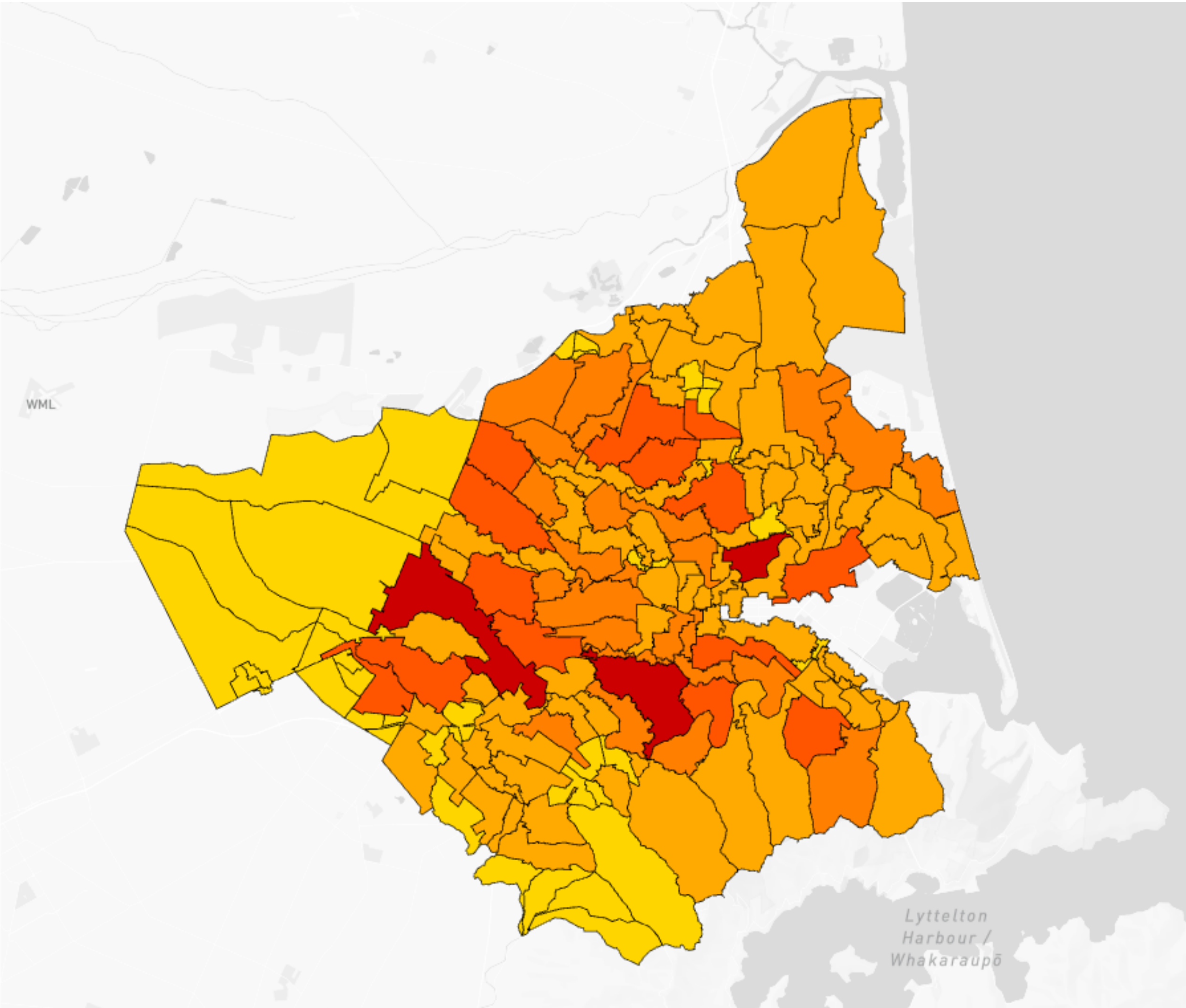
Instream Contaminant Concentration Model

Final Report



Christchurch City Council

44801843

The expert in **WATER ENVIRONMENTS**

September 2025

Instream Contaminant Concentration Model

Prepared for	Christchurch City Council
Represented by	Florian Risse

Project manager	Suzana Shipton

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DHI Water & Environment Ltd• B:HIVE, Smales Farm• 0622• Auckland• New Zealand•
Telephone: +64 9 912 9638 • szs@dhigroup.com• www.dhigroup.com

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Executive Summary

The quality of stormwater reaching the receiving waters can be improved through pollutant source reduction and treatment measures. Characterizing the catchment's stormwater quality is necessary to identify suitable locations for implementing such measures and design targeted stormwater management strategies. Such characterization can be used to develop predictive models for estimating the pollutant load generated in the catchment under various rainfall conditions.

Conventional stormwater quality models have several limitations. For instance, they often use unit-area load factors or aggregate the contributing surface areas by land use, which hinders the ability to pinpoint 'hotspots' within a catchment. These models may also fail to identify peak concentrations responsible for acute toxicity effects, and they typically do not include predictions for dissolved metals, which are crucial for selecting effective metal treatment strategies.

To overcome these limitations, a team comprising the Christchurch City Council, the University of Canterbury, and DHI developed a cloud-based spatial decision support system, called Instream Contaminant Concentration Model (ICCM), that models contaminant loads and concentrations in urban stormwater catchments within Christchurch City. MEDUSA, an event-based contaminant load model, was used to estimate the loads of contaminants generated at the point of runoff by individual impervious surfaces within the stormwater catchments.

In Christchurch City's four major stormwater catchments (Avon, Heathcote, Halswell, and Styx), more than 225,000 individual impervious surfaces were identified. The surfaces are 90% roofs, 6% roads, and 4% paved carparks. Roofs are classified into twelve types based on their material and condition; roads are categorized into seven types based on their usage; and three types of carparks were identified. Contaminant loads and concentrations for Total Suspended Solids, Total Zinc, Dissolved Zinc, Total Copper, and Dissolved Copper were generated for each surface for over 200 rain events across three different rainfall years. Surface-level results are aggregated at three hierarchical levels: Treatment System (~500), Stormwater Catchments (~160), and various locations (~170) within the waterways. Results are obtained for individual stormwater events or the annual total before or after treatment measures are implemented. Four planning years are modelled – 2018, 2023, 2028, and 2043, where treatment systems are incrementally implemented. The cumulative impact of the treatment measures on the waterways is also computed.

Results showed that, at the annual level, for an average rainfall year, carparks generated the highest amount of TSS and Total Copper loads. Roofs generated the highest amount of Total Zinc loads. In terms of pollutant loads, TSS loads are about 100 times that of Zinc loads, which are in turn about 20 times that of the Copper loads. When all the treatment systems are active, the average annual pollutant load reduction per unit area for TSS is about 77% in the Heathcote River Catchment, 35% in the Avon River Catchment, close to 60% in Halswell River Catchment, and about 32% in Styx River Catchment respectively.

A summary of the model and the results is presented in this report.

1 Introduction

Optimised stormwater management outcomes are needed on a city-wide scale to minimise the impact of urban runoff on the water quality in our receiving waterways. This is a complex challenge, as solutions range from source reduction and on-site management to sub-catchment-specific treatment systems and centralised measures.

There is a gap in the market for a decision support system that enables city-scale identification, prioritization, and mitigation of pollutant generation hotspots, and is functional for a wide range of end-users, including design engineers, consent auditors, urban planners, policy analysts and property owners.

Christchurch City Council (client) has relied on contaminant load models (CLMs) to identify the areas of highest contaminant loads and to target stormwater management interventions (source control and/or treatment). However, it is not possible to use the current CLM to assess the impact of contaminant load reductions on water quality (e.g. instream contaminant concentrations). While it is intuitively understood that reducing contaminant loads will affect water quality, the level of that effect cannot be determined.

The Council wished to develop a system that bridged the gap between stormwater contaminant loads (based on land use) and water quality in surface water. This is an essential aspect of determining the effects of stormwater on the receiving environment, thereby enhancing ecological outcomes. As the ecological well-being of urban waterways is related to concentrations of both acute and chronic toxicity effects, such a system must connect the pollutant loads generated from individual surfaces to the resultant concentrations in the receiving environment.

Development of such a system is also a requirement of the Comprehensive Stormwater Network Discharge Consent (CSNDC). While the CSNDC is not explicit, it is assumed that such a system will include the following contaminants - Total suspended solids (TSS), Total and dissolved zinc (Zn), and Total and dissolved copper (Cu).

These contaminants match those included in Table 2 of the CSNDC as the key contaminants to reduce in Christchurch's urban waterways.

Previously, the University of Canterbury (UC) developed a GIS-based contaminant load model called MEDUSA. MEDUSA has been calibrated for a number of Christchurch catchments, including Okeover Stream, Addington Brook, and the Ōpāwaho/Heathcote River. The key advantage of this model is that it is based on local climatic and pollutant load conditions. The model outputs are event-based contaminant loads (TSS, Cu and Zn) from different surface types, which can be amalgamated to produce contaminant loads at various points in the network. MEDUSA has already been used for several stormwater management plans (SMPs).

In 2018, DHI teamed with the University of Canterbury to produce an online version of MEDUSA. MEDUSA Online was first implemented for Addington Catchment. This project was partly sponsored by Environment Canterbury (ECan). Timaru District Council funded the implementation of the MEDUSA Online version for the Washdyke Catchment in Timaru.

The Council commissioned DHI and UC to develop an instream contaminant concentration model (ICCM) that meets both the requirements of the CSNDC and the Council's business needs for informed investment in water quality improvement.

The scope of this project includes the following -

- Use MEDUSA to determine the annual loads of TSS and total and dissolved Cu and Zn generated in the following catchments: Styx, Avon, Heathcote, and Halswell

- Treatment of the annual load is to be assessed and reported on for all treatment catchments and sub-catchments

- The loads will be provided in the form of an online platform.

1.2 Overview of the report

In this report, we provide an overview of ICCM, that enables city-wide source-to-discharge simulations. Specifically, it -

a) Links pollutant generation from individual surfaces to resultant instream concentrations at the stormwater event level and the annual level,

b) Compares the pollutant loads and concentrations before and after application of treatment systems at surface-level to sub-catchment scale, and at overall catchment-scale,

c) Estimates the pollutant loads and concentrations for a range of rainfall years, and

d) Provides users with the ability to test water quality impact mitigation options at the surface to city-wide scale.

The next section contains a description of the underlying modules which power the ICCM online platform. Section 3 gives an overview of the input data to the ICCM. Results are presented in Section 4.

2 ICCM Framework

ICCM has two underlying modules – Pollutant Generation and Pollutant Treatment.

(i) The **Pollutant Generation** module uses the MEDUSA 2.0 engine to generate total and dissolved zinc, copper, and TSS loads from individual surfaces for individual storm events. It generates both first flush and second-stage pollutant loads for individual events and surfaces,

(ii) The **Pollutant Treatment** module simulates the inclusion of site-specific treatment options and catchment-wide measures for different planning years, and

These two modules are integrated into the Baseline Results and Scenario Manager applications within the ICCM platform. The Scenario Manager enables the simulation of various scenarios, including modifications to treatment systems and urban intensification.

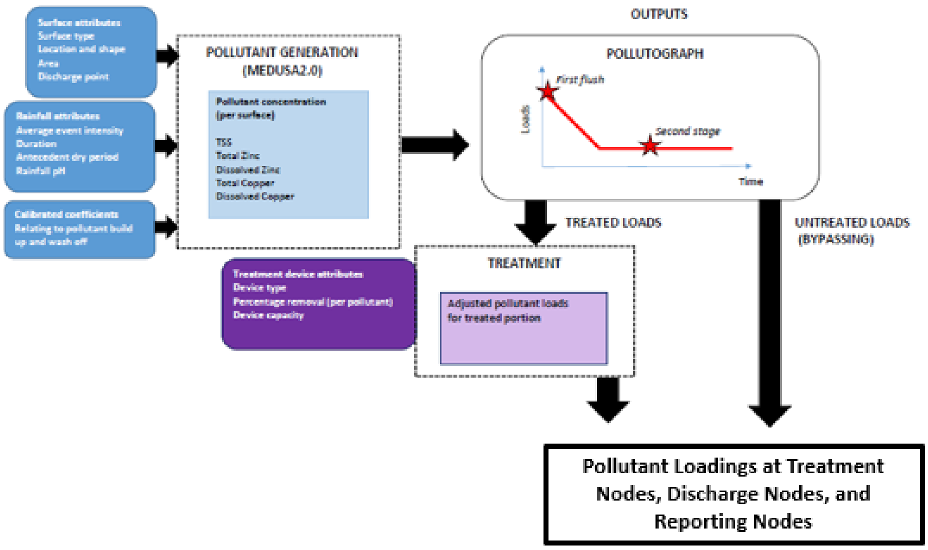


Figure 2-1 ICCM Framework

Figure 2-1 presents the underlying framework of the ICCM. ICCM utilises the University of Canterbury's (UC) GIS contaminant load model called MEDUSA. MEDUSA has been calibrated for several Christchurch catchments, including Okeover Stream, Addington Brook, and the Ōpāwaho/Heathcote River. The key advantage of this model is that it is based on local climatic and pollutant load conditions. The model outputs are event-based contaminant loads from different surface types, which can be amalgamated to produce contaminant loads at various points in the network. MEDUSA has already been used for several stormwater management plans.

2.1 MEDUSA 2.0 inputs and load generation

The MEDUSA (Modelled Estimates of Discharges for Urban Stormwater Assessments) model was used to simulate contaminant loadings from roof, carpark, and road surfaces. MEDUSA simulates sediment and heavy metal loading contribution from individual urban surfaces for a single rainfall event or multiple events (aggregated to a full year). The model estimates total suspended solids (TSS), total zinc (TZn), total copper (TCu), dissolved zinc (DZn), and dissolved copper (DCu) from roofs, roads, and carparks. Coefficients for pollutant build-up and wash-off equations were developed through field measurements of loadings from various surfaces over multiple rainfall events. An analysis of all historical monitoring data was conducted to develop relationships between first-flush and steady-state loads from roof, road, and carpark surfaces. Further information on the tool and its application can be found in these scientific journal publications (open access links):

- **Predicting Event-Based Sediment and Heavy Metal Loads in Untreated Urban Runoff from Impermeable Surfaces**
- **Influences of zinc loads in urban catchment runoff: Roof type, land use type, climate and management strategies**

The integration of MEDUSA into ICCM required compiling climate data, individual surface types and conditions, and establishing connectivity to treatment and discharge nodes.

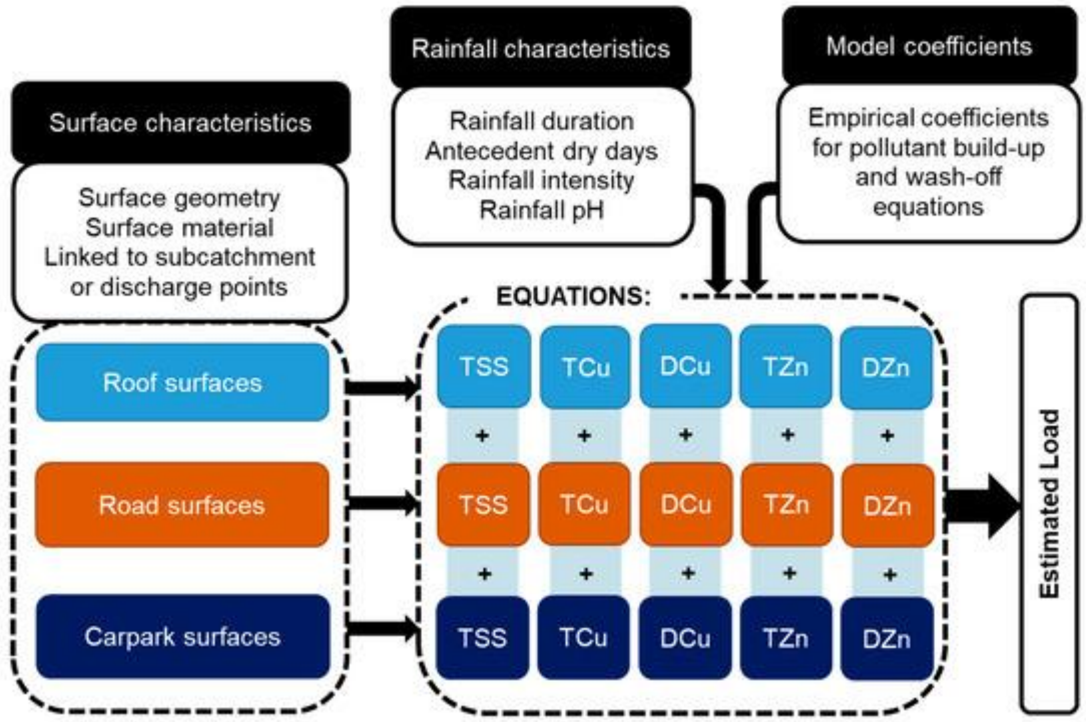


Figure 2-2 MEDUSA2.0 model framework. TSS, total suspended solids; TCu, total copper; DCu, dissolved copper; TZn, total zinc; DZn, dissolved zinc.

Climate data

Climatic inputs for each event included average rainfall intensity during the event (INT), duration (DUR), antecedent dry days (ADD), and rainfall pH (~6.5 for New Zealand). A rainfall event was defined as a continuous or intermittent period of rainfall separated from another event when at least 6 hours of dry weather occurred.

Surface identification and condition

Roads and roofs, as determined by Lynker Analytics Ltd. for Christchurch through remote sensing and analysis of national building footprints, were used for ICCM. All road and roof surfaces were classified into specific MEDUSA surface types. For roofs, the Lynker “Buildings” category was used, which is based on the LINZ building footprints layer and additional remote sensing done by Lynker. Attributes for the roof type (from a deep learning algorithm) and decay factor were used to classify the roof type according to the MEDUSA classification type and to determine whether the roof surface was old or new (a decay factor of 0.4 was used as the threshold between old and new). Any roof surface without an initial roof type classification was assigned as “colour steel” (i.e. less than 40 out of 97,697 polygons for the Avon catchment).

Carpark surfaces were derived from CCC zoning and Lynker landuse maps and classified into Industrial, Commercial, Multiuse, CommServ, and TranspUtil surfaces. These were then converted to MEDUSA type surfaces (Industrial Heavy, Commercial, and Industrial Light). Since the new Lynker roof maps provided were slightly different than the original Lynker landuse, overlaps between roof (building footprint) and carparks had to be resolved.

Issues encountered with catchment and subcatchment boundaries were resolved as follows:

- Roof and Road Surfaces: Centroid points of individual surface polygons were used to identify which catchment or sub-catchment they discharged into.

- Road surfaces: Surfaces were divided (split) using the catchment or subcatchment boundaries. Each part of a road would discharge to its respective catchment/subcatchment. Small road slivers (less than 0.5 m^2 polygon area) were removed, if necessary, as these were only a result of minor differences between subcatchment and catchment delineations.

Connectivity to treatment and discharge nodes:

Each surface was then linked to the relevant treatment node (if applicable) and to the discharge node. The roof polygon centre point was used to determine which sub catchment (and thus treatment/discharge node) it belonged to (i.e. some roof surfaces fell between sub catchments, but their full runoff contributes to only one of the sub catchments).

Multiple nested treatment areas required developing a process to ensure surfaces were linked in the correct order to treatment systems within each subcatchment and also to the final discharge node. This process was automated with ArcGIS Pro and is described in detail in Appendix A.

Validation:

Validation of roof, carpark, and road contributions of TSS, TZn, and TCu loads was done by comparing MEDUSA loading results at individual surfaces and also at catchment discharge nodes (several catchments were verified). Spreadsheet calculations of MEDUSA for select events and years were used for validation and verification purposes of the ICCM platform.

Table 2-1 Sites monitored, MEDUSA 2.0 surface category and classification.

Sites monitored ADD: Addington catchment HCT: Heathcote catchment OKE: Okeover catchment (near UC)	MEDUSA 2.0 Surface Category	CCC classification (based on Lynker Analytics dataset)
Galv unpainted new (ADD TJ)	Galvanised uncoated new	Galvanised (low)
Galv unpainted old (ADD GoBus)	Galvanised uncoated old	Galvanised (high)
Colorsteel New (HCT)	Colorsteel New	ColourSteel (low)
Colorsteel Old (HCT)	Colorsteel Old	ColourSteel (high)
Galv painted (OKE)	Galvanised painted, older	MetalOther or MetalTile (high)
Galv painted (HCT, repainted)	Galvanised painted, newer	MetalOther or MetalTile (low)
Concrete (OKE)	Concrete, no Zn	NonMetal (low)
Concrete, Zn gutters (HCT)	Concrete, Zn guttering	NonMetal (high)
Concrete (OKE)	Non-metallic	NonMetal (low)
Copper (OKE)	Copper	id manually
Zincalume*	Zincalume	Zincalume
Road, major arterial (ADD)	Major arterial	Regional,High Volume or Arterial
Road, minor arterial (ADD)	Minor arterial	Primary collector
Road, Collector (OKE)	Collector	Secondary Collector
Road, Local (HCT)	Local Road	Low Volume
Road, Local (HCT)	Private Road	Access
Carpark, Commercial (ADD)	Commercial	Based on CCC zoning classification (commercial)
Carpark, Standard (ADD)	Industrial Std	Based on CCC zoning classification (industrial)
Carpark, Manoeuvring (ADD)	Industrial Mnv	Based on CCC zoning classification (heavy industrial)

*Note: New Zincalume roof parameters were added for this project based on monitoring. One ZincAlume roof surface was sampled at Hagley Community College, in the Addington catchment, over three rain events, between 2021/22. A second ZincAlume roof surface was sampled over six rain events, 2021/22, at the University of Canterbury in the Okeover catchment (the Forestry building). The same sampling method using first flush samplers and second stage grab sampling was followed as for the Addington and Heathcote sampling programmes. Likewise, samples were held at 4°C and analysed at the University of Canterbury's Environmental Lab, as per the Okeover sampling programme. They were analysed for TZn and DZn only.

3 Input Data and Analysis

ICCM predicts load and concentrations for the four major stormwater catchments in Christchurch (Avon, Heathcote, Halswell, and Styx). The following data was used to develop ICCM –

1. Spatial Data – Catchments, Sub-catchments, Surfaces, Treatment systems, Waterways
2. Material Data – Surface type, Condition of roofs, carpark usage type, road vehicular density type, Area, Treatment type
3. Rainfall Data – Rain events, Antecedent Dry Days, Rainfall Intensity

In each of these catchments, the impervious surfaces (along with their material type and usage type) were delineated as individual polygons and provided by the client as spatial files. We used NIWA's Kyle Street weather station in eastern Riccarton to obtain rainfall data.

Analysis of the data received is briefly summarised in the following tables.

Table 3-1 Catchment-level data

Catchments	No. of Sub-catchments	No. of Treatment Systems	No. of Impervious Surfaces	Area of Impervious Surfaces (ha)	Proportion of Impervious area to total area (%)
Avon	65	148	107,904	2,751.8	26.75
Halswell	28	85	11,288	539.2	14.3
Styx	22	92	24,912	623.9	11.45
Heathcote	46	171	82,000	2,241.8	19.07
Total	**161**	**496**	**226,104**	**6,156.7**	**19.69**

At the catchment level, Avon has the highest number of sub-catchments, impervious surfaces, impervious area, and proportion of impervious area to total catchment area among the four catchments (Table 3-1).

In each catchment, the stormwater treatment systems become active progressively over four planning years – 2018, 2023, 2028, and 2043 (Table 3-2). The number of active treatment systems distinguishes these years. The planning year 2018 had only 80% of the treatment systems active; 2023 had about 94% active; 2028 will have about 95% active; and 2043 will have all treatment systems active.

Table 3-2 Number of active Treatment Systems for each planning year within each of the four catchments.

Catchments	2018	2023	2028	2043
Avon	106	130	133	148
Halswell	51	81	84	85
Styx	71	82	82	92
Heathcote	170	171	171	171
Total	**398**	**464**	**470**	**496**

Impervious surface distribution in each catchment is summarised in Table 3-3.

Table 3-3 Number of impervious surfaces for each major surface type within each Catchment.

Catchments	Roofs	Roads	Carparks
Avon	97,541	6,741	3,622
Halswell	9,853	746	689
Styx	22,776	1,497	639
Heathcote	72,258	4,192	5,550
Total	**202,428**	**13,176**	**10,500**

Eleven (11) types of roof materials were identified in the catchments, as summarised in Table 3-4.

Table 3-4 Roof material types and their numbers in the Catchments

Roof Types	Avon	Halswell	Styx	Heathcote
ColourSteel_high	2,382	164	462	1,568
ColourSteel_low	50,676	5,830	11,062	38,590
Galvanised_high	8,181	616	1,945	6,419
Galvanised_low	6,896	597	1,828	5,215
MetalOther_high	735	57	130	620
MetalOther_low	1,992	166	482	1,795
MetalTile_high	689	31	157	448
MetalTile_low	3,918	725	1,010	3,570

NonMetal_high	3	1	1	6
NonMetal_low	21,673	1,461	5,622	12,782
Zincalume	396	205	77	1,245
Total	**97,541**	**9,853**	**22,776**	**72,258**

Seven (7) types of roads were identified in the catchments, as summarised in Table 3-5.

Table 3-5 Road types and their numbers in the Catchments

Road Types	Avon	Halswell	Styx	Heathcote
Access	1,239	150	383	886
Arterial	790	116	226	787
High Volume	167	37	33	214
Low Volume	787	116	300	557
Primary Collector	1,277	118	139	278
Regional	326	7	43	83
Secondary Collector	2,152	200	373	1,387
Total	**6,738**	**744**	**1,497**	**4,192**

Three types of carparks were classified in the catchments, as summarised in Table 3-6. Residential carparks were not simulated.

Table 3-6 Carpark types and their numbers in the Catchments

Carpark Types	Avon	Halswell	Styx	Heathcote
Commercial	1,999	61	121	1,252
Industrial Heavy	926	450	253	3,235
Industrial Light	697	178	265	1,063
Total	**3,622**	**689**	**639**	**5,550**

Table 3-7 shows impervious area coverage from these 21 different surfaces across the four catchments.

Table 3-7 Impervious surface types and their areas

Surface Types	Avon (ha)	Halswell (ha)	Styx (ha)	Heathcote (ha)
Roofs				
ColourSteel_high	24.85	4.75	4.28	21.90
ColourSteel_low	857.37	136.48	189.73	645.52
Galvanised_high	55.79	6.08	13.01	46.76
Galvanised_low	79.53	8.75	18.41	64.21
MetalOther_high	5.74	0.39	1.02	5.07
MetalOther_low	22.70	3.09	5.62	21.66
MetalTile_high	12.66	0.85	2.56	7.57
MetalTile_low	77.81	15.64	19.84	72.76
NonMetal_high	0.01	0.02	0.01	0.14
NonMetal_low	360.86	27.59	101.73	210.37
Zincalume	51.25	72.99	11.03	181.59
Roads				
Access	134.13	26.82	44.87	107.64
Arterial	95.95	16.75	27.83	99.44
High Volume	26.67	7.84	6.30	23.93
Low Volume	65.19	14.60	26.40	55.01
Primary Collector	143.08	14.10	17.87	39.66
Regional	52.47	1.41	5.50	19.03
Secondary Collector	219.71	24.19	41.75	168.36
Carparks				
Commercial	158.29	11.47	19.77	75.05
Industrial Heavy	92.79	135.12	38.63	271.34
Industrial Light	215.00	10.29	27.73	104.83
Total	**2,751.85**	**539.22**	**623.89**	**2,241.84**

Analysis of the 161 sub-catchments in the four catchments showed that the total impervious area ranged from 0.06 ha to 239 ha. 9 sub-catchments had an impervious area below 1 ha. 15 sub-catchments had an impervious area above 100 ha.

The proportion of impervious area which is connected to active treatment systems in each catchment across the four planning years is summarised in Table 3-8.

Table 3-8 Proportion of Impervious Area undergoing treatment across the years

Catchments	2018 (%)	2023 (%)	2028 (%)	2043 (%)
Avon	27.84	29.52	37.41	47.97
Halswell	74.71	85.58	86.97	87.06
Styx	56.21	65.88	65.88	69.81
Heathcote	53.40	53.59	53.59	53.59
Total	**44.13**	**46.88**	**50.53**	**55.65**

The distribution of the treatment systems among the 161 sub-catchments is shown Figure 3-1.

Results showed that 45 sub-catchments lack any treatment systems. This corresponds to approximately 1,240 ha of impervious surface area in the four river catchments, which is not treated. Thirty-one sub-catchments have single treatment systems, treating approximately 660 Hectares of impervious surface area. Fifty-two sub-catchments have two to five treatment systems, which treat approximately 1,270 ha of impervious surface area. Twenty-four sub-catchments have between six and ten treatment systems, covering an area of 800 Hectares of impervious surface. Finally, nine sub-catchments have more than 10 treatment systems, covering approximately 770 hectares of impervious surface area.

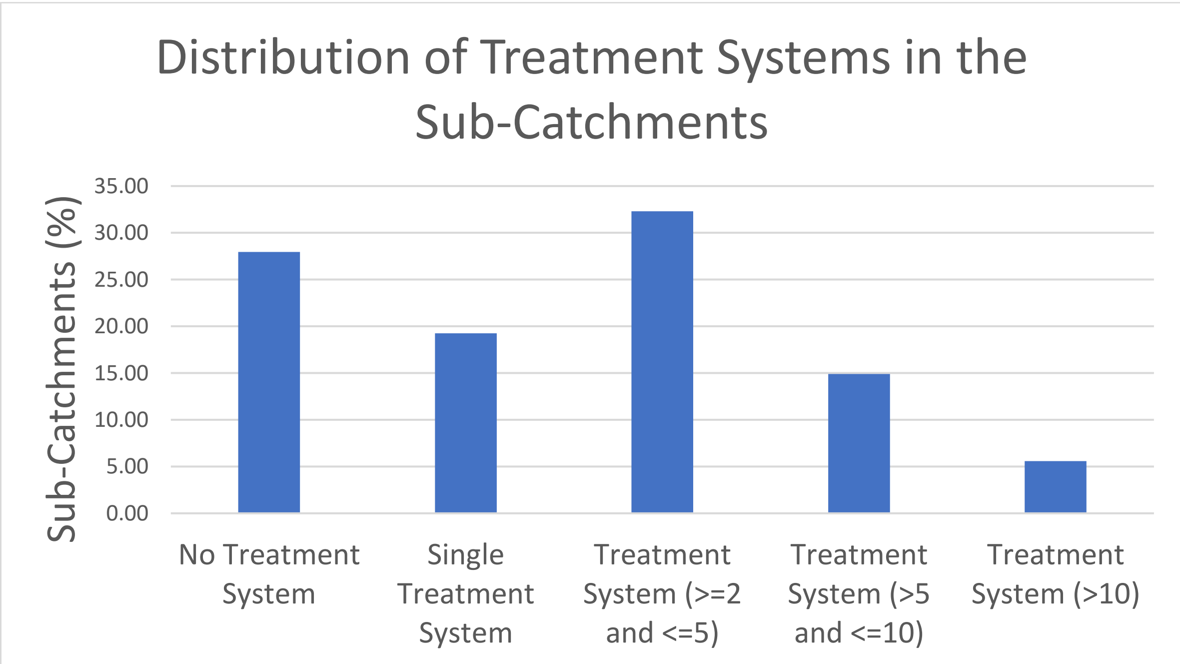


Figure 3-1 Distribution of treatment systems across the catchments

The treatment systems include Wetland, first-flush (dry), first-flush (wet), Rain garden, Stormfilter, Swale, Cartridge filter, Detention basin, and treatment train, as shown in Table 3-9. They treat pollutant loads from an impervious surface area of less than a few square meters to approximately 4 million m². About 10% of the treatment systems are part of a treatment train. The contaminant removal efficiencies of the treatment systems are presented in Table 3-10.

Table 3-9 Treatment system distribution in the Catchments

Treatment Types	Avon	Halswell	Styx	Heathcote
Cartridge filter	1	0	0	2
Detention (dry)	0	0	0	1
First flush (dry)	39	50	36	69
First flush (dry) + wetland	7	6	21	12
First flush (wet)	12	3	2	3
First flush (wet) + wetland	3	0	5	1
Pre-treatment basin	2	0	0	3
Rain garden	46	1	0	4
Rapid soakage	9	10	0	2
Stormfilter	1	0	0	0
Swale	21	15	26	66
To ground	1	0	0	3
Wetland	6	0	2	5
Total	**148**	**85**	**92**	**171**

Table 3-10 Removal efficiency of the Treatment systems

ICCM Treatment Train	TSS Treatment Efficiency (%)			Zinc treatment efficiency (%)			Copper treatment efficiency (%)		
	Roofs	Roads	Carparks	Roofs	Roads	Carparks	Roofs	Roads	Carparks
First flush (dry)	10	60	60	5	20	20	5	30	30
First flush (wet)	10	60	60	5	20	20	5	30	30
Wetland	50	80	80	25	60	60	30	70	70
Pre treatment basin	10	75	75	5	30	30	5	40	40
First flush (wet) + wetland	55	92	92	28.8	68	68	33.5	79	79
Swale	30	75	75	15	40	40	20	50	50
Rain garden	70	80	80	60	70	70	70	75	75
First flush (dry) + wetland	55	92	92	28.8	68	68	33.5	79	79
Stormfilter	50	75	75	15	40	40	20	65	65
Cartridge filter	89	89	89	71	71	71	71	71	71

In consultation with the client, approximately 170 sites along the main waterways in the four catchments were identified to extract relevant results for load, load per area, and average concentration of the target contaminants for each of the four planning years.

In ICCM terminology, these are named as Reporting Nodes. Seventy-one are located in the Avon Catchment, 22 are located in the Halswell Catchment, 22 are located in the Styx Catchment, and 54 are located in the Heathcote Catchment.

In ICCM, the sub-catchments are represented by Discharge Nodes. Each sub-catchment is represented by an individual Discharge Node. This corresponds to 65 Discharge Nodes in Avon Catchment, 28 in Halswell, 22 in Styx, and 46 in Heathcote Catchment, respectively.

Treatment systems are labelled as Treatment Nodes in ICCM. This corresponds to 148 Treatment Nodes in Avon Catchment, 85 in Halswell, 92 in Styx, and 171 in Heathcote Catchment, respectively.

The spatial locations of the Reporting Nodes, along with their network connectivity, are displayed in Figure 3-2 to Figure 3-5 respectively.

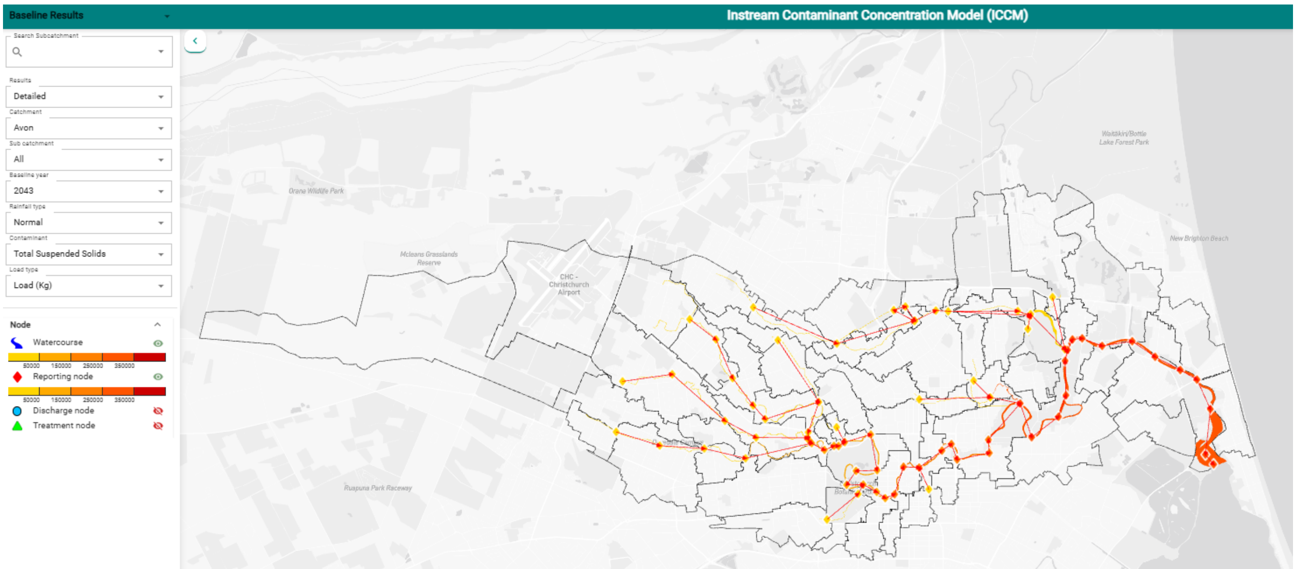


Figure 3-2 Avon Catchment - Connectivity of the Reporting Nodes. The diamond-shaped icons represent the Reporting Nodes in the waterways. The colours refer to the TSS loads (yellow to red shows a progressive increase in loads).

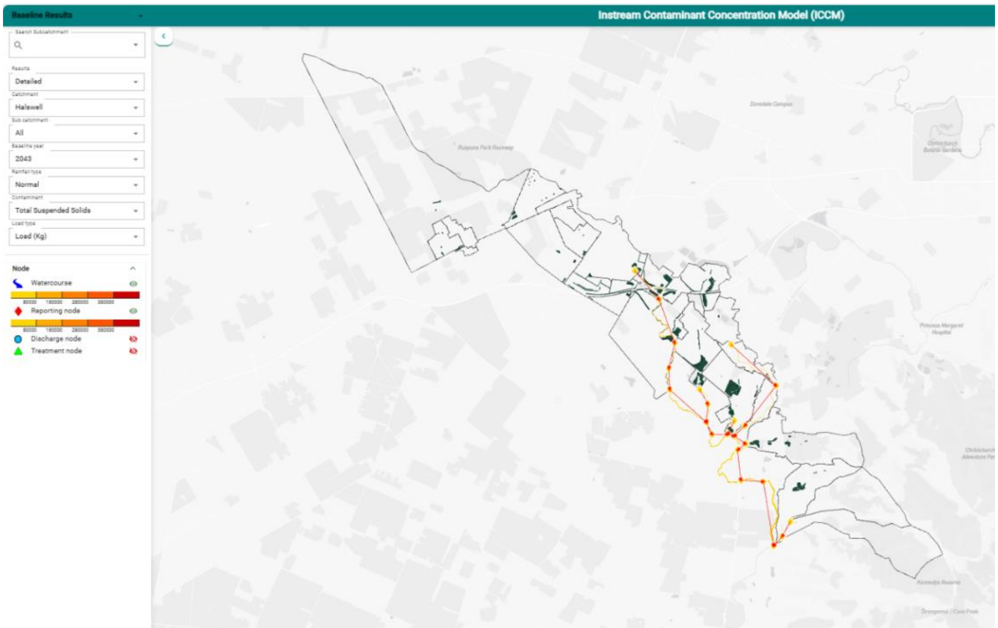


Figure 3-3 Halswell Catchment - Connectivity of the Reporting Nodes. The diamond-shaped icons represent the Reporting Nodes in the waterways. The colours refer to the TSS loads (yellow to red shows a progressive increase in loads).

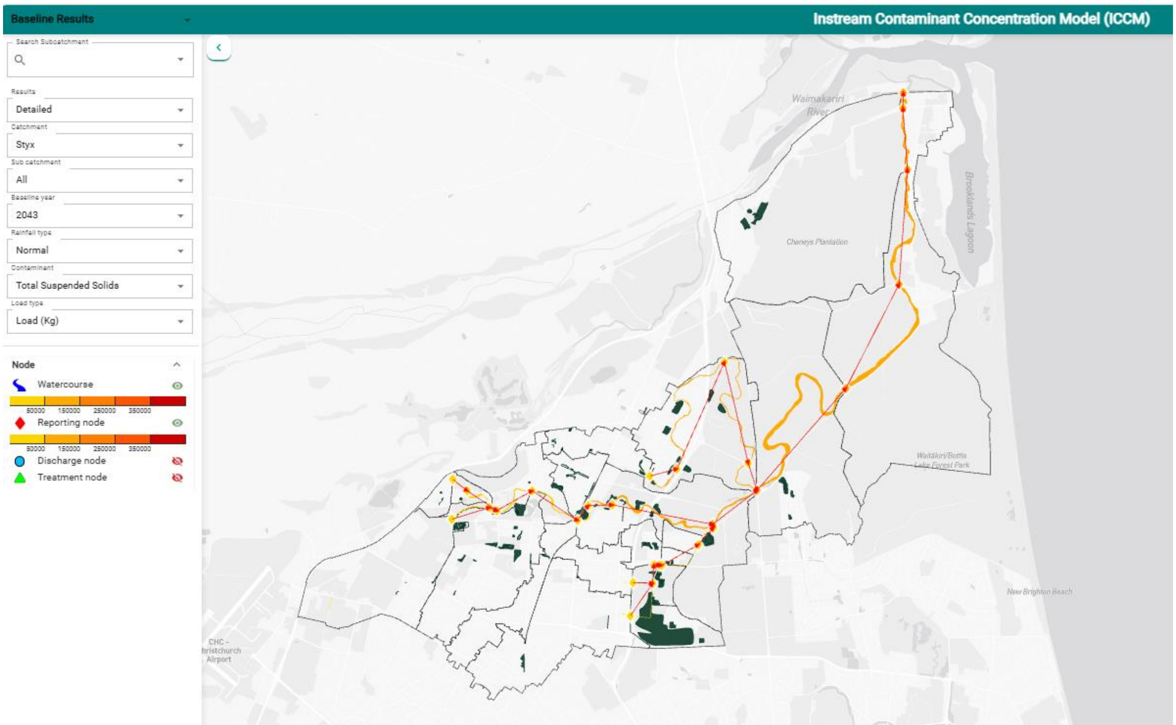


Figure 3-4 Styx Catchment - Connectivity of the Reporting Nodes. The diamond-shaped icons represent the Reporting Nodes in the waterways. The colours refer to the TSS loads (yellow to red shows a progressive increase in loads).

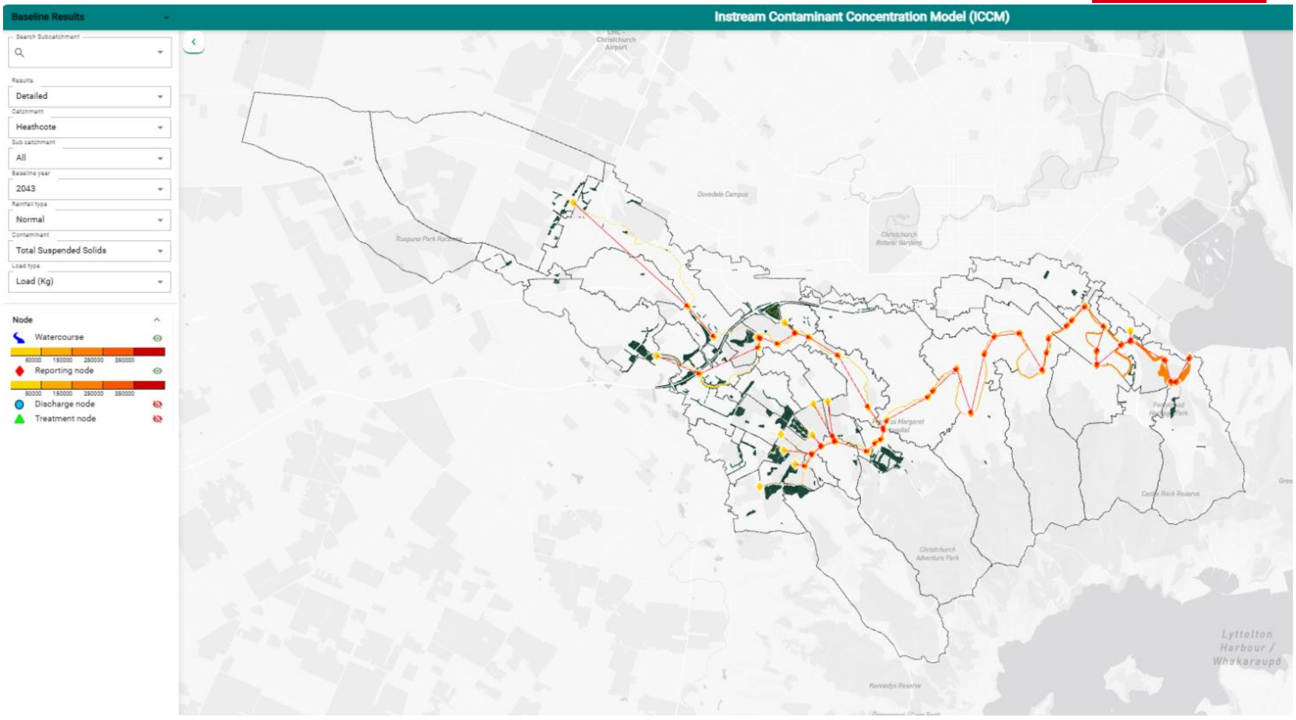


Figure 3-5 Heathcote Catchment - Connectivity of the Reporting Nodes. The diamond-shaped icons represent the Reporting Nodes in the waterways. The colours refer to the TSS loads (yellow to red shows a progressive increase in loads).

Due to the presence of treatment trains in the catchments, we developed a Treatment Node network connectivity map in discussion with the client. Figure 3-6 to Figure 3-9 show the Treatment Node network connectivity in each of the four catchments, respectively. Figure 3-10 shows the zoomed-in figure of the Treatment Node network connectivity in Snellings sub-catchment in Avon Catchment.

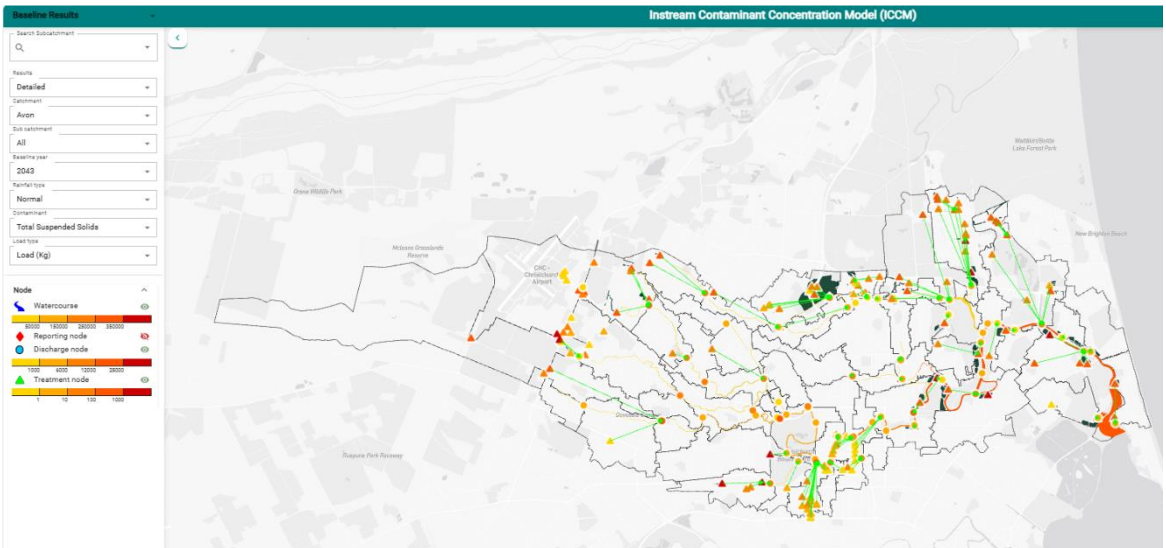


Figure 3-6 Avon Catchment - Connectivity of the treatment train to the sub-catchments. The triangle-shaped icons represent the treatment systems, the circle-shaped icons represent the sub-catchments, and the colours refer to the TSS loads (yellow to red shows a progressive increase in loads). The green-coloured arrows indicate the connectivity between the treatment systems.

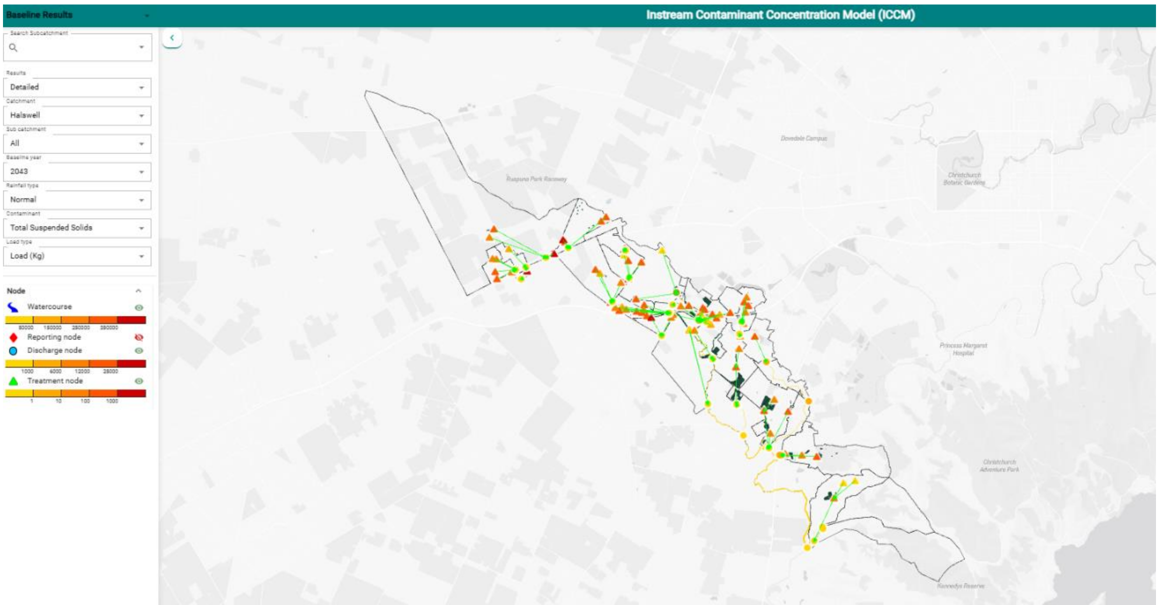


Figure 3-7 Halswell Catchment - Connectivity of the treatment train to the sub-catchments. The triangle-shaped icons represent the treatment systems, the circle-shaped icons represent the sub-catchments, and the colours refer to the TSS loads (yellow to red shows a progressive increase in loads). The green-coloured arrows indicate the connectivity between the treatment systems.

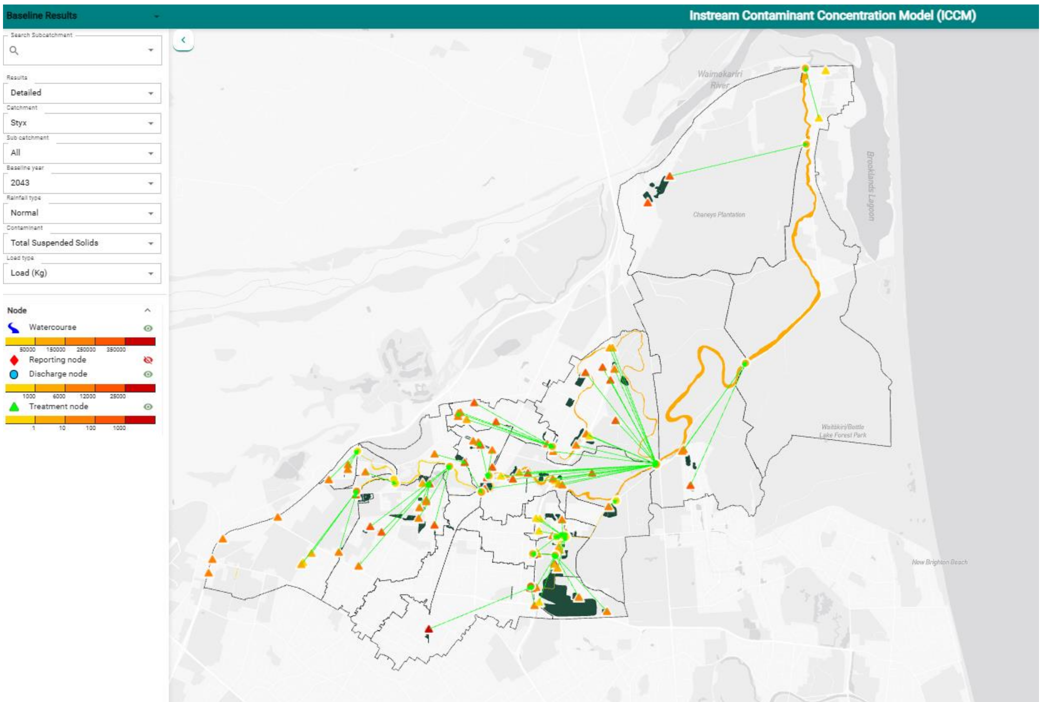


Figure 3-8 Styx Catchment - Connectivity of the treatment train to the sub-catchments. The triangle-shaped icons represent the treatment systems, the circle-shaped icons represent the sub-catchments, and the colours refer to the TSS loads (yellow to red shows a progressive increase in loads). The green-coloured arrows indicate the connectivity between the treatment systems.

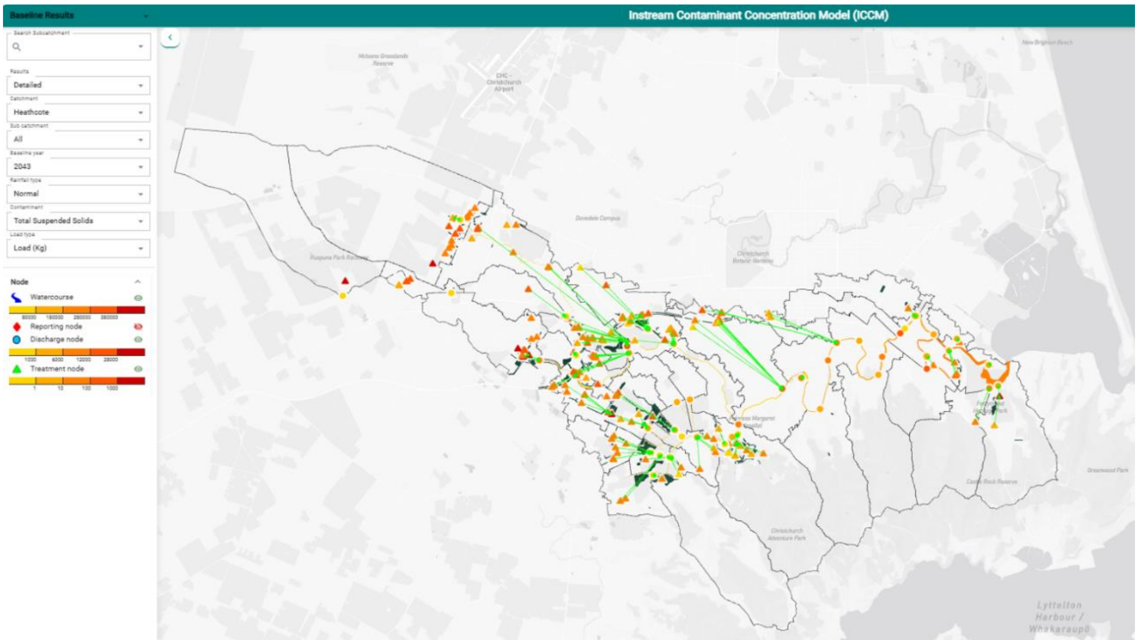


Figure 3-9 Heathcote Catchment - Connectivity of the treatment train to the sub-catchments. The triangle-shaped icons represent the treatment systems, the circle-shaped icons represent the sub-catchments, and the colours refer to the TSS loads (yellow to red shows a progressive increase in loads). The green-coloured arrows indicate the connectivity between the treatment systems.

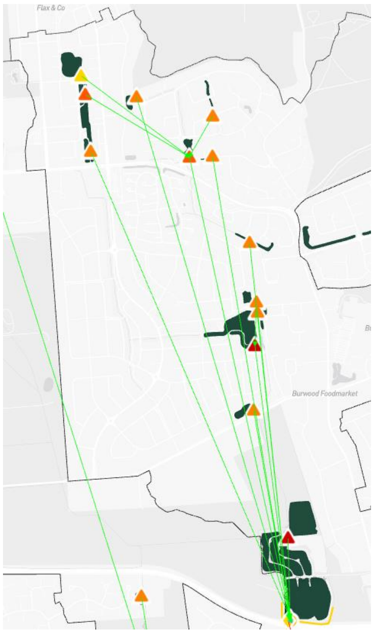


Figure 3-10 Zoomed in figure of the Treatment Node network connectivity in Snellings sub-catchment in Avon Catchment. The triangle-shaped icons represent the treatment systems, the circle-shaped icons represent the sub-catchments, and the colours refer to the TSS loads (yellow to red shows a progressive increase in loads). The green-coloured arrows indicate the connectivity between the treatment systems.

We performed an analysis of the rainfall events data for the years 2010-2021, derived from NIWA's Kyle Street weather station in eastern Riccarton. Table 3-11 summarises each year's characteristics, including whether it can be considered a dry, average or wet year. Subsequent discussions with the client led to the selection of 2020 as the Dry Year, 2021 as the Average Year, and 2018 as the Wet Year for load generation.

Table 3-11 Rainfall distribution in Christchurch City

Parameter	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of events	89	112	88	92	92	93	86	92	90	81	80	75
Annual total depth (mm)	646	689	642	741	751	435	541	759	842	507	403	580
Relative difference from long-term average ((647 mm/yr)	-1%	6%	-1%	14%	16%	-33%	-17%	17%	30%	-22%	-38%	-11%
Classification	Average	Average	Average	Wet	Wet	Dry	Dry	Wet	Wet	Dry	Dry	Average
Average intensity (mm/hr)	0.56 (0.06-1.83)	0.61 (0.10-2.74)	0.79 (0.12-3.96)	0.64 (0.06-4.35)	0.61 (0.10-4.02)	0.64 (0.08-2.15)	0.71 (0.08-4.57)	0.67 (0.10-3.70)	0.90 (0.08-4.80)	0.72 (0.08-2.67)	0.65 (0.10-2.43)	0.96 (0.10-13.60)
ADD (days)	3.6 (0.3-17.7)	3 (0.3-13.5)	3.9 (0.3-19.0)	3.6 (0.3-29.6)	3.6 (0.3-23.1)	3.7 (0.3-17.2)	3.9 (0.3-23.5)	3.5 (0.3-28.8)	3.7 (0.3-20.5)	4 (0.3-26.3)	4.5 (0.3-28.9)	4.4 (0.3-19.5)
Duration (hours)	11.2 (1-135)	7.4 (1-93)	8 (1-41)	10.5 (1-86)	9.5 (1-42)	6.6 (1-47)	8.6 (1-40)	9.9 (1-68)	9.8 (1-55)	7.8 (1-52)	6.2 (1-39)	8.2 (1-78)
Depth (mm)	7.3 (0.2-124.2)	6.2 (0.2-92.7)	7.5 (0.3-69.3)	8.1 (0.2-108)	8.2 (0.3-140.7)	4.7 (0.3-35.2)	6.3 (0.3-38.1)	7.8 (0.3-83.1)	9.2 (0.3-60.3)	6 (0.2-77.2)	4.7 (0.3-41.1)	7.4 (0.3-126)

The Dry Year (2020) had 80 rain events with a total annual depth of 403mm. The Average Year (2021) had 75 rain events with a total annual depth of 580mm. Wet Year (2018) had 90 rain events with a total annual depth of 842 mm.

We used a lumped hydrology approach to convert the rainfall to runoff at the surface, treatment node, discharge node, and reporting node levels. The lumped approach assumed only impervious surfaces in the catchments for runoff generation. The routing did not consider any runoff attenuation from the surfaces to the receiving waters.

The annual runoff results from the surfaces across all four catchments at 10th percentile, 50th percentile, and 90th percentile are summarized in Table 3-12 -

Table 3-12 Annual runoff results from surfaces

Surfaces	Dry Year (m^3/yr)	Average Year (m^3/yr)	Wet Year (m^3/yr)
10th Percentile	9.82	14.23	20.61
50th Percentile	55.79	80.89	117.15
90th Percentile	149.33	216.53	313.59

4 Results

Pollutant loads and concentrations were calculated for approximately 245 rain events observed across three different rainfall years (defined as wet, dry, and normal years based on cumulative annual rainfall) for each of the four planning years. This resulted in more than 280 million records of load, load per area, and average concentration values generated by the Pollution Generation module.

4.1 Pollutant Generation Module Results

The impervious surfaces mapped in the four stormwater catchments were classified based on material type to generate loads. There are 11 types of roof materials, seven types of road types, and three types of carparks as shown in Table 3-4, Table 3-5, and Table 3-6 respectively. 90% of these surfaces were roofs, 6% of roads, and 4% of carparks. In the planning year 2018, about 37% of the surfaces were connected to the treatment systems before discharging to a receiving waterway. This increased to 40% in planning year 2023, 42% in planning year 2028, and 51% in planning year 2043.

For the Average rainfall year, the unit area loads generated from the different impervious surfaces are shown in Table 4-1, Table 4-2, and Table 4-3 respectively –

Table 4-1 Unit area loads from roof surfaces

Surface Types	TSS ($g/m^2/yr$)	Total Zinc ($g/m^2/yr$)	Dissolved Zinc ($g/m^2/yr$)	Total Copper ($g/m^2/yr$)	Dissolved Copper ($g/m^2/yr$)
ColourSteel_high	0.31	0.40	0.40	0.0005	0.00024
ColourSteel_low	0.76	0.09	0.07	0.0011	0.00026
Galvanised_high	11.20	1.48	1.26	0.0021	0.00042
Galvanised_low	13.75	0.50	0.50	0.0061	0.00141
MetalOther_high	2.46	0.26	0.11	0.0032	0.00159
MetalOther_low	0.25	0.18	0.18	0.0041	0.00205
MetalTile_high	2.46	0.26	0.11	0.0032	0.00159
MetalTile_low	0.25	0.18	0.18	0.0041	0.00205
NonMetal_high	0.38	0.16	0.13	0.0068	0.00647
NonMetal_low	2.55	0.01	0.01	0.0032	0.00245
Zincalume	0.76	0.37	0.33	0.0012	0.00027

Table 4-2 Unit area loads from road surfaces

Surface Types	TSS ($g/m^2/yr$)	Total Zinc ($g/m^2/yr$)	Dissolved Zinc ($g/m^2/yr$)	Total Copper ($g/m^2/yr$)	Dissolved Copper ($g/m^2/yr$)
Access	24.14	0.05	9.27E-05	0.0106	2.98E-03
Arterial	45.19	0.36	2.88E-03	0.0199	6.56E-03
High Volume	45.19	0.36	2.88E-03	0.0199	6.56E-03
Low Volume	24.14	0.05	9.27E-05	0.0106	2.98E-03
Primary Collector	27.77	0.2	1.46E-03	0.0197	7.49E-03
Regional	45.19	0.36	2.88E-03	0.0199	6.56E-03
Secondary Collector	24.14	0.05	9.27E-05	0.0106	2.98E-03

Table 4-3 Unit area loads from carpark surfaces

Surface Types	TSS ($g/m^2/yr$)	Total Zinc ($g/m^2/yr$)	Dissolved Zinc ($g/m^2/yr$)	Total Copper ($g/m^2/yr$)	Dissolved Copper ($g/m^2/yr$)
Commercial	25.65	0.10	5.00E-02	0.0117	5.40E-03
Industrial Heavy	42.02	0.11	5.88E-02	0.0258	1.34E-02
Industrial Light	53.47	0.24	6.90E-02	0.0136	2.99E-03

Among roof surfaces, galvanised material generates higher amounts of TSS and Zinc loads per unit area as compared to other surfaces. Among road surfaces, arterial, high-volume, and regional roads generate higher amounts of all three contaminants compared to other types of roads. Among carparks, Industrial light surface generates higher amounts of TSS and Zinc, while industry heavy generates the highest amount of Copper loads per unit area.

For the Average rainfall year, the annual loads generated from the different impervious surfaces in each of the four catchments are shown in Table 4-4 to Table 4-8. Pie charts in Figure 4-1 to Figure 4-3 show the distribution of the generated loads between roofs, roads, and carparks at city level, for an average rainfall year.

Table 4-4 Annual loads – TSS (Kg/yr)

Surface Types	Avon	Halswell	Styx	Heathcote
Roofs				
ColourSteel_high	76.43	14.60	13.18	67.35
ColourSteel_low	6,481.56	1,031.75	1,434.30	4,880.05
Galvanised_high	6,245.51	680.52	1,456.34	5,235.56
Galvanised_low	10,937.33	1,202.94	2,531.20	8,829.96
MetalOther_high	141.24	9.59	25.22	124.79
MetalOther_low	57.19	7.78	14.16	54.58
MetalTile_high	311.58	21.00	63.11	186.31
MetalTile_low	196.08	39.41	49.99	183.34
NonMetal_high	0.04	0.07	0.06	0.54
NonMetal_low	9,219.58	704.88	2,599.11	5,374.66
Zincalume	387.42	551.76	83.42	1,372.81
Roads				
Access	32,378.67	6,475.45	10,831.95	25,984.75
Arterial	43,354.78	7,569.34	12,576.72	44,932.35
High Volume	12,051.78	3,541.81	2,845.95	10,812.70
Low Volume	15,736.05	3,525.49	6,373.46	13,279.29
Primary Collector	39,739.14	3,915.60	4,963.17	11,015.13
Regional	23,709.79	636.77	2,483.68	8,598.67
Secondary Collector	53,039.92	5,839.16	10,078.97	40,643.24
Carparks				
Commercial	40,607.68	2,942.83	5,071.04	19,252.56
Industrial Heavy	38,992.60	56,781.21	16,231.26	114,024.08
Industrial Light	114,958.92	5,503.02	14,825.98	56,049.38
Total	**448,623.29**	**100,994.98**	**94,552.27**	**370,902.10**

Table 4-5 Annual loads – Total Zinc (Kg/yr)

Surface Types	Avon	Halswell	Styx	Heathcote
Roofs				
ColourSteel_high	100.32	19.17	17.30	88.40
ColourSteel_low	742.69	118.22	164.35	559.18
Galvanised_high	826.35	90.04	192.69	692.72
Galvanised_low	397.30	43.70	91.95	320.75
MetalOther_high	15.21	1.03	2.72	13.44
MetalOther_low	41.04	5.58	10.16	39.17
MetalTile_high	33.55	2.26	6.80	20.06
MetalTile_low	140.71	28.28	35.87	131.58
NonMetal_high	0.02	0.03	0.02	0.23
NonMetal_low	51.66	3.95	14.56	30.11
Zincalume	188.60	268.61	40.61	668.31
Roads				
Access	63.46	12.69	21.23	50.93
Arterial	346.40	60.48	100.49	359.01
High Volume	96.29	28.30	22.74	86.39
Low Volume	30.84	6.91	12.49	26.03
Primary Collector	288.11	28.39	35.98	79.86
Regional	189.44	5.09	19.84	68.70
Secondary Collector	103.96	11.44	19.75	79.66
Carparks				
Commercial	152.28	11.04	19.02	72.20
Industrial Heavy	97.48	141.95	40.58	285.06
Industrial Light	511.57	24.49	65.98	249.42
Total	**4,417.28**	**911.65**	**935.13**	**3,921.21**

Table 4-6 Annual loads – Dissolved Zinc (Kg/yr)

Surface Types	Avon	Halswell	Styx	Heathcote
Roofs				
ColourSteel_high	98.32	18.79	16.95	86.64
ColourSteel_low	638.71	101.67	141.34	480.90
Galvanised_high	702.39	76.53	163.79	588.81
Galvanised_low	397.30	43.70	91.95	320.75
MetalOther_high	6.54	0.44	1.17	5.78
MetalOther_low	39.81	5.41	9.85	37.99
MetalTile_high	14.43	0.97	2.92	8.63
MetalTile_low	136.49	27.43	34.80	127.63
NonMetal_high	0.02	0.02	0.02	0.19
NonMetal_low	34.61	2.65	9.76	20.18
Zincalume	169.74	241.75	36.55	601.48
Roads				
Access	0.12	0.02	0.04	0.10
Arterial	2.77	0.48	0.80	2.87
High Volume	0.77	0.23	0.18	0.69
Low Volume	0.06	0.01	0.02	0.05
Primary Collector	2.09	0.21	0.26	0.58
Regional	1.51	0.04	0.16	0.55
Secondary Collector	0.20	0.02	0.04	0.16
Carparks				
Commercial	79.18	5.74	9.89	37.54
Industrial Heavy	54.59	79.49	22.72	159.63
Industrial Light	148.35	7.10	19.13	72.33
Total	**2,528.00**	**612.70**	**562.34**	**2,553.48**

Table 4-7 Annual loads – Total Copper (Kg/yr)

Surface Types	Avon	Halswell	Styx	Heathcote
Roofs				
ColourSteel_high	0.11	0.02	0.02	0.10
ColourSteel_low	9.69	1.54	2.14	7.30
Galvanised_high	1.17	0.13	0.27	0.98
Galvanised_low	4.88	0.54	1.13	3.94
MetalOther_high	0.18	0.01	0.03	0.16
MetalOther_low	0.93	0.13	0.23	0.89
MetalTile_high	0.40	0.03	0.08	0.24
MetalTile_low	3.18	0.64	0.81	2.98
NonMetal_high	0.00	0.00	0.00	0.01
NonMetal_low	11.47	0.88	3.23	6.69
Zincalume	0.60	0.86	0.13	2.14
Roads				
Access	14.28	2.86	4.78	11.46
Arterial	19.08	3.33	5.53	19.77
High Volume	5.30	1.56	1.25	4.76
Low Volume	6.94	1.55	2.81	5.86
Primary Collector	28.21	2.78	3.52	7.82
Regional	10.43	0.28	1.09	3.78
Secondary Collector	23.39	2.58	4.44	17.92
Carparks				
Commercial	18.60	1.35	2.32	8.82
Industrial Heavy	23.98	34.92	9.98	70.12
Industrial Light	29.20	1.40	3.77	14.24
Total	**212.02**	**57.39**	**47.56**	**189.98**

Table 4-8 Annual loads – Dissolved Copper (Kg/yr)

Surface Types	Avon	Halswell	Styx	Heathcote
Roofs				
ColourSteel_high	0.06	0.01	0.01	0.05
ColourSteel_low	2.23	0.35	0.49	1.68
Galvanised_high	0.23	0.03	0.05	0.20
Galvanised_low	1.12	0.12	0.26	0.91
MetalOther_high	0.09	0.01	0.02	0.08
MetalOther_low	0.46	0.06	0.11	0.44
MetalTile_high	0.20	0.01	0.04	0.12
MetalTile_low	1.59	0.32	0.41	1.49
NonMetal_high	0.00	0.00	0.00	0.01
NonMetal_low	8.83	0.68	2.49	5.15
Zincalume	0.14	0.20	0.03	0.49
Roads				
Access	4.00	0.80	1.34	3.21
Arterial	6.30	1.10	1.83	6.52
High Volume	1.75	0.51	0.41	1.57
Low Volume	1.94	0.44	0.79	1.64
Primary Collector	10.72	1.06	1.34	2.97
Regional	3.44	0.09	0.36	1.25
Secondary Collector	6.55	0.72	1.24	5.02
Carparks				
Commercial	8.56	0.62	1.07	4.06
Industrial Heavy	12.47	18.16	5.19	36.46
Industrial Light	6.42	0.31	0.83	3.13
Total	**77.10**	**25.60**	**18.31**	**76.45**

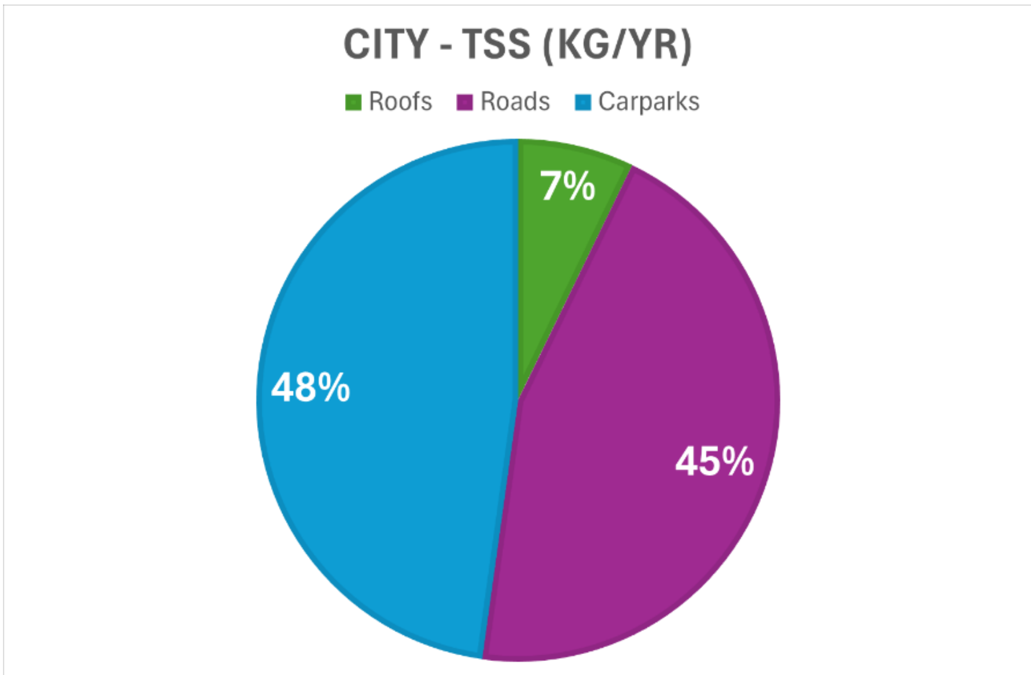
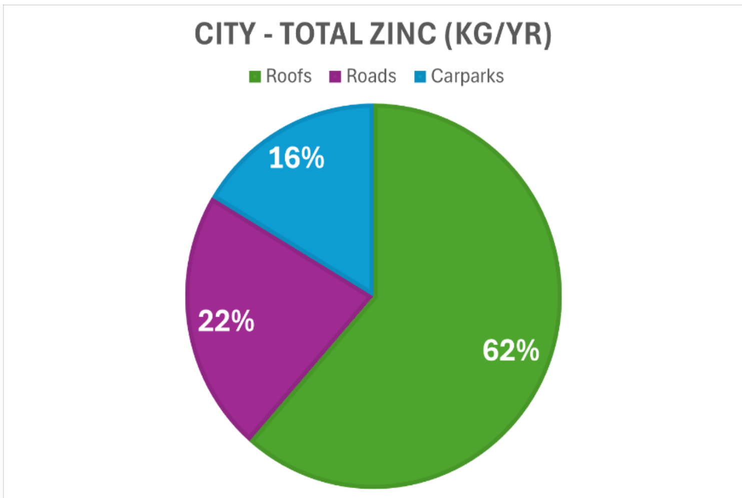


Figure 4-1 – City-level distribution of annual TSS loads (Kg/yr) between roofs, roads, and carparks



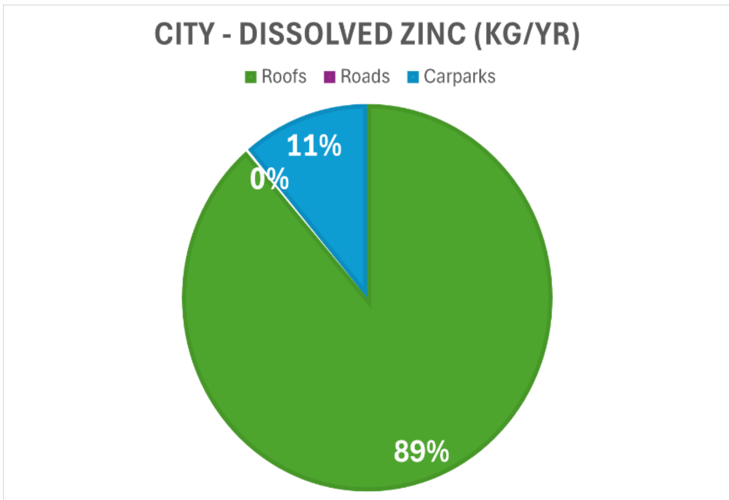
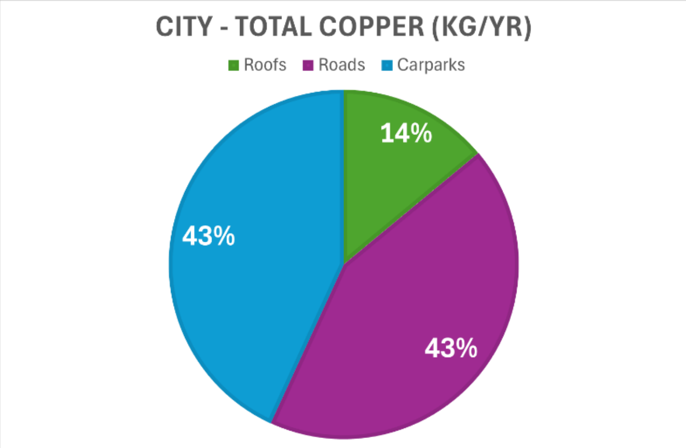


Figure 4-2 - City-level distribution of annual Total Zinc and Dissolved Zinc loads (Kg/yr) between roofs, roads, and carparks



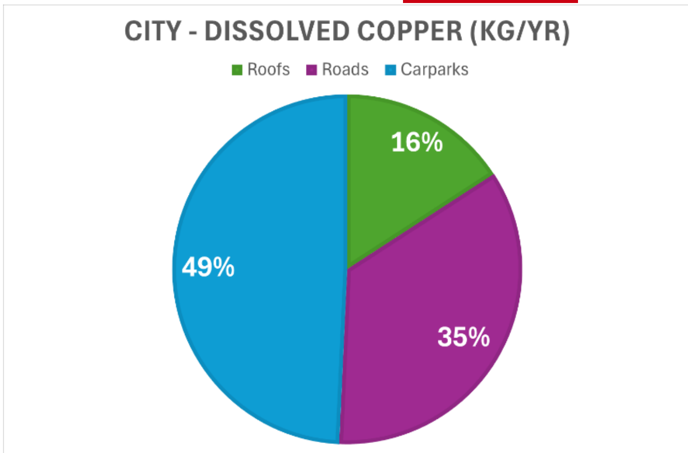


Figure 4-3 - City-level distribution of annual Total Copper and Dissolved Copper loads (Kg/yr) between roofs, roads, and carparks

Results presented in Table 4-4 to Table 4-8 and Figure 4-1 to Figure 4-3 indicate –

- At the City-level, the annual TSS loads generated from the impervious surfaces amount to more than a thousand tonnes, Total Zinc amounts to 10 tonnes , and Total Copper amounts to half a tonne, respectively. Halswell and Styx Catchments contribute approximately 20% of the TSS, Total Zinc, and Total Copper loads generated in the city.
- At the City-level, TSS and Total Copper loads are dominated by roads and carparks. In contrast, Total Zinc loads are dominated by roofs, which contribute more than 60% of the loads generated across the four stormwater catchments.
- At the City-level, dissolved Zinc contribution from roads is negligible. Approximately 89% of the dissolved Zinc load is generated by the roofs. Dissolved Zinc from all the surfaces is about 61% of the Total Zinc.
- At the City-level, dissolved Copper from all the surfaces is about 39% of the Total Copper. Almost 50% of the dissolved Copper is contributed by Carparks.
- Top contributing material for TSS among roofs is Galvanised low, among roads is Secondary collector, and among carparks is Industrial Heavy.
- Top contributing material for Zinc among roofs is Galvanised high, among roads is Arterial, and among carparks is Industrial Light.
- Top contributing material for Copper among roofs is Non metal (low), among roads is Secondary collector, and among carparks is Industrial Heavy.
- Galvanised (low and high) material alone contributes more than 50% of the total TSS load generated by roof surfaces across the four catchments.
- Galvanised (low and high) and Colorsteel (low and high) materials contribute more than 70% of the total Zinc load generated by roof surfaces across the four catchments.

- Along with Non metal roof material, Galvanised (low and high) and Colorsteel (low and high) materials contribute about 80% of the total Copper load generated by roof surfaces across the four catchments.
- Galvanised surfaces (high and low) are the largest contributors to dissolved and total zinc, with Galvanised_high alone contributing over 1,500 kg/year of dissolved zinc.
- Non-metal roofs (e.g., NonMetal_low) surprisingly contribute significantly to TSS and copper, likely due to accumulated particulates rather than leaching.
- Roofs and roads show more variability, depending on material and traffic intensity.

For the Average rainfall year, the annual loads generated from the 161 sub-catchments in the four catchments (before they undergo treatment) were analysed. The results at 10th percentile, 50th percentile, and 90th percentile are summarized in Table 4-9. At the sub-catchment level, results showed that -

- **TSS** - Loads ranged from 1.5 Kg to 55,660 Kg per year. Loads per area ranged from 1.5 g/m^2 to 39 g/m^2 per year. The annual average concentration ranged from 2.8 mg/L to 72 mg/L.
- **Total Zinc** - Loads ranged from 0.12 Kg to 425 Kg per year. Loads per area ranged from 0.1 g/m^2 to 0.4 g/m^2 per year. The annual average concentration ranged from 0.2 mg/L to 0.6 mg/L.
- **Dissolved Zinc** - Loads ranged from 0.1 Kg to 289 Kg per year. Loads per area ranged from 0.04 g/m^2 to 0.28 g/m^2 per year. The annual average concentration ranged from 0.07 mg/L to 0.52 mg/L.
- **Total Copper** - Loads ranged from 1.4 g to 21.8 Kg per year. Loads per area ranged from 1.7 mg/m^2 to 18 mg/m^2 per year. The annual average concentration ranged from 3.1 µg/L to 33 µg/L.
- **Dissolved Copper** - Loads ranged from 0.4g to 9.4 Kg per year. Loads per area ranged from 0.5 mg/m^2 to 8.8 mg/m^2 per year. The annual average concentration ranged from 0.9 µg/L to 16.1 µg/L.

Table 4-9 Sub-catchment level results (Average rainfall year)

Surface Types	TSS	Total Zinc	Dissolved Zinc	Total Copper	Dissolved Copper
Loads (Kg/yr)					
10th Percentile	326.90	5.02	3.12	0.17	0.06
50th Percentile	4,127.05	45.83	25.57	1.96	0.70
90th Percentile	14,481.88	157.04	91.28	7.32	2.88
Load per year ($g/m^2/yr$)					
10th Percentile	8.86	0.12	0.07	0.0051	0.0018
50th Percentile	14.00	0.16	0.10	0.0068	0.0024
90th Percentile	22.32	0.22	0.14	0.0116	0.0050
Average concentration (mg/l)					
10th Percentile	16.28	0.22	0.13	0.0093	0.0032
50th Percentile	25.73	0.30	0.18	0.0125	0.0044
90th Percentile	41.03	0.40	0.26	0.0213	0.0092

4.2 Pollutant Treatment Module Results

In this module, results from the pollutant treatment module are aggregated at three levels: Treatment system level (Treatment Node), Sub-catchment level (Discharge Node), and in the receiving waterways (Reporting Node). Pollutant load and concentration results are available for individual storm events and at the annual level.

At the annual level, for an average rainfall year, in the planning year 2043, when all the treatment systems are active, the average pollutant load reduction observed at the Treatment Nodes is summarized in Table 4-10.

Table 4-10 Average load reduction (%) at Treatment Nodes

Contaminant	Avon	Halswell	Styx	Heathcote	City
TSS	64.79	58.69	65.18	62.74	63.15
Total Zinc	33.15	18.21	26.01	21.93	25.32
Total Copper	45.93	32.71	41.17	36.85	39.61

A summary of pollutant reductions at the catchment level is presented in the following tables (Table 4-11 to Table 4-14). In these tables, only the loads entering the waterways after treatment are taken into consideration. Loads which get infiltrated after treatment are not considered.

Table 4-11 Average load reduction (%) across the years – Avon Catchment

Contaminant	2018 (%)	2023 (%)	2028 (%)	2043 (%)
TSS	16.04	17.13	23.33	28.99
Total Zinc	8.84	9.34	14.29	16.66
Total Copper	11.71	12.38	18.16	22.02

Table 4-12 Average load reduction (%) across the years– Halswell Catchment

Contaminant	2018 (%)	2023 (%)	2028 (%)	2043 (%)
TSS	67.22	75.71	76.89	76.90
Total Zinc	46.02	51.97	52.71	52.81
Total Copper	57.55	63.65	64.80	64.82

Table 4-13 Average load reduction (%) across the years– Styx Catchment

Contaminant	2018 (%)	2023 (%)	2028 (%)	2043 (%)
TSS	23.09	29.10	29.10	39.69
Total Zinc	8.24	11.51	11.51	13.11
Total Copper	15.98	20.45	20.45	25.99

Table 4-14 Average load reduction (%) across the years– Heathcote Catchment

Contaminant	2018 (%)	2023 (%)	2028 (%)	2043 (%)
TSS	52.30	52.37	52.37	52.37
Total Zinc	22.89	22.93	22.93	22.93
Total Copper	42.17	42.25	42.25	42.25

In the planning year 2043, when all treatment systems are active, for an average rainfall year, the annual pollutant load reduction in sub-catchments with a single treatment system averages about 41% for TSS, 29% for Total Zinc, and 34% for Total Copper, respectively. The average increases to 64% for TSS, 32% for Total Zinc, and 49% for Total Copper, respectively, when the sub-catchments have more than ten active treatment systems.

Reporting Nodes represent locations that are distributed along the course of the waterways from the upstream reaches to the mouth of the river estuary. At each of these locations, we calculated the pre-treated load and concentration, as well as the post-treated load and concentration, for TSS, Total Zinc, and Total Copper, respectively.

Table 4-15 compares the average annual pollutant load reduction per unit area (m^2) in the receiving waterways for a wet rainfall year between planning years 2018 and 2043. As mentioned earlier, only 80% of the treatment systems were active in 2018, compared to all of them becoming active in 2043. The table shows that the annual pollutant load reduction increased from 2018 to 2043, with the highest increase observed for TSS loads in the Styx River Catchment.

Table 4-15 Average annual pollutant load reduction per unit area (m^2) in the receiving waterways

Catchments	TSS (%)		Total Zinc (%)		Total Copper (%)	
	2018	**2043**	**2018**	**2043**	**2018**	**2043**
Avon	27.13	35	29.66	43.14	23.84	30.34
Halswell	49.6	58.66	13.62	18.61	29.15	35.61
Styx	18.84	32.18	7.3	11.43	12.59	20
Heathcote	76.97	77.15	57.32	57.42	70.94	71.11

5 Scenario Manager Results

In the Scenario Manager module, users can simulate various "what-if" scenarios to see how changing single or multiple treatment types or adjusting land use intensification in any of the sub-catchments affects pollutant loads and concentrations in downstream waterways, leading to evidence-based decisions.

The module enables users to model and compare multiple scenarios or strategies side by side, allowing them to select the most effective course of action. Users can model future growth scenarios, such as the doubling of impervious surface coverage or the non-implementation of a planned treatment system infrastructure and assess the downstream effects of these decisions.

The scenario manager facilitates easier collaboration among stakeholders and provides quick responses to queries. With clear visualizations, data-backed estimates, and outcome comparisons, this module works effectively for cross-functional planning and presentations. Catchment managers can utilise this module to engage residents in virtual catchment simulations and solicit their preferences to enhance the water quality and ecosystem health of the waterways.

In the Scenario Manager application, as shown in Figure 5-1, the user has the option to replace existing treatment systems in the Worsleys Spur sub-catchment, from First flush (dry) into another treatment system, such as First flush (dry) + wetland.

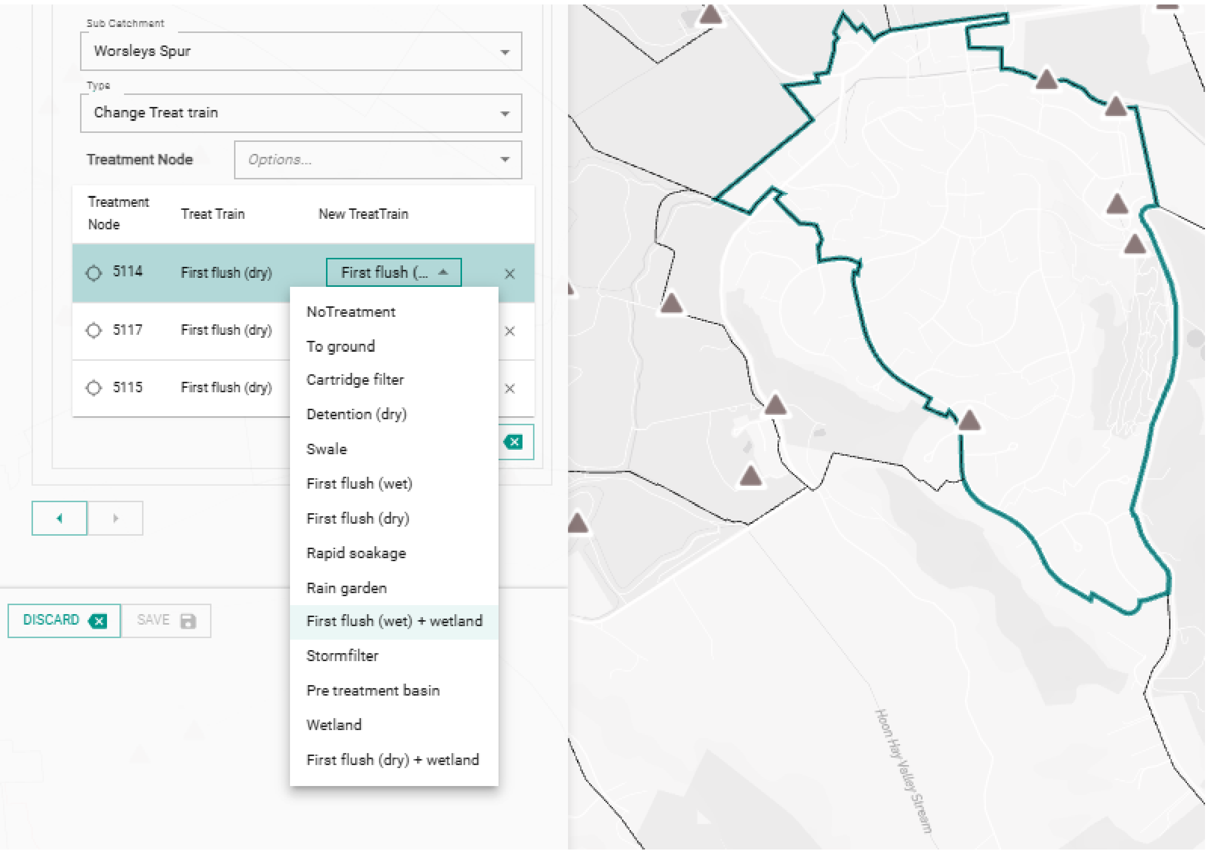


Figure 5-1 Scenario Manager example 1 – Option to change the treatment system in a sub-catchment in the Heathcote River Catchment

In the Scenario Manager application, as shown in Figure 5-2, the user also has the option to select a single or multiple surfaces in a sub-catchment and assign a load reduction/increase factor to simulate deintensification/intensification, respectively.

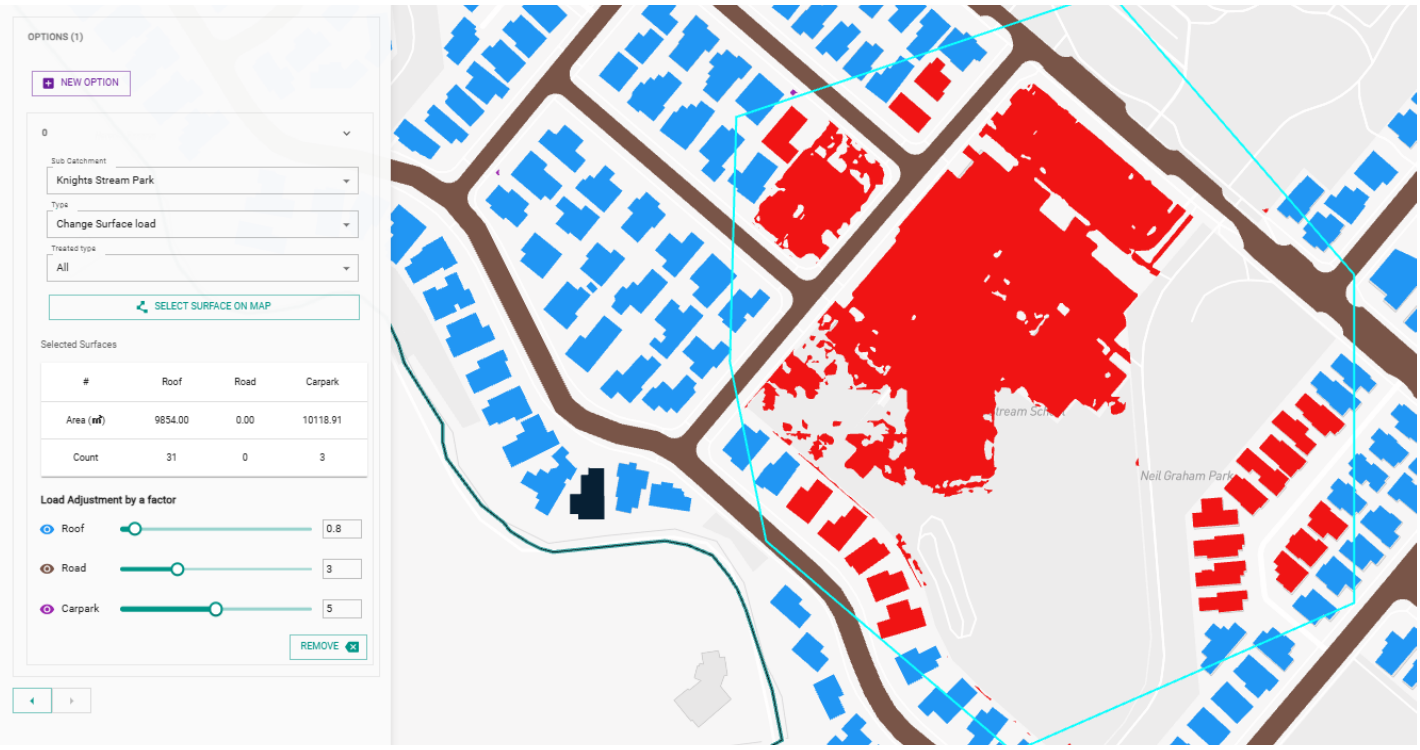


Figure 5-2 Scenario Manager example 2 – Option to select a group of surfaces in a sub-catchment in the Halswell River Catchment

The scenario manager module offers additional benefits, including –

- Assess the impact on downstream waterways by selecting up to 10 treatment options in a single scenario.
- Compare whether making changes in the upstream sub-catchments makes more impact at the river mouth than the downstream sub-catchments.
- Quantify the impact of intensification (such as more buildings and roads in a sub-catchment) on the water quality in the receiving waterways.
- Investigate the impact of decommissioning a few treatment systems on the downstream pollutant load and concentration.
- Estimate the amount of load reduction required to meet regulatory thresholds of pollutant concentration in the waterways.

Users can clone any scenario and design additional options to test for combinatory effects.

The scenario manager facilitates easier collaboration among stakeholders and provides quick responses to queries. With clear visualizations, data-backed estimates, and outcome comparisons, this module works effectively for cross-functional planning and presentations. Catchment managers can use this module to engage residents in virtual catchment simulations and gauge their preferences to improving the water quality and ecosystem health of the waterways.

6 Discussion

In the previous section, we learnt that ICCM provides contaminant loads and concentrations for 245 rainfall events (and annual sums) observed in three different rainfall years for every impervious surface mapped in the 161 sub-catchments distributed across the four major river catchments in Christchurch City. ICCM links pollutant generation from individual surfaces to resultant instream concentrations, compares pollutant loads and concentrations before and after the application of treatment systems, and features options to test water quality impact assessment.

The ICCM result database has more than 280 million records of load, load per area, and average concentration values generated by the Pollution Generation module. Results are available at a surface level, treatment node level, discharge node level, and reporting node level. Results can be used to address the following queries –

- Which untreated subcatchment has the highest source of contaminant loads?
- Where is the highest concentration of untreated, poor-quality roofs?
- What are the effects on each waterway from development?
- What are the net effects of intensification on water quality in the waterways?

7 Summary

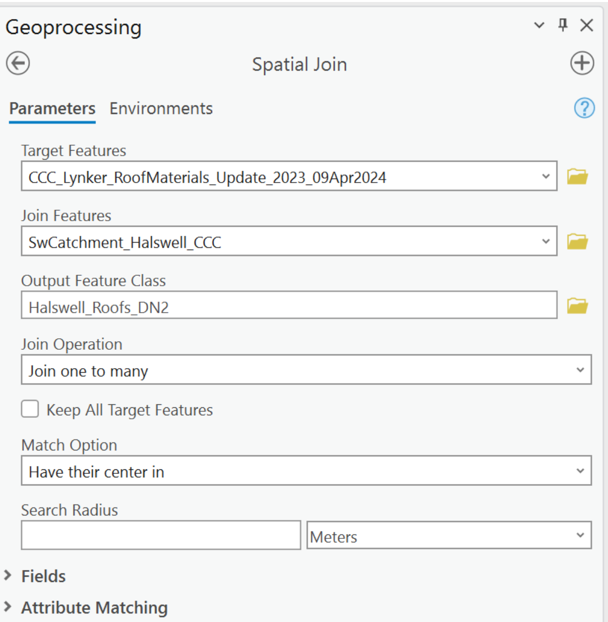
The Christchurch City Council, University of Canterbury, and DHI co-developed the "Instream Contaminant Concentration Model (ICCM)" to enable city-scale urban stormwater quality modelling, thereby improving the health of Christchurch's urban waterways. ICCM highlights the following benefits:

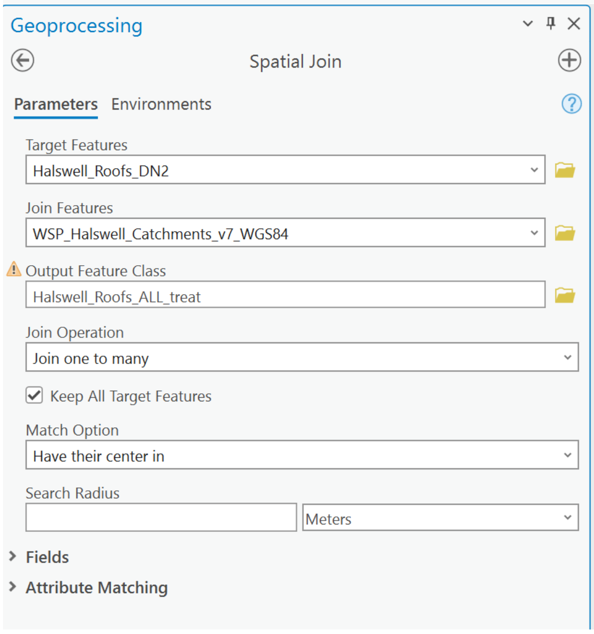
- ICCM quantifies and visualizes the impacts of diffuse pollution (urban stormwater) on the receiving environment, including spatially and for different events and years.
- ICCM can be accessed online and uses a cloud-based web portal. Compared to other modelling software available on the market, it is intuitively easy to use.
- Complex critical information is summarized for easy access for all stakeholders.
- ICCM provides a visualization platform that unlocks the science, offering an improved understanding of water quality and facilitating robust decision-making to ensure cost-effective stormwater treatment solutions can be implemented without compromising the environmental values of urban receiving waterways.
- ICCM reduces the cost and time associated with optioneering for infrastructure scenario planning.
- Through its graphic-rich environment, ICCM can facilitate stakeholder engagement and acceptance of recommended stormwater treatment options.

A Appendix - Process for linking surfaces in a catchment to their discharge nodes (DN) and treatment nodes (TN)

Roofs

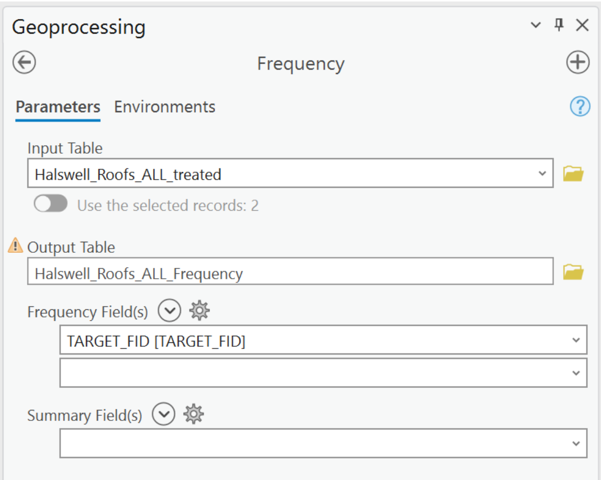
1. Spatial join with all catchments (centre in) – note that for this first one remove "Keep All Target features"
2. Spatial join with treated catchment (centre in) – for this one select "Keep All Target Features"





NOTE: under Fields, make sure you Edit/Reset to ensure all fields are captured.

3. Remove polygon duplicates and only keep the polygon linking with the immediate (highest) treatment level.
    a. Run frequency tool on "Target FID" to find duplicates. Note that using the Target_FID_1 works best.



    b. Join the output table from the Frequency tool with the original roof surfaces. There should now be a frequency column in the Attribute table.
    c. Save and create a new file with the join (use Right click data / Export).
    d. Assign a value of 1 to those rows in the attribute table which are duplicated and which we do not need (those with values of Treatment level lower than those of the Frequency). Assign 0 to rows we want to keep, which link to their first treatment level or discharge point (Table 1).

Create a Field in the attribute table and label it as "Duplicate". Then use this code to populate the field (Calculate Field):

```
isdup(!FREQUENCY!,!TreatLevel!)
def isdup(FREQUENCY, TreatLevel):
  if (FREQUENCY > TreatLevel):
    return 1
  else:
    return 0
```

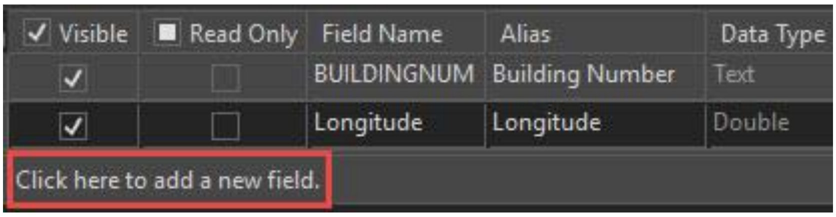
    e. Delete all rows with Duplicate equal to 1. Save file.

Table 1. Example of fields used to identify those rows want to keep (0 values under duplicate) and those we will later delete (1 values under Duplicate).

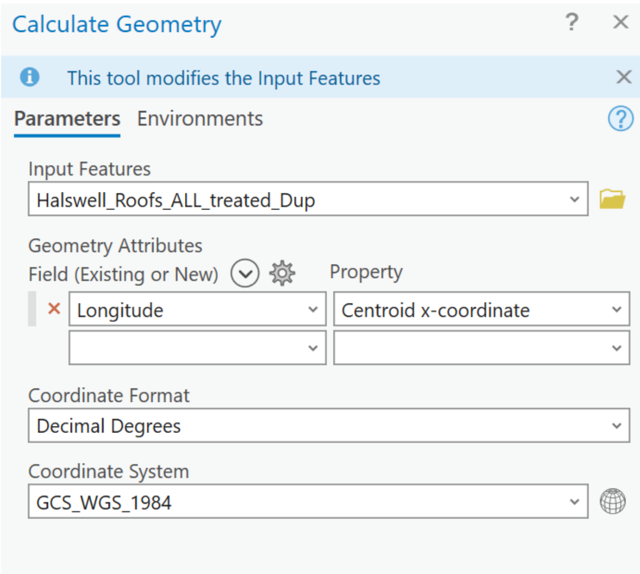
Frequency	Treatment level	Duplicate
1	1	0
2	1	1
2	2	0
3	2	1
3	1	1
3	3	0

4. Add Latitude and Longitude coordinates to the Attribute table.
    a. Click Add Field in the attribute table.

b. Name the new field Longitude, and change the data type to Double.
c. Click “Click here to add a new field” and name the field Latitude.
d. Change the data type to Double and click Save on the Fields ribbon tab.
e. Close the Fields View tab.



f. Right-click the Longitude or Latitude field header in the attribute table, and select Calculate Geometry to open the Calculate Geometry geoprocessing pane.
g. Select Longitude from the drop-down for Field. Select Centroid x-coordinate from the drop-down for Property.
h. Select Latitude from the drop-down for Field. Select Centroid y-coordinate from the drop-down for Property.
   - For Coordinate Format, leave the parameter as default.
   - Select Current Map [Map] from the drop-down for Coordinate System.
   - Click OK

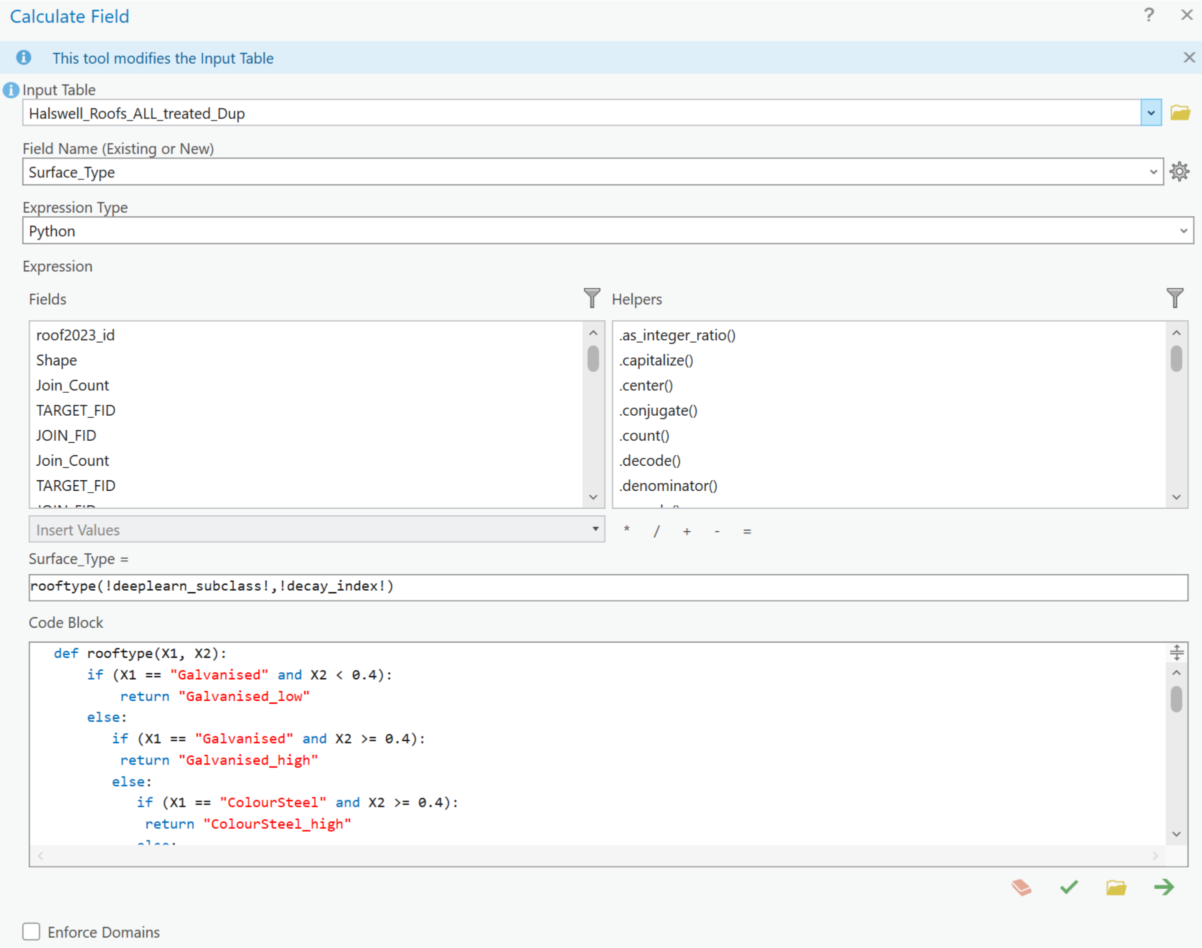


5. Create Field of surface type:

Add field, name it Surface_Type, set it as Text. Then use the code below:
rooftype(!deeplearn_subclass!,!decay_index!)

```
def rooftype(X1, X2):
   if (X1 == "Galvanised" and X2 < 0.4):
      return "Galvanised_low"
   else:
     if (X1 == "Galvanised" and X2 >= 0.4):
      return "Galvanised_high"
     else:
       if (X1 == "ColourSteel" and X2 >= 0.4):
        return "ColourSteel_high"
```

```
else:
 if (X1 == "ColourSteel" and X2 < 0.4):
  return "ColourSteel_low"
 else:
  if (X1 == "MetalOther" and X2 < 0.4):
   return "MetalOther_low"
  else:
   if (X1 == "MetalOther" and X2 >= 0.4):
    return "MetalOther_high"
   else:
    if (X1 == "MetalTile" and X2 < 0.4):
     return "MetalTile_low"
    else:
     if (X1 == "MetalTile" and X2 >= 0.4):
      return "MetalTile_high"
     else:
      if (X1 == "NonMetal" and X2 < 0.4):
       return "NonMetal_low"
      else:
       if (X1 == "NonMetal" and X2 >= 0.4):
         return "NonMetal_high"
       else:
        if (X1 == "Zincalume"):
         return "Zincalume"
        else:
          return "ColourSteel_low"
```



6. Create Field of treatment level:

Add Field named Treatment_Level as text.

```
treat(!TreatLevel!)
def treat(X1):
    if (X1 == 1 or X1 == 2 or X1 == 3 or X1 == 4):
        return "Treated"
    else:
        return "Untreated"
```

7. Create Field of Material.

Add Field named Material. Set all rows to “Roof”

8. Rename Fields:

“Surface_Type”
"Material"
"Shape_Area"
"Treatment_node"
“Discharge_node”
"Catchment_name"
"Sub_catchment_name"

"Treatment_level"
"Longitude" (polygon centre point in WGS84 degrees)
"Latitude" (polygon centre point in WGS84 degrees)

9. Export of GeoJSON. Feature to JSON – select WGS84, GeoJSON, etc.

Roads

1. Use pairwise Clip between SWcatchment and road layer to "cut" roads at the boundary
2. Split roads into segments by subcatchment
    a. Edit
    b. Split
    c. Input feature: SwCatchment (select all rows in the attribute table)
    d. Target feature: RoadNew_catch (select all rows in the attribute table)
    Note: (make sure Map and individual layers have same coordinate system)
3. Do the same for WSP catchments (repeat 2).

4. Do a spatial join (as in 1 and 2 of the Roof's section) with the SWCathments and WSP catchments.

5. Repeat steps 3 in Roof section above to remove duplicate polygons.

6. Spatial Join of ONRC line data with Roads to get an improved Surface type if necessary.

7. Add long/Lat and other fields to the database as per Roof's section.

8. Remove road areas less than 0.5m2 (slivers and others…) if necessary

9. Rename Fields:

"Surface_type"
"Road_type"
"Area_roads"
"Treatment_node"
"Discharge_node"
"Catchment_name"
"Sub_catchment_name"
"Treatment_level"
"Longitude" (polygon centre point in WGS84 degrees)
"Latitude" (polygon centre point in WGS84 degrees)

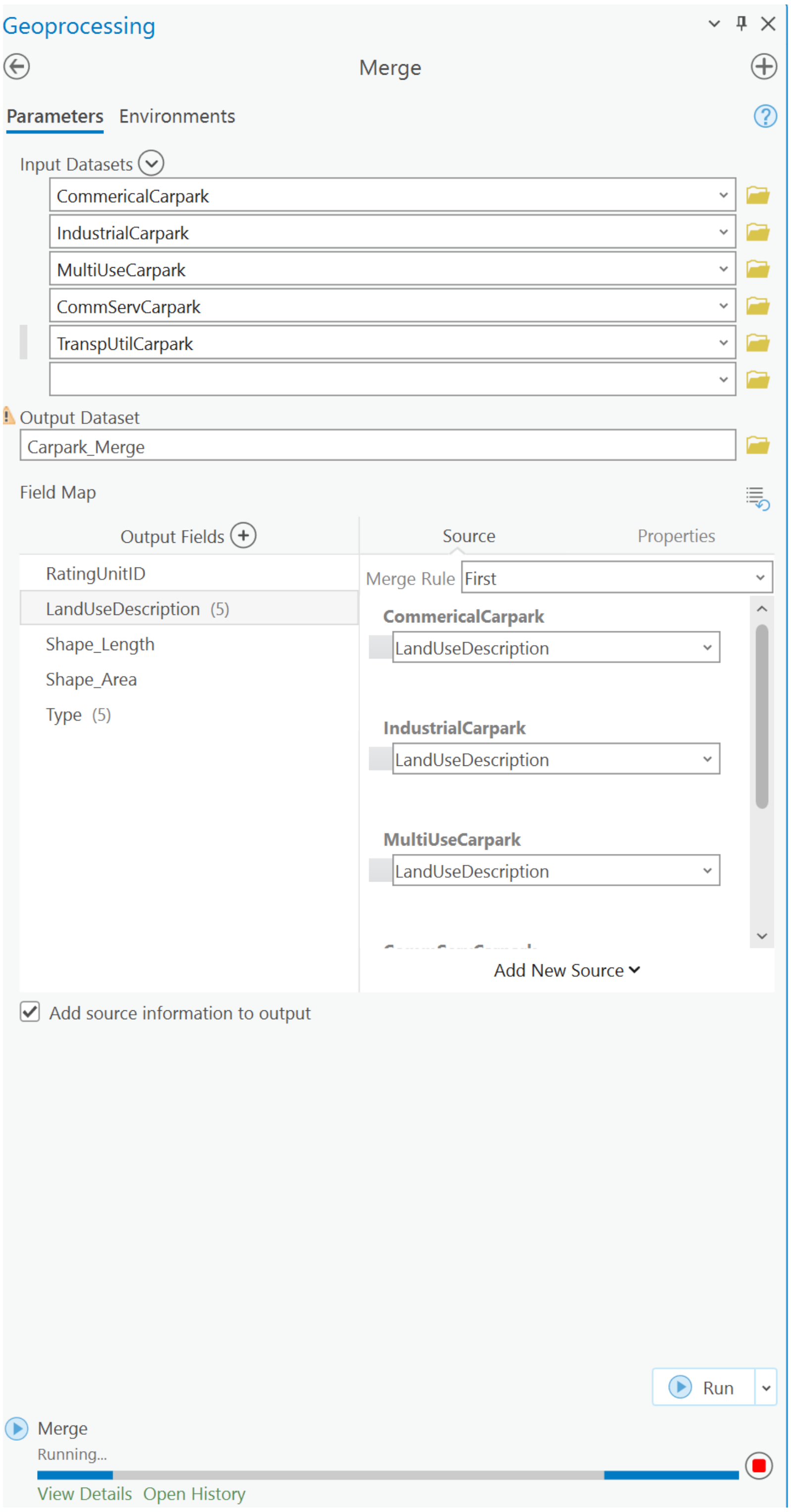
10. Export of GeoJSON. Feature to JSON – select WGS84, GeoJSON, etc.

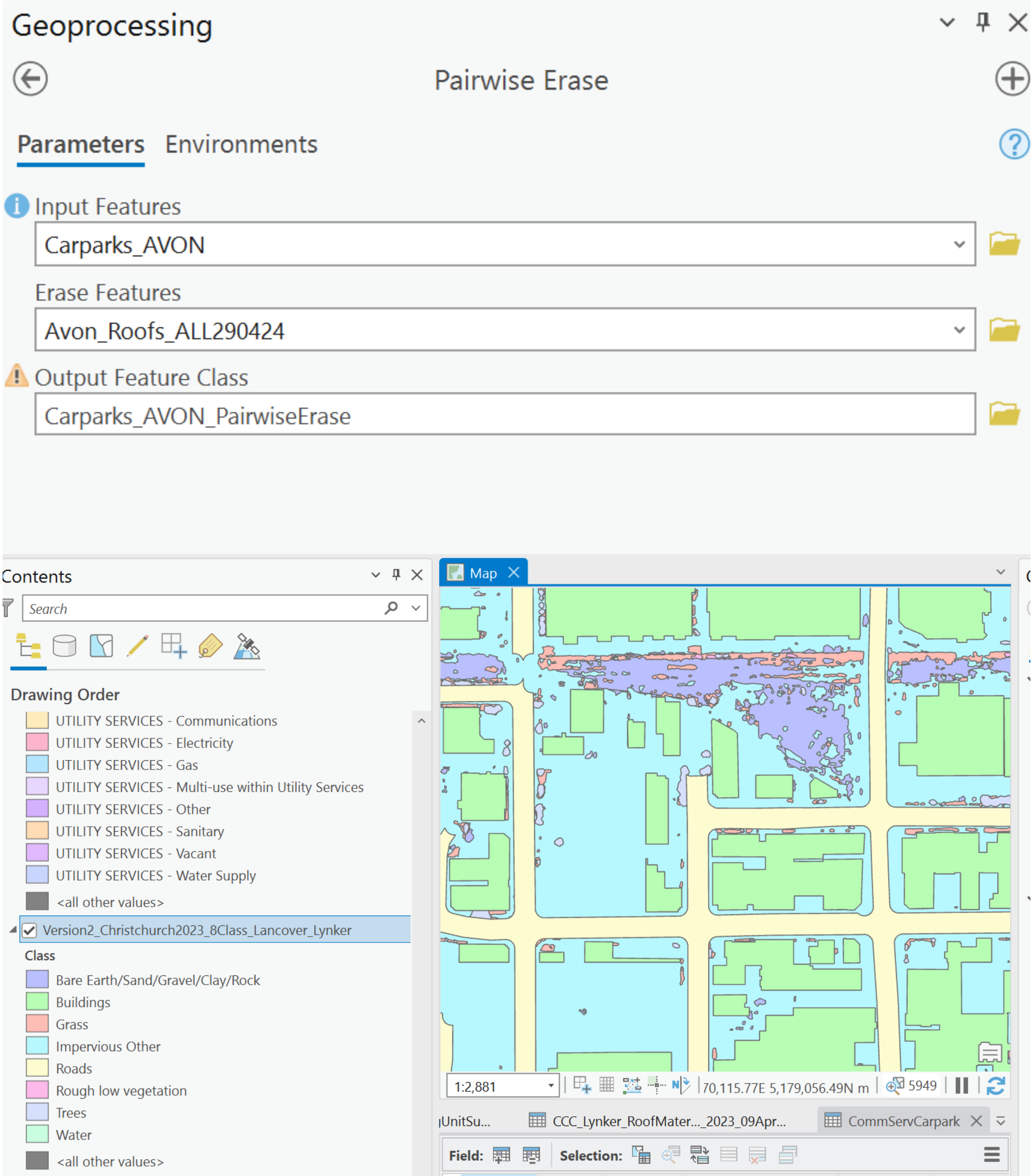
Carparks

1. Use zoning and Lynker impervious other layer to create carpark polygons
2. Use table below to assign carparks to MEDUSA type inputs

Zoning/Lynker carparks	MEDUSA type
Industrial	Industrial Heavy
Commercial	Commercial
Multiuse	Commercial
CommServ	Industrial Light
TranspUtil	Industrial Light

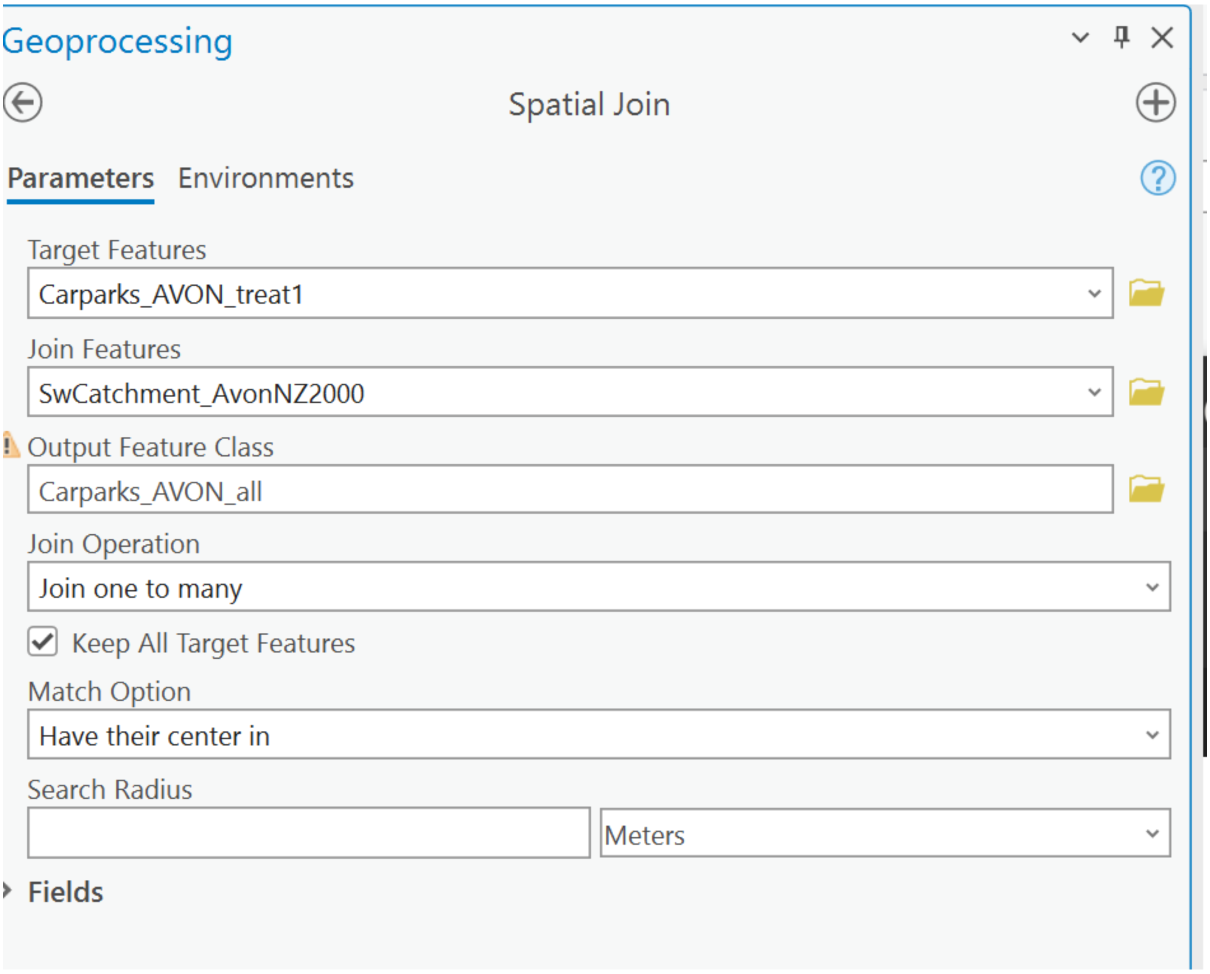
3. Join all layers into one file using the Merge tool (image below)
4. Remove any overlap between carparks and roof by using pairwise Erase. This needs to be done because the original Lynker landuse layer is older than the new roof layer.

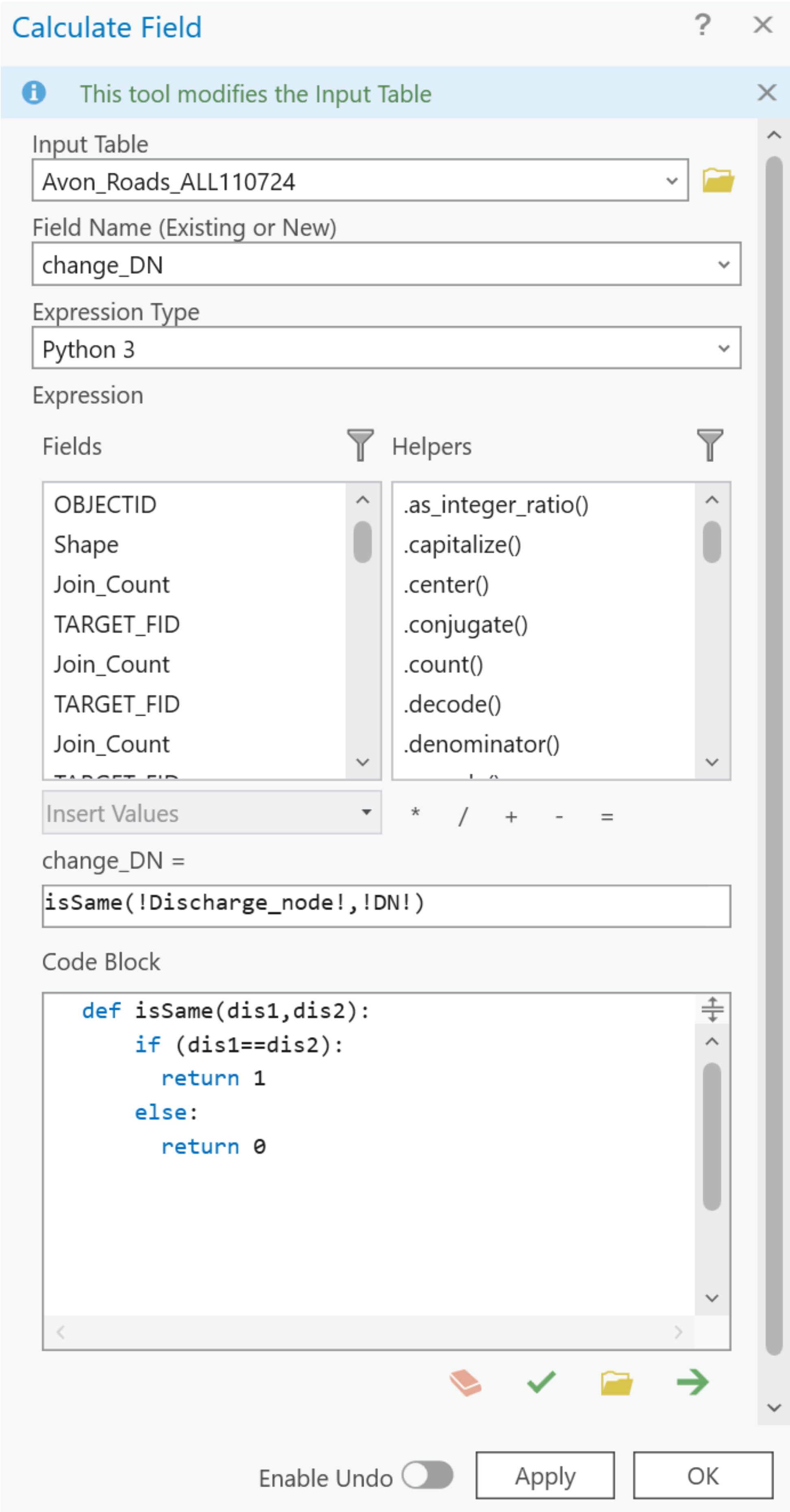

Geoprocessing
Merge
Parameters
Environments
Input Datasets
CommericalCarpark
IndustrialCarpark
MultiUseCarpark
CommServCarpark
TranspUtilCarpark
Output Dataset
Carpark_Merge
Field Map
Output Fields
Source
Properties
RatingUnitID
LandUseDescription (5)
Shape_Length
Shape_Area
Type (5)
Merge Rule
First
CommericalCarpark
LandUseDescription
IndustrialCarpark
LandUseDescription
MultiUseCarpark
LandUseDescription
Add New Source
Add source information to output
Run
Merge
Running...
View Details
Open History

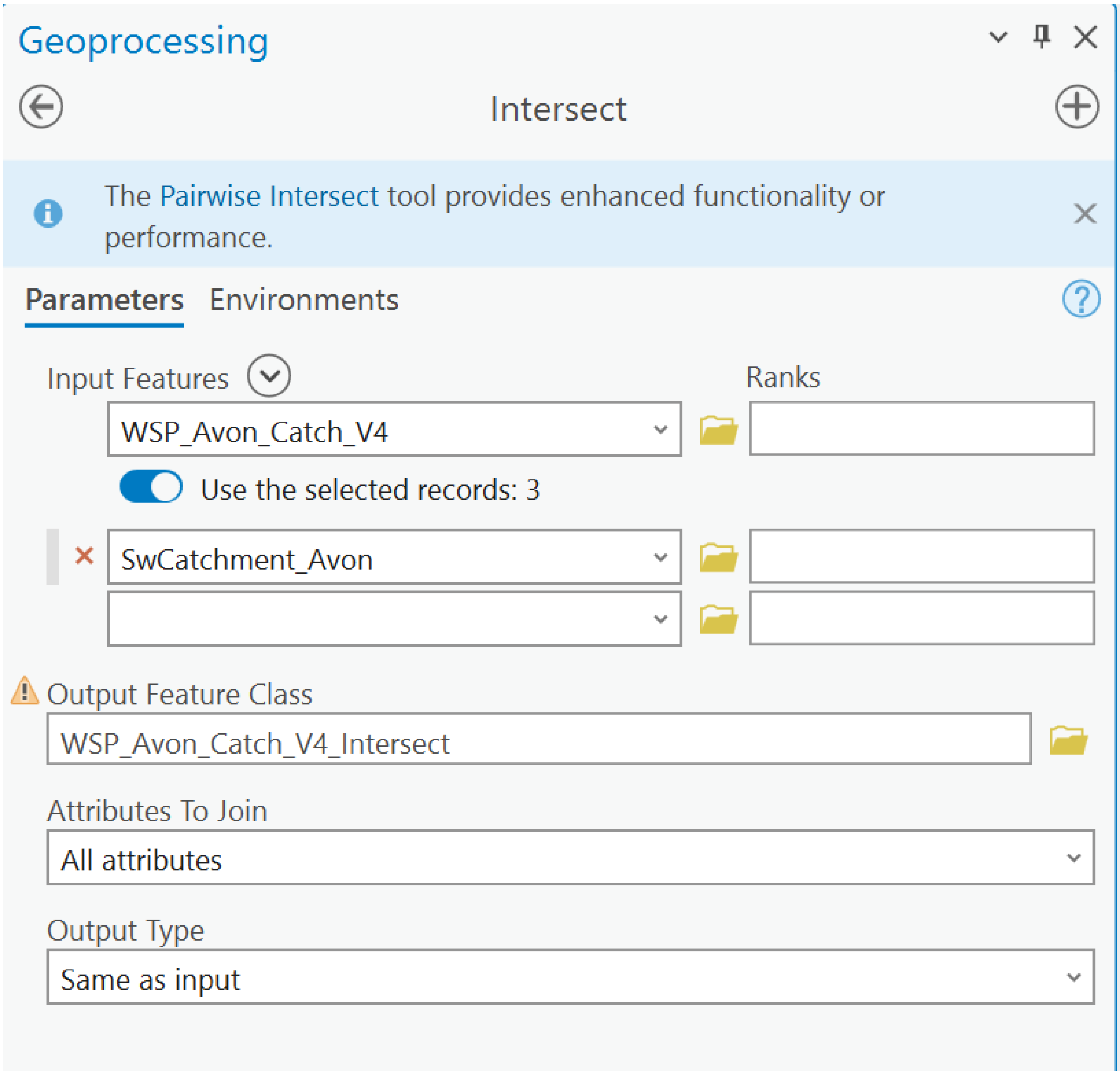


5. Spatial join to treated and untreated catchments as previously done
6. ID duplicates as previously done
7. Create Lat/Long, Treatment_Level, and Material fields.
8. Rename to:
    - “Carpark_Type”
    - “Surface_Type”
    - "Shape_Area"
    - "Treatment_node"
    - “Discharge_node”
    - "Catchment_name"

- "Sub_catchment_name"
- "Treatment_level"
- "Treatment" – (untreated and treated)
- "Longitude" (polygon centre point in WGS84 degrees)
- "Latitude" (polygon centre point in WGS84 degrees)

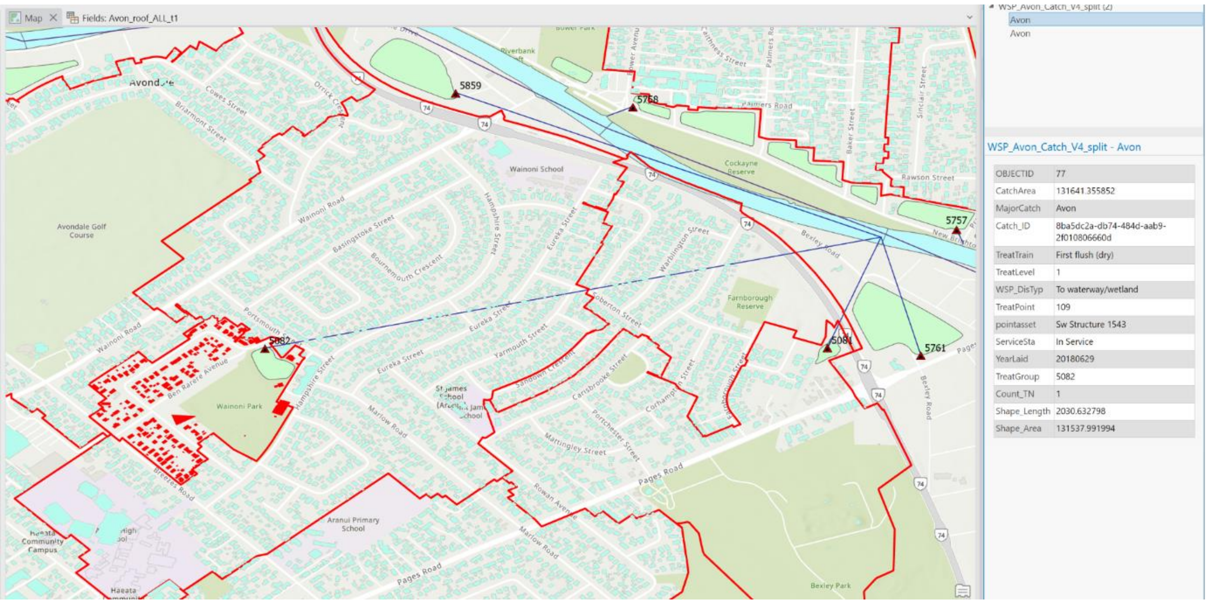



Calculate Field
This tool modifies the Input Table
Input Table
Avon_Roads_ALL110724
Field Name (Existing or New)
change_DN
Expression Type
Python 3
Expression
Fields
Helpers
OBJECTID
Shape
Join_Count
TARGET_FID
Join_Count
TARGET_FID
Join_Count
.as_integer_ratio()
.capitalize()
.center()
.conjugate()
.count()
.decode()
.denominator()
Insert Values
* / + - =
change_DN =
isSame(!Discharge_node!,!DN!)
Code Block
def isSame(dis1,dis2):
if (dis1==dis2):
return 1
else:
return 0
Enable Undo
Apply
OK

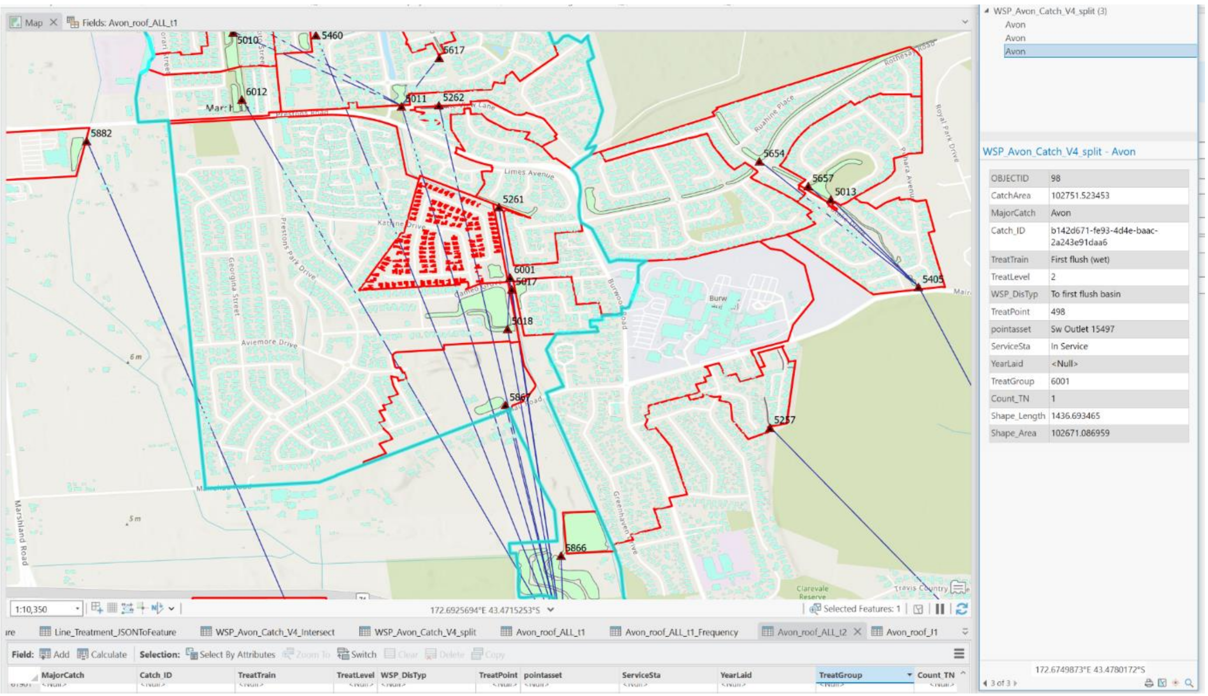


Routing of surfaces to of dummy treatment.
1. Split the affected catchments to ensure creating of new dummy catchments (i.e. 5XXX_1). Use editing tool and split tool (select treated and untreated catchment to create a split). Note that small catchments may be created due to minor inconsistencies between catchment delineations.
2. Check treatment levels are correctly assigned to each catchment. If a subcatchment is nested inside one or more catchments, it should be appropriately assigned a treatment level (1,2, 3 or 4). For example:

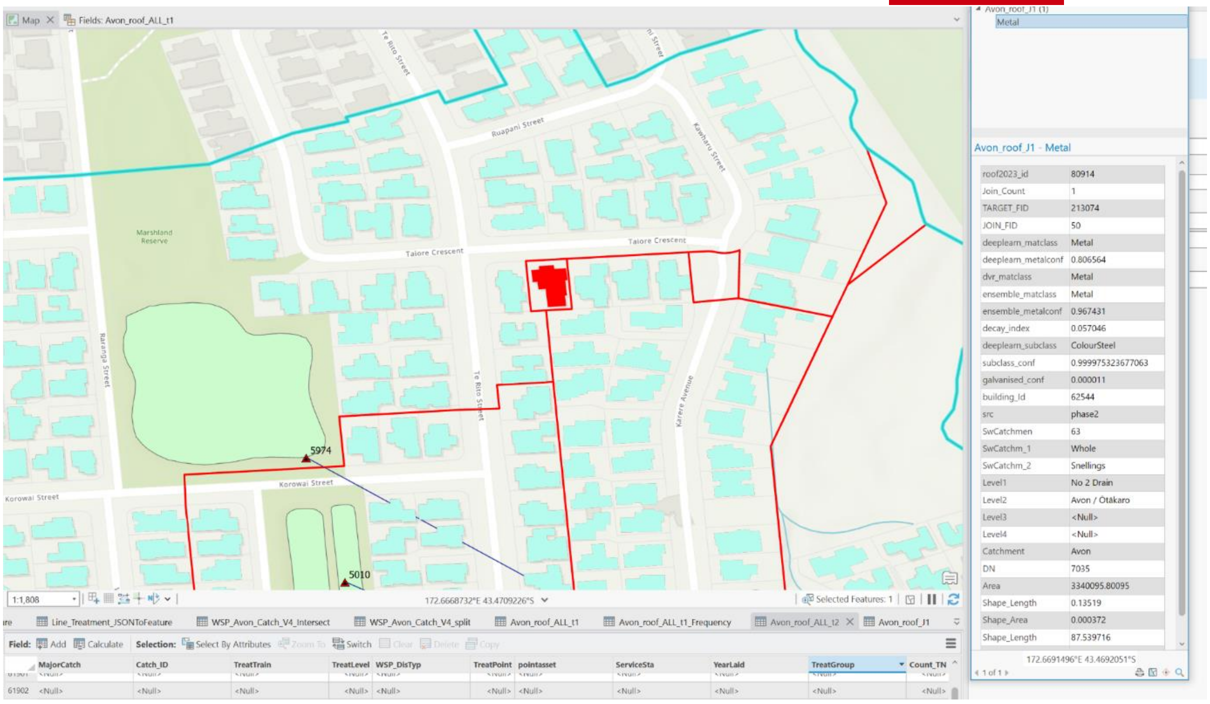
a. Treatment level for WSP treated subcatchments were not set right (two overlapping subcatchments had the same treatment level). Changed it from 1 to 2 for the one discharging to 5082.



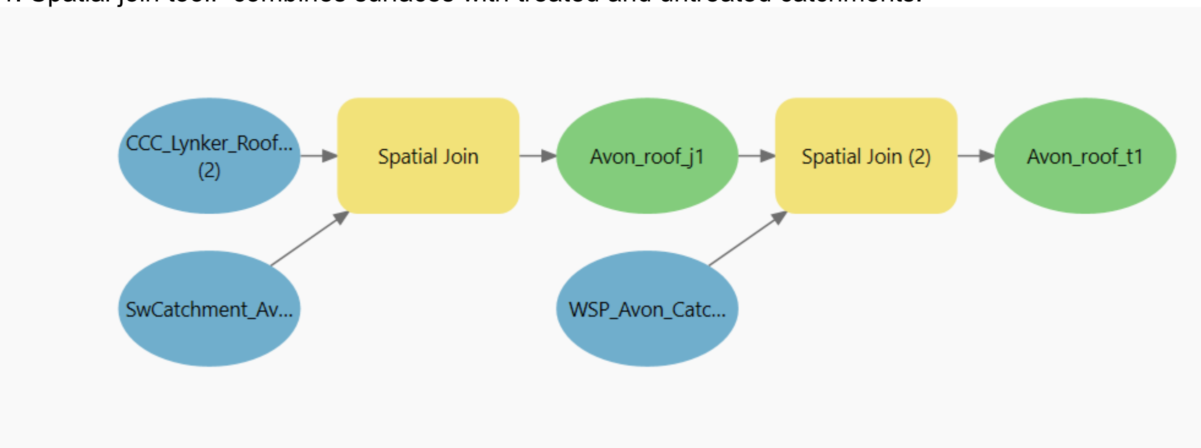
b. Similar issue… Treatment level for WSP treated subcatchment below were not set right (two overlapping subcatchments had the same treatment level). Changed treatment level to 3 from 2 for 6001



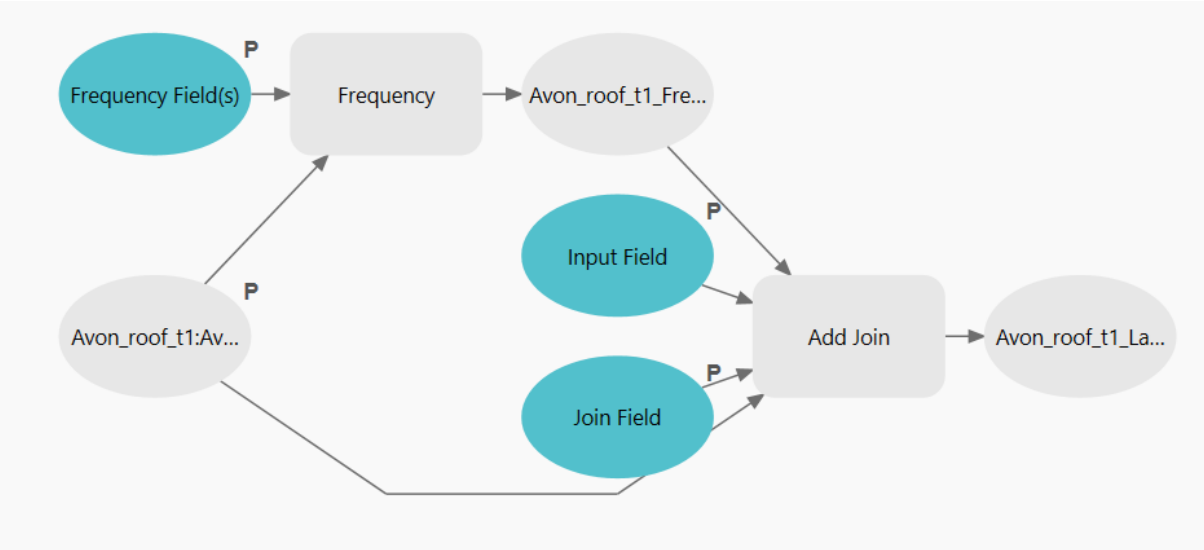
c. The surface below was under 3 nested subcatchment. Manually fixed it to discharge to 5460.



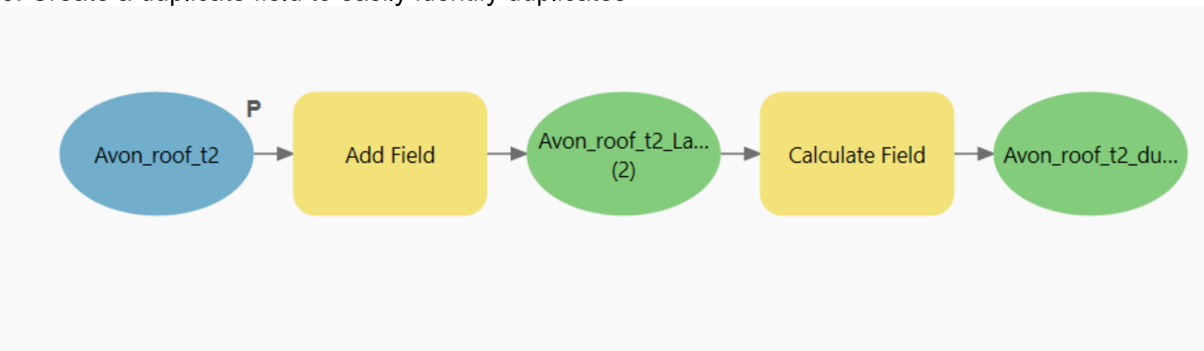
To automate the process, a series of ArcGIS modelling tools were created.
1. Spatial join tool: combines surfaces with treated and untreated catchments.



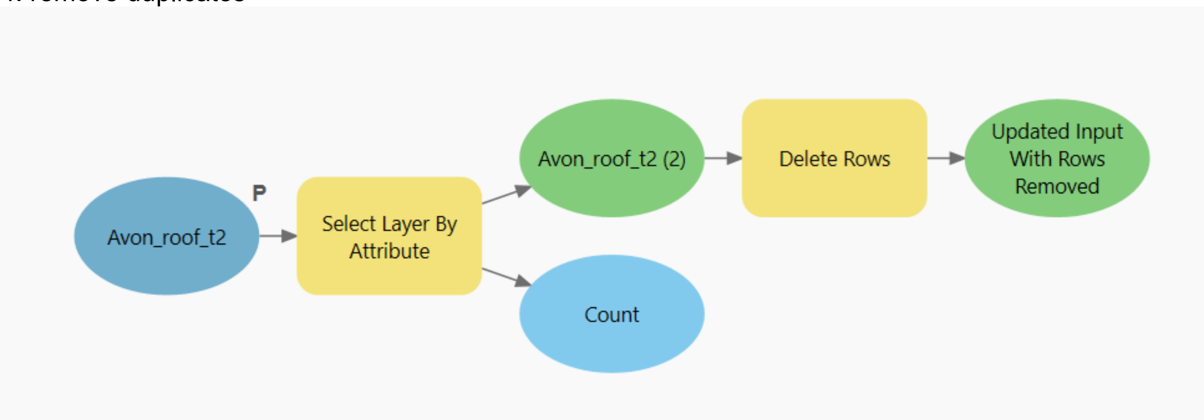
2. Create a frequency table to identify overlapping surfaces (due to nesting of catchments). Join that table to the surface map to identify those surfaces that are overlapping.



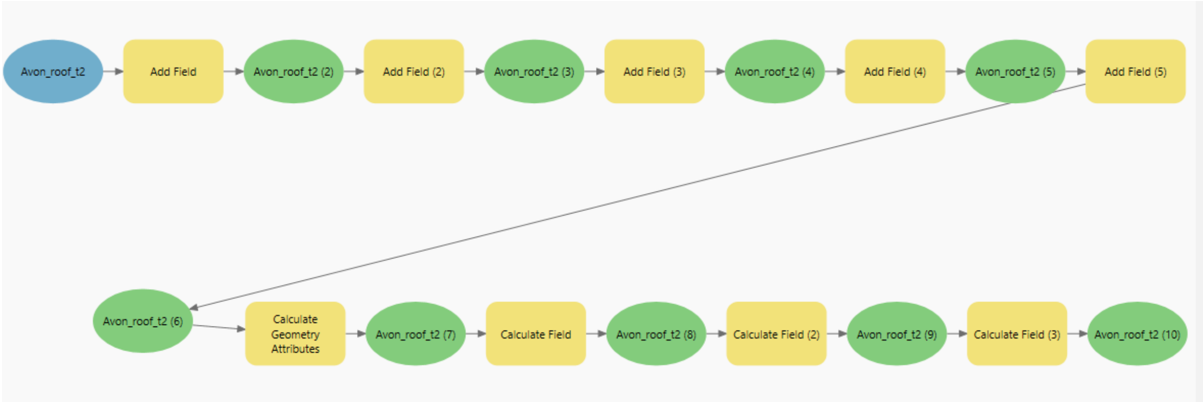
3. Create a duplicate field to easily identify duplicates



4. remove duplicates



5. add required fields to surface table and calculate attributes for these fields (various fields).


Avon_roof_t2
Add Field
Avon_roof_t2 (2)
Add Field (2)
Avon_roof_t2 (3)
Add Field (3)
Avon_roof_t2 (4)
Add Field (4)
Avon_roof_t2 (5)
Add Field (5)
Avon_roof_t2 (6)
Calculate Geometry Attributes
Avon_roof_t2 (7)
Calculate Field
Avon_roof_t2 (8)
Calculate Field (2)
Avon_roof_t2 (9)
Calculate Field (3)
Avon_roof_t2 (10)