.3	*27.0*	0.3	1.5	*33.8*	0.8	1.4	*49.9*	0.0	1.0	*1.6*	0.0	1.6	2.0	7.9
2011 (112 events)	**ALL HEATHCOTE**	***96.7***	**5.5**	**16.6**	***315.8***	**2.8**	**14.6**	***206.7***	**4.4**	**7.5**	***632.5***	**0.4**	**11.8**	***76.1***	**1.6**	**4.4**	**14.8**	**54.8**
	Curries and Jardens Drains	*7.0*	0.4	1.2	*17.0*	0.2	0.8	*9.9*	0.2	0.4	*42.9*	0.0	0.8	*4.5*	0.1	0.3	0.9	3.4
	Awatea	*6.5*	0.4	1.1	*23.9*	0.2	1.1	*16.4*	0.4	0.6	*95.0*	0.1	1.8	*2.3*	0.0	0.1	1.0	4.7
	Waltham	*15.8*	0.9	2.7	*21.4*	0.2	1.0	*22.3*	0.5	0.8	*48.0*	0.0	0.9	*12.3*	0.3	0.7	1.9	6.1
	Curletts Drain	*7.6*	0.4	1.3	*15.1*	0.1	0.7	*5.9*	0.1	0.2	*35.6*	0.0	0.7	*14.4*	0.3	0.8	1.0	3.7
	Jacksons Creek	*8.0*	0.5	1.4	*16.9*	0.2	0.8	*23.1*	0.5	0.8	*33.9*	0.0	0.6	*1.1*	0.0	0.1	1.1	3.7
	Wilderness Drain	*11.6*	0.7	2.0	*27.0*	0.2	1.2	*33.8*	0.7	1.2	*49.9*	0.0	0.9	*1.6*	0.0	0.9	1.7	6.3
AVERAGE YEARS (S1 Baseline)	**ALL HEATHCOTE**	***96.7***	**8.1**	**24.2**	***315.8***	**4.4**	**21.4**	***206.7***	**6.2**	**11.1**	***632.5***	**0.5**	**16.8**	***76.1***	**2.3**	**6.4**	**21.6**	**80.0**
	Curries and Jardens Drains	*7.0*	0.6	1.8	*17.0*	0.2	1.2	*9.9*	0.3	0.5	*42.9*	0.0	1.1	*4.5*	0.1	0.4	1.3	5.0
	Awatea	*6.5*	0.5	1.6	*23.9*	0.3	1.6	*16.4*	0.5	0.9	*95.0*	0.1	2.5	*2.3*	0.1	0.2	1.5	6.9
	Waltham	*15.8*	1.3	4.0	*21.4*	0.3	1.5	*22.3*	0.7	1.2	*48.0*	0.0	1.3	*12.3*	0.4	1.2	2.7	9.0
	Curletts Drain	*7.6*	0.6	1.9	*15.1*	0.2	1.0	*5.9*	0.2	0.3	*35.6*	0.0	0.9	*14.4*	0.4	1.4	1.5	5.5
	Jacksons Creek	*8.0*	0.7	2.0	*16.9*	0.5	1.1	*23.1*	0.7	1.2	*33.9*	0.0	0.9	*1.1*	0.0	0.1	2.0	5.4
	Wilderness Drain	*11.6*	1.0	2.9	*27.0*	0.4	1.8	*33.8*	1.0	1.8	*49.9*	0.0	1.3	*1.6*	0.0	1.5	2.5	9.3



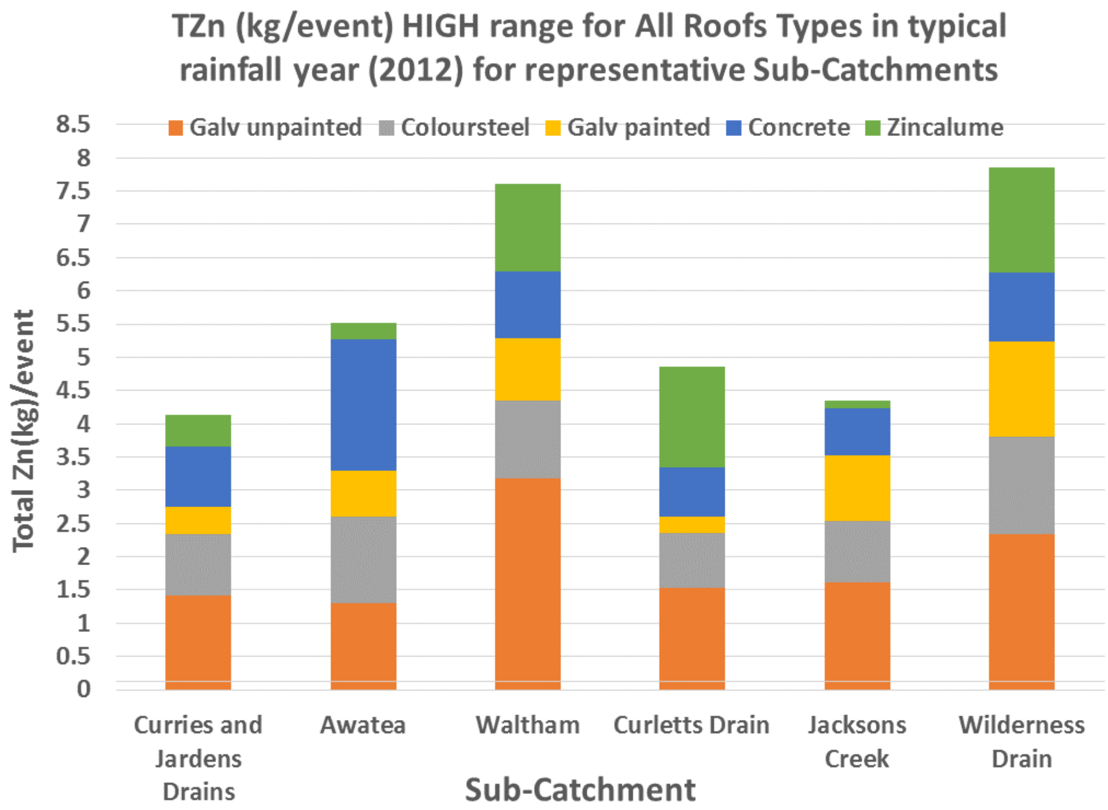


Figure 3- 6 Total Zn (kg/event) LOW (top) and HIGH (bottom) ranges (e.g. Table 3-4) derived from roof types within Heathcote subcatchments for the modelled year 2012 (a typical rainfall year).

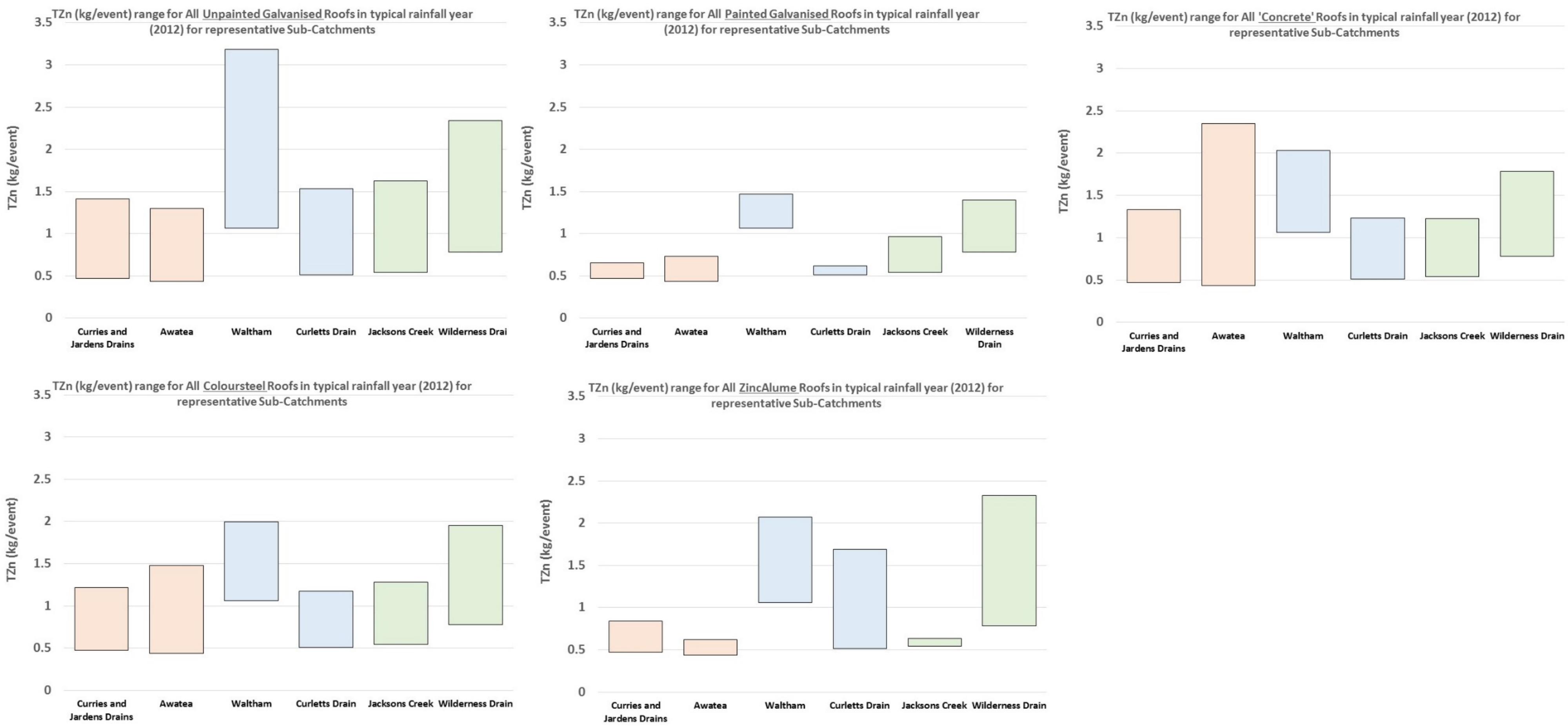


Figure 3- 7 Total Zn (kg/event) ranges derived from roof types within Heathcote representative subcatchments for the modelled year 2012 (a typical rainfall year in Christchurch). Lower and upper and ends of the hanging bars lower define the lower and upper ranges (e.g. as defined in Table 3-4), respectively.

3.3.3 *Zinc Loads from All Roofs in the Heathcote and All Management Scenarios: Multiple Years.*

In addition to the baseline (status quo) scenario 1 modelled for the whole Heathcote Catchment for the different roof types, different management scenarios were then modelled to predict changes in zinc loads originating from roof runoff resulting from a change in roof type. These scenarios were outlined in Section 2.2 and essentially stipulated that *all metal* roof areas within each (sub)catchment were comprised of: 90 % new Coloursteel® and 10 % old Coloursteel® (Scenario 2); 50 % new Coloursteel® and 50 % old Coloursteel® (Scenario 3) and all concrete, i.e. no metallic roofs (Scenario 4). For scenarios S1, S2 and S3, the amount of 'concrete' roofs remained the status quo, while for scenario 4 (S4), there were no metal roofs included in the model simulation (i.e. all areas were classified as 'concrete' or equivalent).

Total Zn loads for each roof surface for the whole Heathcote Catchment and within each representative subcatchment, for each year modelled, are detailed in Table A3-1. Figure 3-8 shows how a change, from scenario 1 (the current status), in the proportional area of metal roof type and condition as stipulated in the scenarios above, would result in a reduction of total zinc runoff from roofs in the whole Heathcote Catchment across all the modelled years. This reduction is more pronounced at the higher ranges for each scenario. While the model predicts that there will be a reduction from the status quo in net zinc load in runoff if metal roofs were comprised of 90 % new + 10 % old Coloursteel® (i.e. S2) or no metal (S4) at both zinc load ranges, scenario 3 (which comprises 50 % new + 50 % old Coloursteel® roofs and existing concrete roofs) indicated that the 'low' range of this scenario would be slightly higher than the status quo. This is explained by the fact that old ('high') Coloursteel® roofs have a much higher zinc runoff rate (mg/m^2/event) than even painted galvanized roofs. By increasing the proportion of those older Coloursteel® roofs in the catchments to 50 % (and thereby removing the other metal roofs except new Coloursteel® roofs), effectively increases the net amount of zinc load derived from old Coloursteel® roofs in the catchments. (These numbers are also detailed in scenario 3 results in Table A3-1).

There is some variability between years, as discussed earlier, due to the influence of rainfall parameters on runoff concentrations.

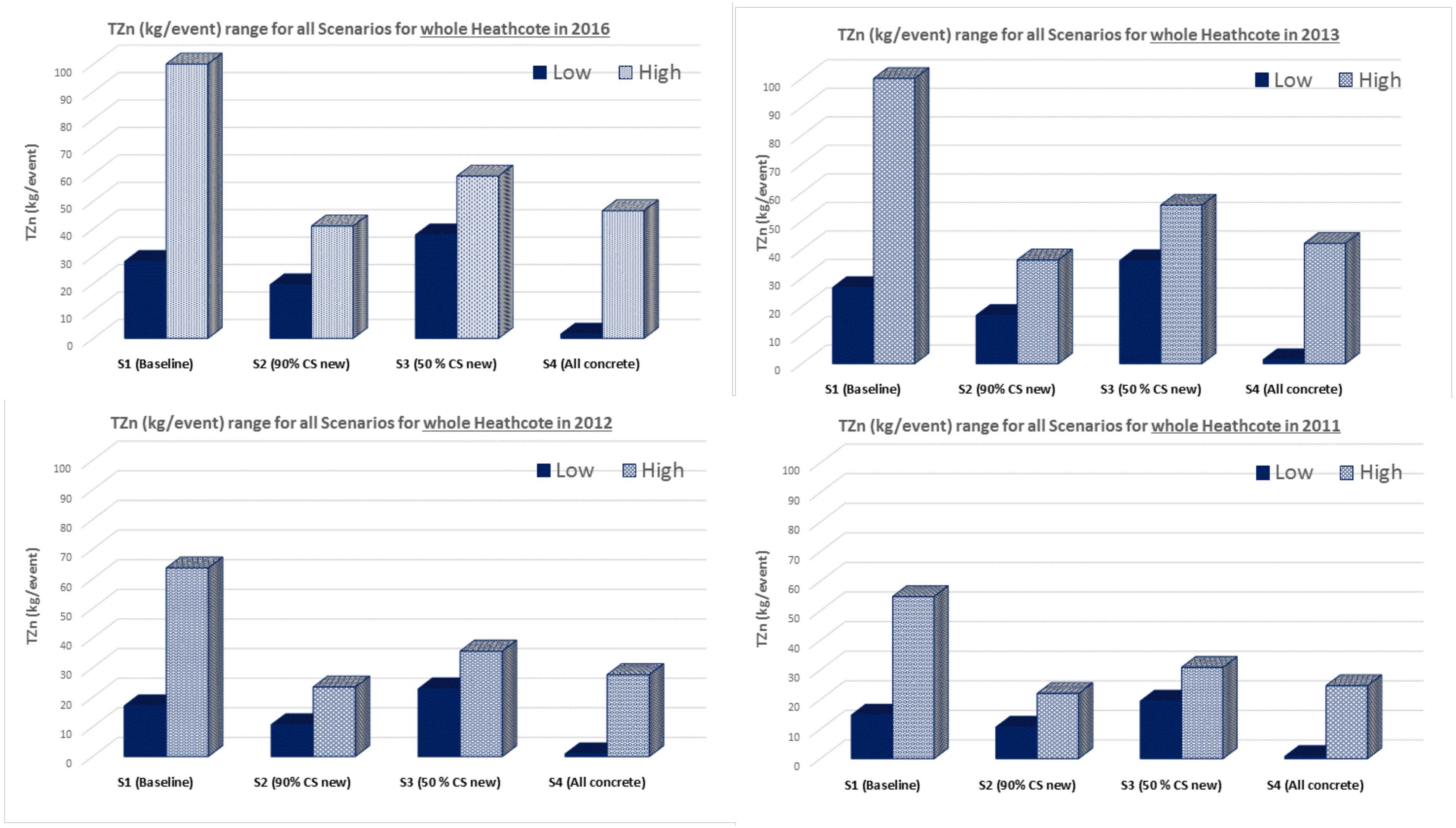


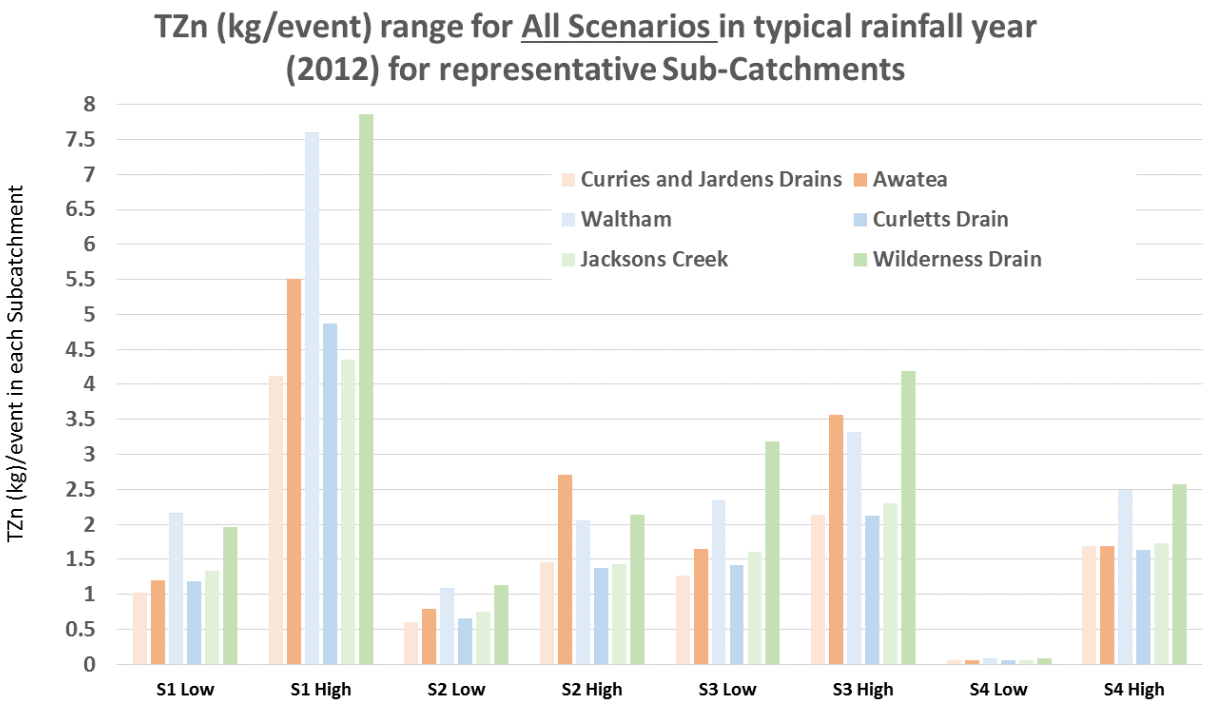
Figure 3- 8 TZn loads for each modelled management scenario across all modelled years for the whole Heathcote Catchment. Note Low and high ranges are shown (depending on whether values measured from concrete roofs with or without zinc guttering are used).

3.3.4 *Zinc Loads from All Management Scenarios for Representative Subcatchments*

Total Zn loads (kg/event) low and high ranges for all roofs surfaces contributing runoff within each representative subcatchment are presented in Figure 3.9. The data summarises results (from Table A3-1) for the year 2012 (a typical rainfall year in Christchurch). Total Zn loads (kg/event) low and high ranges for all roofs surfaces contributing runoff within each representative subcatchment for all scenarios are also presented in Figure 3-10 for each year modelled to reflect changes in yearly rainfall characteristics. The data summarises results from Table A3-1.

In the current situation (e.g. scenario 1 representing existing current roof surfaces), the subcatchments Waltham and Wilderness Drain contribute the greatest amounts of total Zn, on average per event, by comparison to the other modelled subcatchments (Figure 3-9 and Figure 3-10). However, if all *metal* roofs were changed to comprise 90 % 'Coloursteel® new' and 10 % as 'Coloursteel® old' (i.e. scenario 2), while a reduction in net zinc loads from roof runoff would clearly result across all years and subcatchments, higher proportional loads would originate from Awatea and Wilderness Drain subcatchments. If 50 % of the roofs were changed to 'Coloursteel® new' and the remaining 50 % to 'Coloursteel® old' (i.e. scenario 3), there would be less total Zn arising from each subcatchment compared to the highest current range. However, the relative TZn contributions from each subcatchment would increase for the lower range compared to the status quo, with Wilderness Drain and Waltham contributing the highest proportions (Figure 3-9). This observation was explained earlier (e.g. higher zinc runoff rate and proportional area for old Coloursteel® roofs) and so it can be derived from the data that scenario 3 of changing 50 % of the roofs to be 'older' (i.e. weathered Coloursteel®) is not a good option for net reduction of total zinc in roof runoff (assuming that concrete roofs have no galvanized components since the 'low' and 'high' net loads are also influenced by the condition and proportion of concrete roofs in the catchment).

If no metal roofs existed within the catchments, those with no galvanized guttering (S4 Low) would have negligible TZn runoff, but those with galvanized drainage components (S4 High), such as the roof measured on Curletts Road, would have somewhat elevated TZn loads but far less than the status quo (Table 3-7 and Figure 3-9). It seems that Wilderness Drain and Waltham would produce the most total zinc load per event on average in this scenario. These data reflect the large proportion of 'concrete' roofs within their catchments.



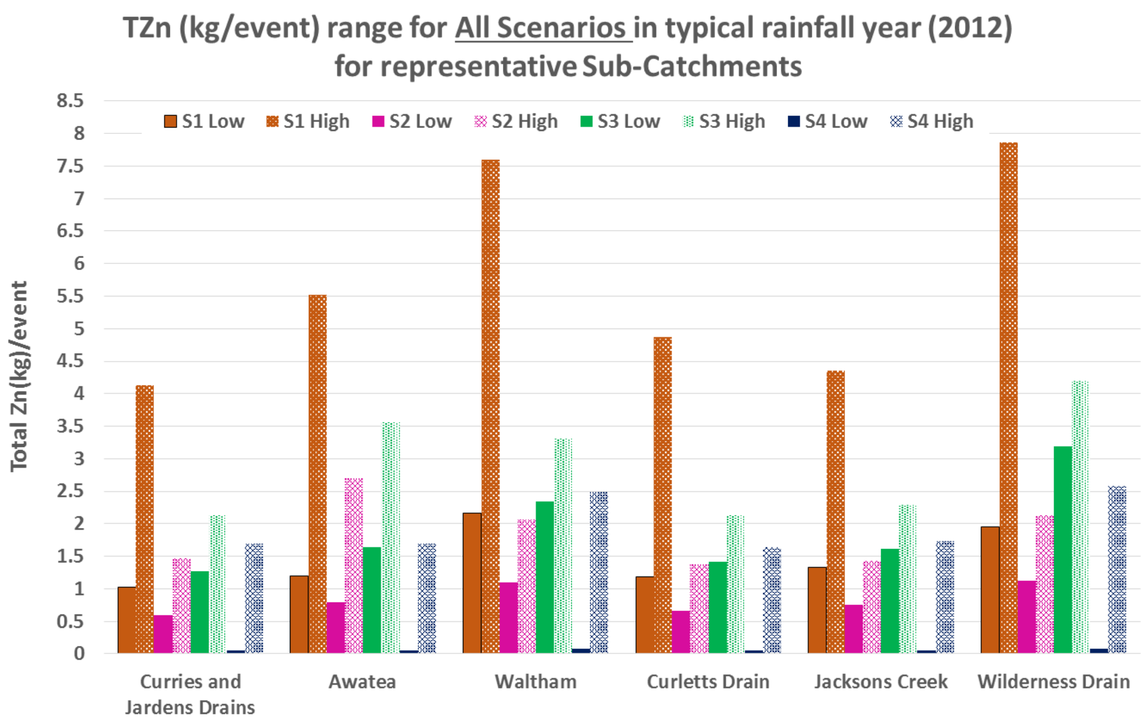


Figure 3- 9 Total Zn load (kg/event) for all roofs surfaces contributing runoff within each representative subcatchment for the year 2012 (a typical rainfall year in Christchurch).

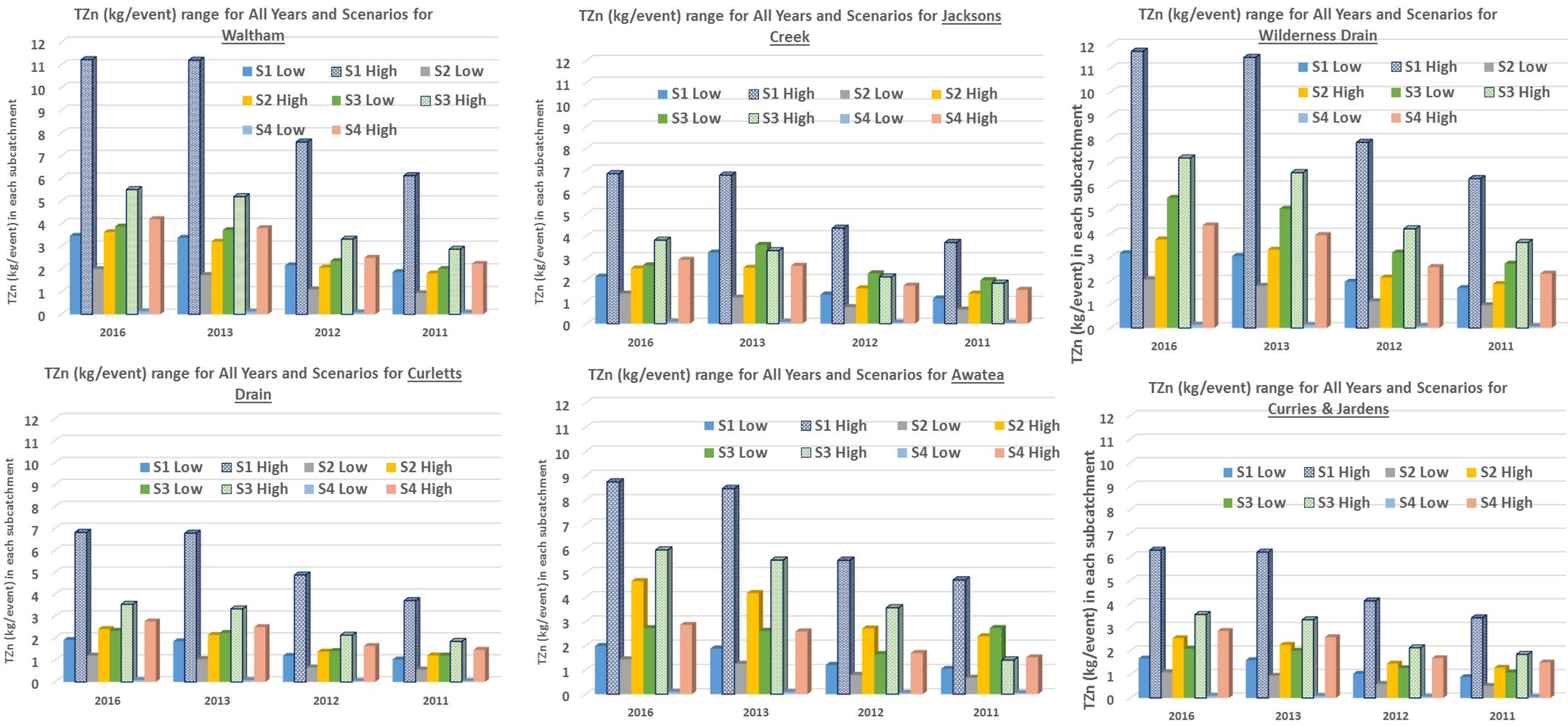


Figure 3- 10 Total Zn loads (kg/event) for all roofs surfaces contributing runoff within each representative subcatchment for all modelled years.

4 Summary and Recommendations

The scope of this study was to measure concentrations of key pollutants in stormwater runoff specifically from different impermeable surface types within the Heathcote Catchment. Additionally, zinc loads within the Heathcote and some of its subcatchments (representing residential, industrial and mixed land use areas) were predicted from the roof areas existing in the catchments. This was achieved by modelling different yearly scenarios using the pollutant event load model MEDUSA that was calibrated to the Heathcote conditions. Further analysis was then undertaken to estimate the zinc loads that could be expected in roof runoff from a change in proportional roof type areas within the different subcatchments.

The study highlighted that proportional areas of different roof types and their condition are key determinants of the total zinc loads in roof runoff and that this varies between catchments and rainfall events. Understanding specific (i.e. hotspot) contributions originating within each subcatchment (such as large areas of unpainted galvanised roofs) can provide valuable information in targeting a reduction of diffuse zinc loads received by Christchurch waterways. Modelled scenarios can produce valuable information with respect to how total zinc (and other) pollutant loads change with a modified management scenario within a catchment and can help guide management decisions for ultimately reducing zinc originating from roof runoff entering receiving waterways through unmitigated stormwater runoff.

This study was limited to examining six (out of 19) representative subcatchments of the Heathcote. Analysing other specific subcatchments of priority for the Christchurch City Council, along with total catchment analysis that includes all the impermeable surfaces types (roads, carparks etc.) would provide a whole systems approach for guiding catchment management practices. Additionally, deeper analysis of the other key stormwater pollutants TSS and copper (such as for targeted subcatchments) would afford greater insight into significant pollutant contributors within the Heathcote. In order to undertake a whole (sub)catchment approach, the carpark data provided in the CCC GIS files needs to be modified appropriately to enable it to be modelled within MEDUSA. Additionally, some further monitoring of a range of concrete roofs (with and without galvanised downpipes) along with 'ground-truthing' impermeable surfaces types is recommended to refine the calibration of the modelling for the Heathcote. Modelling the scenarios for more yearly events, as well as extracting particularly large or lengthy rainfall events, would yield insight into the influence of climate change on stormwater pollutant loads.

5 Acknowledgements

The authors would like to thank Paul Dickson from the Christchurch City Canterbury for initiating this project and providing very valuable discussions and technical knowledge on the catchment specifics. Sebastian King from Pattle Delamore Partners delineated all the impermeable surfaces within the Heathcote catchment and provided spreadsheets of these. We also thank the local property owners and their site managers for allowing access to their sites for sampling, their assistance with health and safety training when applicable, and general support for this project. This project has been funded by Christchurch City Council.

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7 Appendices

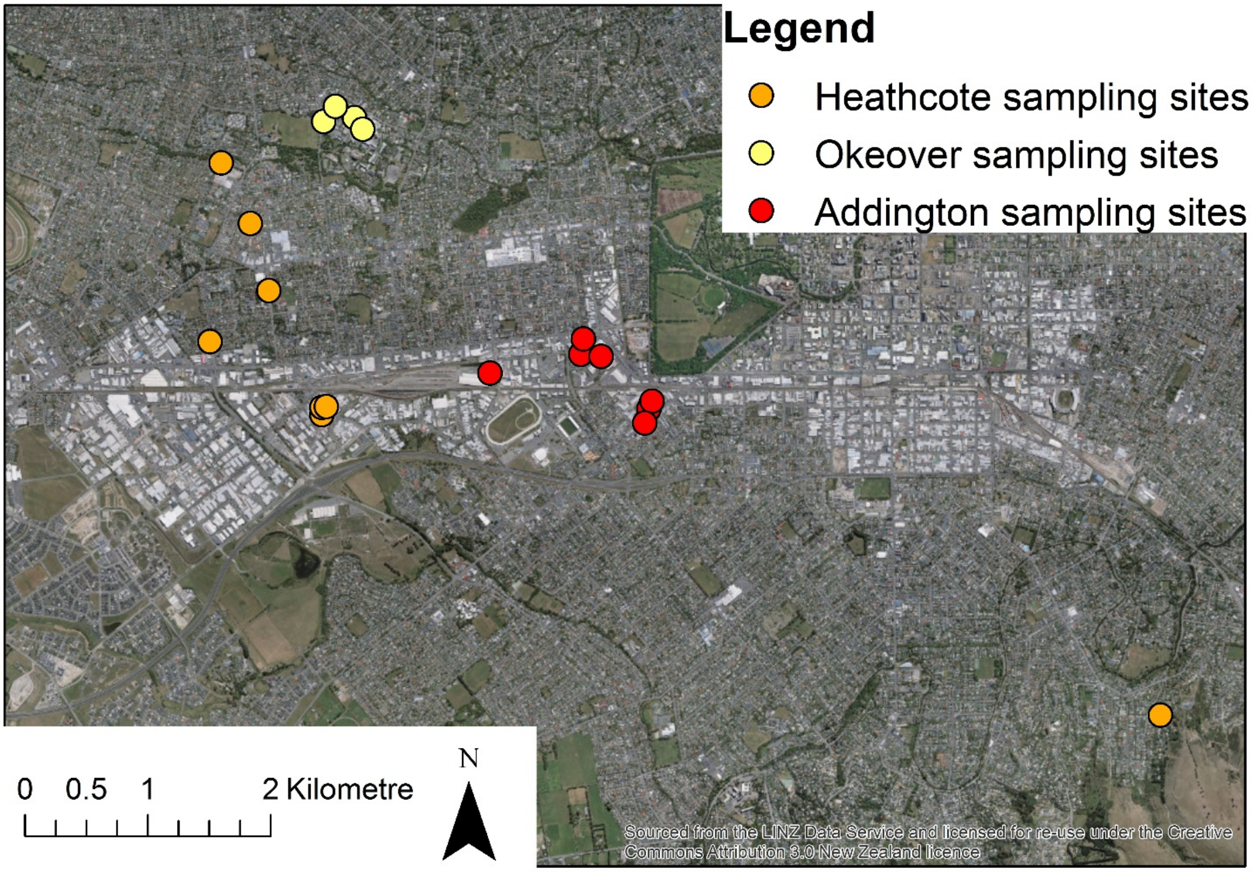

Figure A2 1 Sampling site locations for Okeover (blue), Addington (purple) and Heathcote (red) catchments. Note Rapaki roof site in SE corner.

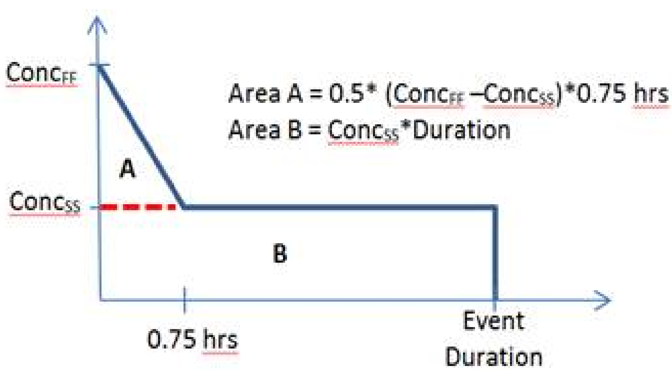

Figure A2 2 Derivation of Event Mean Concentration (EMC) based on proportional FF (Area A) and SS (Area B) concentrations of each event (e.g. (Area A + Area B)/Duration). The transition between FF to SS occurred as an approximate linear decay over an assumed time of 0.75 hours, based on the observed typical transition time from extensive intra-event sampling in the Okeover catchment (Charters, 2016).

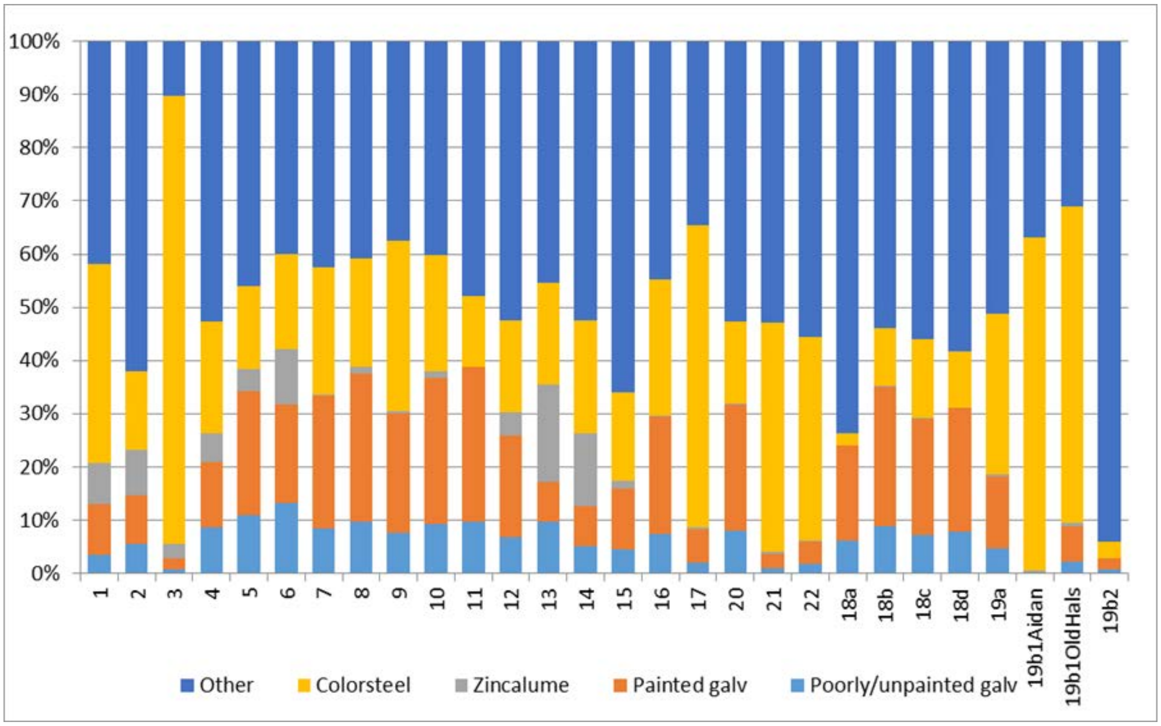

Figure A3- 1*:* Roof types as a proportion of each Heathcote subcatchment. Subcatchment codes defined in Table 3-1.

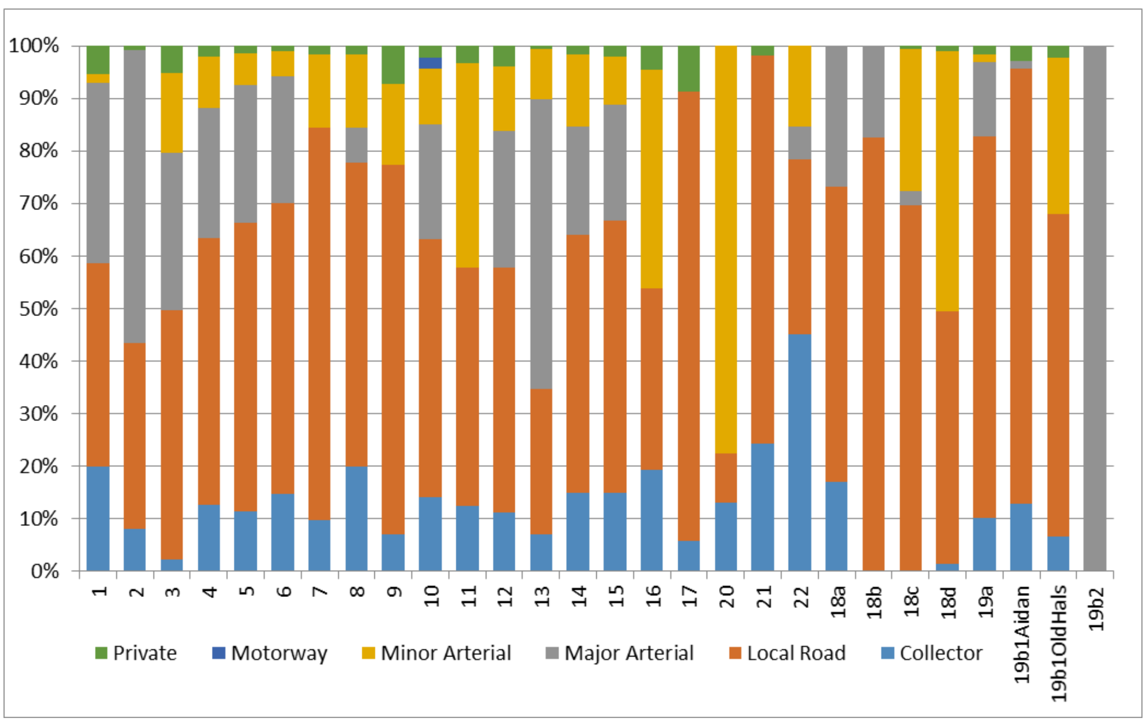

Figure A3- 2*:* Road types as a proportion of each Heathcote subcatchment. Subcatchment codes defined in Table 3-1.

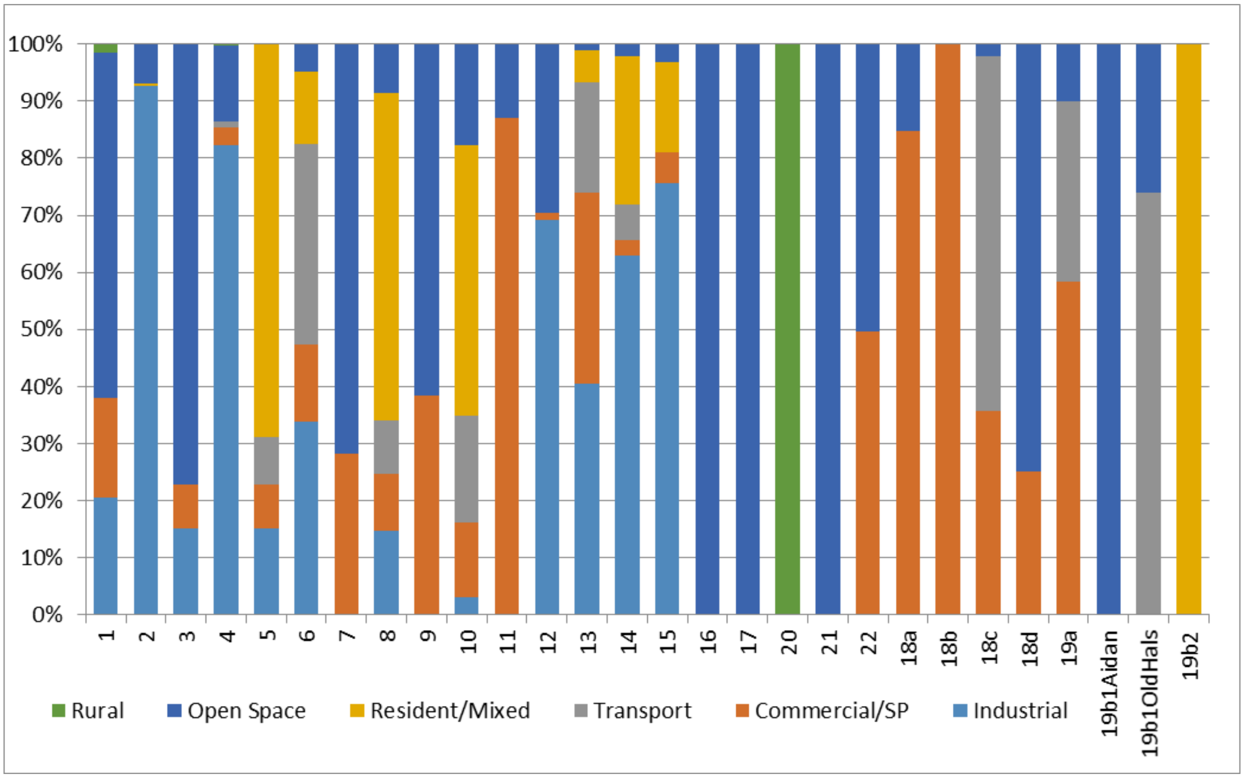

Figure A3- 3*:*Paved types (excluding roads) Road types as a proportion of each Heathcote subcatchment. Subcatchment codes defined in Table 3-1.

Table A3 1 Total Zn loads for each roof surface within the whole Heathcote and each representative subcatchment for each year modelled and each scenario S, S2 and S3 (S1 was presented in Table 3-6). Note for scenarios S2 and S3, respectively, 90 % and 50 % of all metal roofs are represented as 'low' Coloursteel® with the remaining 10 % (for S2) and 50 % (for S3) represented as 'high' Coloursteel® .

		TZn kg/event for all roof area type in EACH subcatchment							
S2 (90% new Colorsteel + 10% old coloursteel) + existing	Catgeory	*Roof TYPE area (Ha)*	Coloursteel		*Roof TYPE area (Ha)*	Concrete		TOTAL Roofs in Cacthment	
	Range		low	high		low	high	low	high
2016 (9 monitored)	**ALL HEATHCOTE**	***695.26***	**12.824**	**5.971**	***632.52***	**0.718**	**22.166**	**19.514**	**40.962**
	Curries and Jardens Drains	*38.47*	0.710	0.330	*42.88*	0.049	1.503	1.089	2.543
	Awatea	*49.10*	0.906	0.422	*94.97*	0.108	3.328	1.435	4.656
	Waltham	*71.77*	1.324	0.616	*48.01*	0.055	1.683	1.995	3.623
	Curletts Drain	*43.01*	0.793	0.369	*35.63*	0.040	1.249	1.203	2.411
	Jacksons Creek	*49.24*	0.908	0.423	*33.92*	0.039	1.189	1.370	2.520
	Wilderness Drain	*73.97*	1.364	0.635	*49.88*	0.057	1.748	2.056	3.747
2013 (66 events)	**ALL HEATHCOTE**	***695.26***	**10.312**	**5.950**	***632.52***	**0.671**	**20.086**	**16.933**	**36.348**
	Curries and Jardens Drains	*38.47*	0.571	0.329	*42.88*	0.045	1.362	0.945	2.261
	Awatea	*49.10*	0.728	0.420	*94.97*	0.101	3.016	1.249	4.164
	Waltham	*71.77*	1.065	0.614	*48.01*	0.051	1.525	1.730	3.203
	Curletts Drain	*43.01*	0.638	0.368	*35.63*	0.038	1.131	1.044	2.137
	Jacksons Creek	*49.24*	0.730	0.421	*33.92*	0.036	1.077	1.188	2.229
	Wilderness Drain	*73.97*	1.097	0.633	*49.88*	0.053	1.584	1.783	3.314
2012 (88 events)	**ALL HEATHCOTE**	***695.26***	**6.535**	**3.758**	***632.52***	**0.424**	**13.169**	**10.717**	**23.461**
	Curries and Jardens Drains	*38.47*	0.362	0.208	*42.88*	0.029	0.893	0.598	1.462
	Awatea	*49.10*	0.461	0.265	*94.97*	0.064	1.977	0.791	2.704
	Waltham	*71.77*	0.675	0.388	*48.01*	0.032	1.000	1.095	2.062
	Curletts Drain	*43.01*	0.404	0.232	*35.63*	0.024	0.742	0.661	1.378
	Jacksons Creek	*49.24*	0.463	0.266	*33.92*	0.023	0.706	0.752	1.435
	Wilderness Drain	*73.97*	0.695	0.400	*49.88*	0.033	1.038	1.128	2.133
2011 (112 events)	**ALL HEATHCOTE**	***695.26***	**6.535**	**3.758**	***632.52***	**0.362**	**11.754**	**10.654**	**22.047**
	Curries and Jardens Drains	*38.47*	0.309	0.177	*42.88*	0.025	0.797	0.511	1.283
	Awatea	*49.10*	0.394	0.226	*94.97*	0.054	1.765	0.675	2.385
	Waltham	*71.77*	0.576	0.331	*48.01*	0.027	0.892	0.935	1.799
	Curletts Drain	*43.01*	0.345	0.198	*35.63*	0.020	0.662	0.564	1.206
	Jacksons Creek	*49.24*	0.395	0.227	*33.92*	0.019	0.630	0.642	1.253
	Wilderness Drain	*73.97*	0.594	0.341	*49.88*	0.029	0.927	0.963	1.862
AVERAGE YEARS (S2: 90% new CS + 10% old)	**ALL HEATHCOTE**	***695.262***	**9.051**	**4.859**	***632.522***	**0.544**	**16.794**	**14.455**	**30.704**
	Curries and Jardens Drains	*38.469*	0.488	0.261	*42.881*	0.037	1.139	0.786	1.887
	Awatea	*49.101*	0.622	0.333	*94.972*	0.082	2.522	1.037	3.477
	Waltham	*71.774*	0.910	0.487	*48.014*	0.041	1.275	1.438	2.672
	Curletts Drain	*43.012*	0.545	0.292	*35.626*	0.031	0.946	0.868	1.783
	Jacksons Creek	*49.241*	0.624	0.334	*33.919*	0.029	0.901	0.988	1.859
	Wilderness Drain	*73.966*	0.938	0.502	*49.876*	0.043	1.324	1.483	2.764

S3 (50% new Colorsteel + 50% old coloursteel) + existing concrete		TZn kg/event for all roof area type in EACH subcatchment							
	Catgeory	*Roof TYPE area (Ha)*	Coloursteel		*Roof TYPE area (Ha)*	Concrete		TOTAL Roofs in Cacthment	
	Range		low	high		low	high	low	high
2016 (9 monitored)	**ALL HEATHCOTE**	***695.26***	**7.124**	**29.857**	***632.52***	**0.718**	**22.166**	**37.700**	**59.148**
	Curries and Jardens Drains	*38.47*	0.394	1.652	*42.88*	0.049	1.503	2.095	3.549
	Awatea	*49.10*	0.503	2.109	*94.97*	0.108	3.328	2.720	5.940
	Waltham	*71.77*	0.735	3.082	*48.01*	0.055	1.683	3.872	5.500
	Curletts Drain	*43.01*	0.441	1.847	*35.63*	0.040	1.249	2.328	3.536
	Jacksons Creek	*49.24*	0.505	2.115	*33.92*	0.039	1.189	2.658	3.808
	Wilderness Drain	*147.93*	2.274	3.176	*49.88*	0.057	1.748	5.507	7.198
2013 (66 events)	**ALL HEATHCOTE**	***695.26***	**5.729**	**29.751**	***632.52***	**0.671**	**20.086**	**36.151**	**55.566**
	Curries and Jardens Drains	*38.47*	0.317	1.646	*42.88*	0.045	1.362	2.009	3.325
	Awatea	*49.10*	0.405	2.101	*94.97*	0.101	3.016	2.606	5.521
	Waltham	*71.77*	0.591	3.071	*48.01*	0.051	1.525	3.714	5.187
	Curletts Drain	*43.01*	0.354	1.840	*35.63*	0.038	1.131	2.233	3.326
	Jacksons Creek	*49.24*	0.406	2.107	*33.92*	0.036	1.077	2.549	3.590
	Wilderness Drain	*147.93*	1.828	3.165	*49.88*	0.053	1.584	5.046	6.577
2012 (88 events)	**ALL HEATHCOTE**	***695.26***	**3.630**	**18.790**	***632.52***	**0.424**	**13.169**	**22.844**	**35.589**
	Curries and Jardens Drains	*38.47*	0.201	1.040	*42.88*	0.029	0.893	1.269	2.133
	Awatea	*49.10*	0.256	1.327	*94.97*	0.064	1.977	1.647	3.561
	Waltham	*71.77*	0.375	1.940	*48.01*	0.032	1.000	2.347	3.314
	Curletts Drain	*43.01*	0.225	1.162	*35.63*	0.024	0.742	1.411	2.129
	Jacksons Creek	*49.24*	0.257	1.331	*33.92*	0.023	0.706	1.611	2.294
	Wilderness Drain	*147.93*	1.159	1.999	*49.88*	0.033	1.038	3.191	4.196
2011 (112 events)	**ALL HEATHCOTE**	***695.26***	**3.102**	**16.021**	***632.52***	**0.362**	**11.754**	**19.485**	**30.877**
	Curries and Jardens Drains	*38.47*	0.172	0.886	*42.88*	0.025	0.797	1.083	1.855
	Awatea	*49.10*	0.219	1.131	*94.97*	0.054	1.765	1.405	3.115
	Waltham	*71.77*	0.320	1.654	*48.01*	0.027	0.892	2.002	2.866
	Curletts Drain	*43.01*	0.192	0.991	*35.63*	0.020	0.662	1.203	1.845
	Jacksons Creek	*49.24*	0.220	1.135	*33.92*	0.019	0.630	1.374	1.985
	Wilderness Drain	*147.93*	0.990	1.704	*49.88*	0.029	0.927	2.723	3.621
AVERAGE YEARS (S3: 50% new CS + 50% old)	**ALL HEATHCOTE**	***695.262***	**4.154**	**21.520**	***632.522***	**0.486**	**15.003**	**26.160**	**40.677**
	Curries and Jardens Drains	*38.469*	0.271	1.306	*42.881*	0.037	1.139	1.614	2.715
	Awatea	*49.101*	0.346	1.667	*94.972*	0.082	2.522	2.094	4.534
	Waltham	*71.774*	0.505	2.437	*48.014*	0.041	1.275	2.983	4.217
	Curletts Drain	*43.012*	0.303	1.460	*35.626*	0.031	0.946	1.794	2.709
	Jacksons Creek	*49.241*	0.347	1.672	*33.919*	0.029	0.901	2.048	2.919
	Wilderness Drain	*147.931*	1.563	2.511	*49.876*	0.043	1.324	4.117	5.398

S4 (100 % concrete (no metal roofs)		TZn kg/event for all roof area type in EACH subcatchment							
	Catgeory	Roof TYPE area (Ha)	Coloursteel		Roof TYPE area (Ha)	Concrete		TOTAL Roofs in Cacthment	
	Range		low	high		low	high	low	high
2016 (9 monitored)	ALL HEATHCOTE				1327.78	1.508	46.532	1.508	46.532
	Curries and Jardens Drains				81.35	0.092	2.851	0.092	2.851
	Awatea				144.07	0.092	2.851	0.092	2.851
	Waltham				119.79	0.136	4.198	0.136	4.198
	Curletts Drain				78.64	0.089	2.756	0.089	2.756
	Jacksons Creek				83.16	0.094	2.914	0.094	2.914
	Wilderness Drain				123.84	0.141	4.340	0.141	4.340
2013 (66 events)	ALL HEATHCOTE				1327.78	1.408	42.164	1.408	42.164
	Curries and Jardens Drains				81.35	0.086	2.583	0.086	2.583
	Awatea				144.07	0.086	2.583	0.086	2.583
	Waltham				119.79	0.127	3.804	0.127	3.804
	Curletts Drain				78.64	0.083	2.497	0.083	2.497
	Jacksons Creek				83.16	0.088	2.641	0.088	2.641
	Wilderness Drain				123.84	0.131	3.933	0.131	3.933
2012 (88 events)	ALL HEATHCOTE				1327.78	0.890	27.644	0.890	27.644
	Curries and Jardens Drains				81.35	0.055	1.694	0.055	1.694
	Awatea				144.07	0.055	1.694	0.055	1.694
	Waltham				119.79	0.080	2.494	0.080	2.494
	Curletts Drain				78.64	0.053	1.637	0.053	1.637
	Jacksons Creek				83.16	0.056	1.731	0.056	1.731
	Wilderness Drain				123.84	0.083	2.578	0.083	2.578
2011 (112 events)	ALL HEATHCOTE				1327.78	0.760	24.675	0.760	24.675
	Curries and Jardens Drains				81.35	0.047	1.512	0.047	1.512
	Awatea				144.07	0.047	1.512	0.047	1.512
	Waltham				119.79	0.069	2.226	0.069	2.226
	Curletts Drain				78.64	0.045	1.461	0.045	1.461
	Jacksons Creek				83.16	0.048	1.545	0.048	1.545
	Wilderness Drain				123.84	0.071	2.301	0.071	2.301
AVERAGE YEARS (S4: 100% concrete roofs; no metal roofs)	ALL HEATHCOTE				1327.784	1.019	31.494	1.019	31.494
	Curries and Jardens Drains				81.349	0.070	2.160	0.070	2.160
	Awatea				144.073	0.070	2.160	0.070	2.160
	Waltham				119.787	0.103	3.180	0.103	3.180
	Curletts Drain				78.638	0.068	2.088	0.068	2.088
	Jacksons Creek				83.160	0.071	2.208	0.071	2.208
	Wilderness Drain				123.842	0.106	3.288	0.106	3.288