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Prioritising high-risk urban stormwater sub-catchments in Nelson: data review, risk assessment and method development

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Prioritising high-risk urban stormwater sub-catchments in Nelson: data review, risk assessment and method development

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Prepared for Nelson City Council

CAWTHRON

Glossary

Term	Definition
Attribute	A measurable characteristic of fresh water (including physical, chemical and biological properties) that supports values.
Catchment	An area of land where the stormwater run-off flows to a discharge point at a watercourse or the sea.
Contaminant	Any substance (liquid, solid, micro-organisms) that is likely to change the physical, chemical or biological condition of the land or water into which it is discharged.
Ecosystem	The dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
Environment	Ecosystems and their constituent parts (including people and communities), all natural and physical resources and amenity values, as well as the social, economic, aesthetic and cultural conditions that affect or are affected by these.
First flush	Initial surface run-off of a storm event, which usually contains more contaminants than those present in run-off later in the storm.
Freshwater Management Unit	Waterbody, multiple waterbodies or any part of a waterbody determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes.
Impermeable surface	Hard surface area that prevents or retards the entry of water into the soil. Examples include roofs, car parks and roads.
Macroinvertebrate Community Index	An indicator of stream ecological health. Higher index scores indicate better stream conditions.
Permeable pavement	Surface that allows water to pass through voids in the paving material and / or between paving units while providing a stable, load-bearing surface.
Run-off	Water flows that result from rainwater and is not absorbed by permeable surfaces or that which falls on impermeable surfaces.
Stormwater	Run-off water (excluding water in a river) that is diverted through channels or pipes for discharge into rivers, streams or the coastal marine area.
Surface water	Any body of water above ground, including streams, rivers, wetlands and creeks.
Urban area	Residential zone, inner city zone, suburban commercial zone, industrial zone and any part of the open space and recreation zone that is surrounded by one of these zones.
Urban streams	Parts of a river or stream within the urban area. In the context of this report, these include Orphanage Creek, Orchard Creek, Poorman Valley Stream, Arapiki Stream, Jenkins Creek, York Stream, Maitai River, The Brook, Oldham Creek and Todd Valley Stream.

Abbreviations

Term	Definition
C-CALM	Catchment Contaminant Annual Loads Model
C-CLM	Christchurch Contaminant Load Model
CLUES	Catchment Land Use for Environmental Sustainability
CREST	Coastal Receiving Environment Scenario Tool
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
FMU	Freshwater management unit
FWMT	Freshwater Management Tool
GIS	Geographic information system
LAWA	Land, Air, Water Aotearoa
LID	Low impact design
LiDAR	Light detection and ranging
LSPC	Loading Simulation Program in C
MEDUSA	Modelled Estimates of Discharges for Urban Stormwater Assessments
MCI	Macroinvertebrate Community Index
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NCC	Nelson City Council
NPS-FM	National Policy Statement for Freshwater Management 2020 (amended December 2025)
NRMP	Nelson Resource Management Plan
REC	River Environment Classification
RES	Receiving environment sensitivity
RMA	Resource Management Act
RSS	Road Stormwater Screening Model
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWMM	Storm Water Management Model
TSS	Total suspended solids

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Executive summary

The Cawthron Institute (Cawthron) was commissioned by Nelson City Council (NCC) to start developing a method to identify high-risk urban stormwater sub-catchments, where targeted interventions will likely improve receiving environments. The recommended risk assessment approach is intended to provide a practical, long-term method for tracking the effectiveness of NCC's stormwater quality interventions and guiding future monitoring. The approach taken will begin to address the emerging risk-based statutory requirements under the Local Government (Water Services) Act 2025.

Effective stormwater improvement prioritisation in Nelson requires more than targeting the most contaminated stormwater discharges. The greatest likelihood of measurable and ecologically meaningful gains occurs when interventions focus on sub-catchments that discharge to receiving environments and where contaminants are likely to accumulate, persist or interact with sensitive values (e.g. low-flow river reaches and depositional estuarine areas). In contrast, many stormwater contaminants are event-driven and transient, so improvements may be detectable only during stormflow monitoring and may not translate into sustained improvements in receiving water condition. For this reason, prioritisation tools should also consider dry-weather misconnections and other chronic sources, supported by targeted dry-weather outfall monitoring.

Given the limitations outlined above, and based on our review of a selection of stormwater risk assessment models used in Aotearoa New Zealand and internationally, any prioritisation tool should integrate: (i) stormwater system contaminant sources and loads (dry and wet weather), (ii) receiving environment condition and sensitivity, and (iii) hydrological / geomorphic processes that control contaminant transport and retention. Minimum inputs include sub-catchment boundaries and flow paths, imperviousness and land use, rainfall characteristics, copper / zinc / total suspended solids (TSS) loads, receiving environment sensitivity indicators (e.g. Macroinvertebrate Community Index, depositional zones), basic hydrology / topography and stormwater infrastructure data.

NCC appears to hold most datasets required to implement a practical, screening-level model. However, the current first-flush stormwater monitoring programme has low replication, which limits its representativeness. Increasing the monitoring intensity and coverage would strengthen model inputs, confidence and validation.

Key considerations for implementation include:

- maintaining monitoring for model-relevant contaminants (copper, zinc, TSS) alongside consent requirements
- explicitly addressing uncertainty and ground-truthing; accounting for dry-weather misconnections and chronic sources through targeted dry-weather outfall monitoring
- aligning outputs with emerging risk-based statutory requirements under the Local Government (Water Services) Act 2025.

Of the evaluated models, the Road Stormwater Screening Model (RSS) met several key criteria, including suitability for Aotearoa New Zealand conditions, non-commercial availability and a receiving environment risk framework. However, RSS focuses primarily on road run-off and lacks the network-scale detail needed for tracing sources through NCC's pipe system, suggesting

that coupling it with a hydrological / hydraulic model such as the Storm Water Management Model would be necessary to support pathway tracing and targeted infrastructure upgrades.

Next steps for implementation are to:

1. Clarify whether NCC's stormwater risk assessment objectives are aligned with the requirements of the Local Government (Water Services) Act 2025.
2. Undertake short trials of available stormwater risk modelling tools to assess suitability, data needs and licencing.
3. If no single tool meets NCC's needs, assess whether a fit-for-purpose custom solution is warranted.

1. Introduction

1.1 Background

The Cawthron Institute (Cawthron) was commissioned by Nelson City Council (NCC) to assist with informing the Nelson stormwater quality improvement strategy for urban areas within Nelson (Envirolink advice grant number: 2612-NLCC135). Specifically, NCC want to conduct a data and method development review for identification of high-risk stormwater urban sub-catchments that may be included in the NCC stormwater strategy. This involves developing a long-term approach for identifying which freshwater management unit (FMU) sub-catchments (Figure 1) would benefit the most from improvements in stormwater quality.

Ultimately, it is expected that the recommended risk assessment approach will become a practical, long-term solution for evaluating the success of stormwater quality interventions undertaken by NCC and will help guide future monitoring efforts. It is also likely that it will become a useful case study for other councils that are attempting to manage and monitor stormwater quality improvements in a practical and cost-effective way.

The Local Government (Water Services) Act 2025[1] aims to improve stormwater quantity and quality management. It has new legislative requirements for managing stormwater networks, especially in urban areas zoned as residential, industrial or commercial land use. Section 201 stipulates that councils must develop a stormwater network risk management plan. It is anticipated that the recommended risk assessment outlined in this report will aid NCC in meeting this legislative requirement.

Scope

This report presents:

- A review of stormwater risk assessment approaches, that can be used by the council to make informed decisions with regards to stormwater improvements and monitoring.
- Identification of sub-catchment attributes that might contribute to, or indicate, reduced stormwater quality.
- An information stocktake and monitoring review of available sub-catchment attribute data to inform risk assessment approaches, including identification of information gaps (to help focus future monitoring efforts).
- Recommendations for a suitable stormwater risk assessment approach.
- Identify the next steps to implement the recommended risk assessment approach.

[1] Local Government (Water Services) Act 2025 No 42: https://legislation.govt.nz/act/public/2025/42/en/latest/#LMS1004209



Figure 1. Nelson freshwater management unit (FMU) sub-catchments that apply to this study, and main urban rivers and streams. Geospatial data from TOTSM (2024). Figure made using ArcGIS Pro 3.1.2.

1.2 Urban stormwater impacts

Urbanisation drives an increase in the number of potential stormwater sources, contaminants and impacts on aquatic environments. Progressive increases in the size and density of stormwater drainage systems invariably result in increasing negative impacts on receiving freshwater and coastal environments. Stormwater run-off affects not just the quality but also the quantity of the water discharged, and stormwater drainage and run-off act together to adversely impact the ecosystem health of receiving environments (Palmer and Ruhi 2019).

Urban stormwater contaminants are numerous and include trace metals and hydrocarbons, pesticides and pharmaceuticals, pathogens, organic matter and nutrients. Stormwater is also a major source of litter, particularly plastic (Gallo et al. 2018). Water quality in stormwater system discharges is extremely variable, both spatially and temporally. However, despite this inherent variability in the composition of discharges, it is a general rule that the greater the effective impermeable area of the landscape surrounding the receiving environment, the faster and more efficient the delivery of contaminants from the landscape to the receiving river, lake or estuary. There is a direct relationship between increasing impermeable area and detrimental effects on the ecological quality of freshwater and coastal environments (Walsh et al. 2005a, 2005b).

Increasing frequency and size of stormwater events can increase sedimentation in the receiving environment through the direct discharge of suspended solids from impermeable surfaces and destabilisation of riverbanks. This can result in smothering of instream habitats such as macrophytes (aquatic plants), boulders / cobbles and tree roots. Sensitive macroinvertebrate and fish species may be eliminated and replaced by more tolerant organisms capable of surviving in the degraded habitat. Sediments may also contain elevated levels of contaminants, some of which can cause acute and chronic toxicity in fish, macroinvertebrates and macrophytes. These impacts are likely to be most evident in slower-flowing areas of rivers and streams, where suspended solids settle out. Downstream depositional environments in estuaries and harbours may ultimately suffer the greatest impacts as river inputs continually contribute contaminants during storm events.

Relevance of stormwater quality to receiving environment water quality

While the water quality of Nelson's rivers and coastal areas is relatively good by national standards (Larned et al. 2018), some river sites show episodic deterioration in quality with respect to *E. coli*, and nutrients (dissolved reactive phosphorus, dissolved inorganic nitrogen). Many of these sites are subjected to stormwater discharges. The Land, Air, Water Aotearoa (LAWA) – River quality site states:

> Overall water quality in Nelson is highest in the forested catchments that dominate most of the Nelson land area, and poorest in urban streams at the base of the catchments. The most degraded sites monitored in the Nelson region are highly modified urban streams, and do not represent the general state of water quality across the region's FMUs. Rivers and streams are intermittently affected by factors such as microbial contamination associated with rural and urban land use; sediment resulting from land disturbance; and stormwater in city areas.[2]

[2] https://www.lawa.org.nz/explore-data/nelson-region/river-quality [accessed 16 March 2026]

The Draft Nelson Plan (RI18 Freshwater environment, RI18.vi) states:

> The quality of stormwater flowing into Nelson's urban streams reflects urban land uses. It is the key water quality issue for the urban area, affecting both the small streams it enters and the sensitive coastal receiving environment into which the streams flow (Waimea Inlet and Nelson Haven).[3]

The criteria for water quality classification outlined in the National Policy Statement for Freshwater Management 2020 (NPS-FM; MfE 2025) and the Nelson Plan were developed for river, stream and lake environments. While these criteria provide some context for discharges, they have limited relevance to the stormwater discharge contaminant concentrations themselves. Therefore, despite the intrinsic links between stormwater and receiving fresh waters, the receiving environment water quality criteria should not be applied directly to assessing the quality of any stormwater discharge. Although stormwater contaminants may be highly concentrated, they are also highly transitory, and the overall volume of the stormwater discharge is comparatively small in relation to the receiving environment (Sneddon 2010; Campos et al. 2021).

Because stormwater discharges to rivers are so transitory, their potential impacts on water quality in the receiving environment need to be interpreted in the context of mixing and dilution, total contaminant inputs and wet-weather flows. Large differences in the concentration of water contaminants are evident between storm flows and base flows, with the highest mass of many contaminants discharged in the first flush of a stormwater event (Lee et al. 2002). Contaminants often exhibit extreme variability within the receiving environment, with concentrations in the water column varying across the width and depth of the channel. The antecedent dry period (the period since a previous storm event) contributes to the variability, especially for source-limited contaminants, which may be present in significant amounts in stormwater due to their gradual build-up on impermeable surfaces. Despite the large spatial and temporal variability in concentrations of contaminants in stormwater, any significant improvements to stormwater inputs will contribute to improving receiving environment water quality to some degree.

Background investigations to this review

As part of early steps in sub-catchment and site prioritisation for NCC, Cawthron undertook a provisional data gap analysis and initial risk assessment in 2020 (O. Johnston, Cawthron, unpublished data). This work identified a range of potential information sources that could support the identification of high-risk stormwater sub-catchments, as well as indicators of receiving environments that may be more susceptible to the effects of poor stormwater quality (discussed further in Section 2.3). The analysis was largely informed by the Blanket Stormwater Consent and Asset Management Plan, and the direction provided in the Nelson Plan.

Building on this initial assessment, a scoping study was completed for three high-risk catchments (MacNeil and Campos 2022) to explore any detectable relationships between stormwater discharges and river water quality immediately downstream of stormwater outfalls (using river water quality samples taken immediately upstream of stormwater discharge points as controls). A field study was

[3] https://shape.nelson.govt.nz/nelson-plan/draft-nelson-plan-documents [accessed 16 March 2026]

conducted on 27 June 2023 in one of these catchments, Orchard Stream, following a significant rainfall event within the previous 24 hours (MacNeil et al. 2023). In some areas, it appeared that stormwater quality could be influencing receiving water quality; but this was not the case in other locations where alternative pollution sources and diffuse pollution might be more important (MacNeil et al. 2023). Nevertheless, the scoping study showed that stormwater was a measurable pressure in some river sites.

1.3 Legislative considerations

Stormwater quality management is shaped by legislation and planning instruments that set required outcomes and compliance obligations. This section summarises the key national and local requirements relevant to NCC, and how they influence prioritisation, monitoring and consent processes. Several of the requirements discussed relate to the freshwater receiving environments that Nelson's stormwater network discharges to directly (e.g. rivers and streams) and these requirements therefore influence how stormwater effects are managed and assessed. Relevant coastal-specific legislation and planning provisions have not been assessed as part of this review.

National Policy Statement for Freshwater Management

The NPS-FM (MfE 2025) requires councils to manage activities in a way that protects and, where necessary, improves freshwater values within FMUs. The NPS-FM drives a shift towards outcome-focused, risk-based stormwater management, where prioritisation, monitoring and consenting are aligned with protecting freshwater values at the FMU scale, rather than assessing stormwater discharges in isolation. The NPS-FM sets out compulsory values that apply to FMUs or their parts. These are defined in appendices 1A and 1B of the NPS-FM and include:

- ecosystem health (water quality, quantity, habitat, aquatic life, ecological processes)
- human health (which must consider pathogens)
- water clarity
- deposited sediment
- plant growth (from macrophytes to phytoplankton)
- cyanobacteria
- other toxicants and litter.

Nelson Resource Management Plan[4]

The Nelson Resource Management Plan (NRMP; NCC 2004) provides the primary regional-level regulatory framework through which stormwater discharges to freshwater are managed. While the NRMP does not set stormwater-specific performance standards, it strongly influences how stormwater risks are prioritised, monitored and addressed through consent conditions and compliance frameworks.

[4] https://www.nelson.govt.nz/1your-council/resource-management-plans

The current NRMP sets out water quality classification standards for freshwater, from Class A (high conservation / ecological value) to Class D (degraded). The water quality criteria for determining grades are defined for:

- waterborne disease risk (faecal coliforms, viruses, protozoa)
- toxic algae
- dissolved oxygen
- turbidity
- clarity
- temperature
- pH
- periphyton (river and streams)
- nutrients (phosphorus and nitrogen in respect of rivers and lakes)
- toxicants – toxic, radioactive or deleterious material (the specific toxicants and associated trigger levels defined in appendix 28.6i surface water and appendix 28.6ii sediments of the Nelson Plan[5]).

Nelson City Council stormwater discharge consent

The Blanket Consent (the Consent) for the entire Nelson Region reticulated system (RM075499V1; NCC 2018) grants NCC authorisation to discharge stormwater from the reticulated system to various rivers, streams and creeks in the catchment. It also prescribes stormwater monitoring and reporting conditions for these waterways (detailed in MacNeil et al. 2025 and the Nelson Stormwater Quality and Improvement Plan[6]). The Consent stipulates the collection of samples of stormwater during first-flush conditions at six sites, which represent six different catchment types, and the testing of these samples for water quality parameters on an annual basis. Interpretative reporting of these annual monitoring results is undertaken on a 6-yearly basis. The catchment types and sites that are monitored under this programme are:

- car park areas (i.e. Stoke car park)
- commercial areas in an urban setting (i.e. Trafalgar Street drain)
- light industrial (i.e. Bolt Road)
- old residential (i.e. Bronte Street)
- new residential (i.e. Kingsford Drive)
- undeveloped / rural (i.e. Songer Street).

The latest monitoring occurred in February 2026. While sampling just six catchment types is spatially limited and a relatively narrow representation of the range of land uses in Nelson, it does provide a basis for identifying and quantifying longer-term temporal trends in stormwater quality at the sampled sites. The standards set out in the Nelson Plan provide the benchmark for water quality improvements throughout the region, and they include some of the parameters monitored to satisfy the requirements

[5] https://shape.nelson.govt.nz/nelson-plan/draft-nelson-plan-documents
[6] https://www.nelsoncity.co.nz/assets/Our-council/Downloads/reticulated-stormwater-quality-improvement-plan.pdf

of the Blanket Consent. Continuation of first-flush monitoring at the six sites will improve understanding of stormwater pollutant loads over time.

NCC's current stormwater monitoring approach (established under the global stormwater consent) has operated broadly unchanged since it was designed in 2004. Since the programme began, catchment land use, the stormwater network, council objectives and the wider regulatory context have changed substantially. For these reasons, we anticipate that a targeted review of the monitoring design (e.g. site selection, frequency / replication, analytes and alignment with risk-based decision-making) will be required to ensure that it is fit for purpose for assessing and managing stormwater risk over time. It is likely that the original intent was for the monitoring programme to be regularly updated to reflect evolving objectives and legislative requirements.

Local Government (Water Services) Act 2025

The Local Government (Water Services) Act[7] aims to improve stormwater quantity and quality management. It includes new legislative requirements for managing stormwater networks, especially in urban areas zoned as residential, industrial or commercial land use. Section 201 stipulates that councils must develop a stormwater network risk management plan. Section 203 also states that the plan must include a number of specified components, including (but not limited to):

- a map of the stormwater network
- identification of overland flow paths and watercourses that receive stormwater from, or take stormwater to, critical infrastructure in the stormwater network
- stormwater environmental performance standards under section 139A of the Water Services Act 2021. This environmental performance of the network must include the quality and quantity of stormwater, as well as discharges to water.

Relevant reviews

Focusing on Aotearoa New Zealand, WSP (2020) reviewed stormwater provisions across selected Resource Management Act (RMA) planning documents and recommended a risk-based management approach focused on preventing or minimising adverse effects on receiving environments. Key elements include water-sensitive design, avoidance of development in sensitive areas, source control and on-site treatment, and both local and catchment-scale mitigation measures. Considering WSP's recommendations, any stormwater risk assessment approach will likely need to be both practical and flexible enough to inform management approaches that address these components.

[7] Local Government (Water Services) Act 2025 No 42: https://legislation.govt.nz/act/public/2025/42/en/latest/#LMS1004209

2. Review

This section provides an overview of stormwater modelling tools available for use in Aotearoa New Zealand, as well as data sources that can be used to identify at-risk catchments and support prioritisation of sub-catchments for targeted improvements.

2.1 Risk assessment modelling approaches

General model types

Stormwater risk assessment modelling uses mathematical, hydrological and hydraulic tools to simulate run-off and pollutant loads, helping assess risks from flooding, erosion and contamination. There are three general types of stormwater modelling:

4. **Water quality contaminant load models** – used to estimate contaminant loads (e.g. copper, zinc, total suspended solids [TSS]) generated from road run-off and other urban surfaces (by land-use or surface type), often supporting 'hotspot' identification (high-risk areas) for targeted stormwater management.
5. **Hydrological models** – used to evaluate how rainfall, general hydrology and water quality relate to stormwater effects. Continuous models simulate long-term hydrology and water quality to evaluate overall system behaviour, pollutant loads over time and infrastructure performance. Event-based models simulate short-duration rainfall events to assess acute effects such as peak flows, first-flush contaminant loads or short-term toxicity.
6. **Hydrodynamic / hydraulic models** – used to carry out flood risk assessments by mapping flood extents, depths and velocities, and identifying shortfalls in infrastructure capacity.

Across all three modelling types, a key purpose is to identify areas with high pollutant concentrations ('hotspots') or elevated flood risk to support targeted maintenance, regulatory compliance and consent processes for urban development and road networks. The following sections review the stormwater modelling tools available in Aotearoa New Zealand to identify catchments that are subject to poor stormwater quality. These tools can also help prioritise sub-catchments for targeted improvements. The most relevant type of model for the purpose of this current NCC assessment is likely to be a water quality contaminant load model.

Storm Water Management Model (SWMM)

The US Environmental Protection Agency's (US EPA) Storm Water Management Model (SWMM)[8] estimates run-off quantity and quality in drainage systems (integrates model types 1, 2 and 3; see Section 2.1 – General model types). It was first released in 1971 and has since undergone major upgrades. Although developed in the United States, SWMM is widely used internationally. The current edition, Version 5, is focused on the simulation of stormwater run-off and pollution loads. It does this by

[8] https://www.epa.gov/water-research/storm-water-management-model-swmm#software%20and%20compatibility

simulating dynamic rainfall run-off for single events or continuous (long-term) data on a collection of sub-catchment areas, enabling prediction of run-off concentrations and loads. The routing portion of SWMM transports this run-off through a system of pipes, channels, storage / treatment devices, pumps and regulators. SWMM tracks the quantity and quality of run-off generated within each sub-catchment, alongside the flow rate, flow depth and quality of water in each pipe and channel during a simulation.

SWMM was developed to help implement local, state and national-level stormwater management objectives. It also supports the reduction of discharges that cause impairment to receiving waterbodies. In this way, the model is used for decision support, planning, analysis and design related to stormwater, combined and sewer systems, as well as other drainage systems. It can also be used to create stormwater control strategies or evaluate grey infrastructure such as pipes and storm drains.

A range of SWMM implementations are available online, including geographic information system (GIS)-integrated add-ins and standalone modelling platforms. A full review of all available options was outside the scope of this investigation; however, several available SWMM-based tools are listed below for further consideration:

- GeoSWMM (Utilian)[9] is a commercial GIS-enhanced interface built around the US EPA SWMM engine. It does not change the underlying SWMM model but rather adds tools intended to improve workflow efficiency, model set up and spatial analysis within ArcGIS Pro.
- PCSWMM[10] is a commercial SWMM platform that extends SWMM5 with an enhanced user interface and additional capabilities for scenario management, calibration support and results visualisation.
- InfoSWMM[11] is a commercial SWMM platform with GIS integration and database-driven workflows, commonly used for municipal stormwater and wastewater network modelling.

Where available, it would be beneficial to trial free (time-limited) versions of these tools (e.g. 30-day trials) to assess usability, data compatibility, out-sourcing risk and total cost of ownership before committing to a preferred platform.

Freshwater Management Tool (FWMT)

Auckland Council has developed a tailor-made stormwater catchment contaminant load model, the Freshwater Management Tool (FWMT; Bambic et al. 2019; Auckland Council 2021, 2024, 2026). The FWMT is designed to track and estimate water quality (e.g. contaminant loads and concentrations) over time across Auckland (integrates model types 1 and 2, with elements of 3; see Section 2.1 – General model types). It provides a decision-support system and is built on the following US EPA open-source, continuous, process-based models:

[9] https://utilian.com/geoswmm
[10] https://www.pcswmm.com/
[11] https://help.innovyze.com/space/infoswmm/

- **Loading Simulation Program in C (LSPC)**[12] is a watershed modelling system that includes Hydrologic Simulation Program Fortran algorithms for simulating hydrology, sediment and general water quality on land as well as in a simple stream fate / transport mode.
- **System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN)**[13] is a US EPA-derived decision-support system that assists with developing and implementing plans for flow and pollution control measures to protect source waters and meet water quality goals. SUSTAIN allows development and selection of optimal best management practice combinations at various watershed scales. **It should be noted that the US EPA is no longer developing or supporting SUSTAIN, and there are no plans for updated versions**.[9]

Instead of relying solely on a limited number of monitoring sites, the FWMT simulates time-series estimates of flow and contaminant loads (and, where applicable, concentrations) at 15-minute intervals across nearly 5,500 sub-catchments in Auckland. In this way, the FWMT provides additional predictive capability by acting as a 'virtual sensor' across the region.

In terms of contaminants, the FWMT can model heavy metals (copper and zinc), sediment and associated nutrients, and *E. coli*. It links urban stormwater management with rural 'field-edge' mitigations and land-use planning and can combine urban / rural / planning levers in one framework to estimate how they jointly affect downstream water quality. Because it is process-based (rather than relying on average export rates), the model can help trace contaminant pathways back to likely sources on land or within streams, and test how changes (in boundary conditions) such as climate change, farming intensification, development or management actions may affect water quality. As a continuous model (rather than an event-based model), it can describe both short-term event impacts (acute) and longer-term pressures (chronic), including downstream and coastal loadings.

For stormwater management applications, the FWMT's current operational focus is typically on contaminants such as TSS, copper and zinc. Scenario updates are implemented by refreshing key spatial layers that drive run-off generation and contaminant build-up / wash-off (e.g. land use and imperviousness) and by adding or modifying representations of treatment devices and network changes. This enables comparison of model outputs between a baseline configuration (e.g. circa 2017) and subsequent updates (e.g. reflecting network and land-use changes around 2022) to estimate the likely direction and magnitude of future water quality outcomes.

The key data inputs for the FWMT model include:

- sub-catchments and flow paths, delineated using regional light detection and ranging (LiDAR)-based topography and overland flow path information
- stream and drainage networks, including mapped stream reaches and major stormwater pipes (> 500 mm) where they influence flow paths and connectivity
- climate forcing (e.g. rainfall and other meteorological variables), drawing on both gauged records and virtual climate station networks to provide continuous time-series inputs

[12] https://santafenm.gov/document_center/document/8985
[13] System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN) | US EPA

- observed water quality monitoring data (stormwater and / or instream), used to derive representative concentrations (e.g. event mean concentrations) and to calibrate and validate modelled contaminant loads and concentrations where monitoring is available
- wastewater networks and discharges, including six major reticulated networks (Watercare) and representation of on-site wastewater where relevant to catchment loads
- impoundments (ponds, dams and reservoirs) to represent storage and associated effects on flow and contaminant transport
- hydrological response units, combining soils, slope and land-activity factors to define distinct run-off and contaminant-generation behaviours (Stage 1 included 106 unique response units)
- reach groups to represent differences in instream processes such as nutrient cycling and erosion potential.

FWMT / CREST model coupling

In collaboration with Auckland Council (Healthy Waters), the Danish Hydraulic Institute (DHI) have also coupled their Coastal Receiving Environment Scenario Tool (CREST) with the FWMT to create an integrated 'mountains-to-sea' digital twin of the Manukau and Waitematā Harbours using continuous, process-based modelling (Kpodonu et al. 2022). Coupling the FWMT to CREST allows evaluation of the transport and fate of pollutants in the harbours and can help identify pollution load targets for coastal health.

It should be noted that NCC currently uses the hydrologic CREST model (DHI 2025) to integrate remote-sensing climate data, flood and coastal hydrology, and land-use characteristics to quantify contaminant inputs (loads) from land to rivers and estuaries. This provides a basis for prioritising catchment-scale remediation actions most likely to improve desired water quality outcomes. However, unlike Auckland Council, NCC's current application of CREST is not linked to a dedicated stormwater management tool or stormwater network model (e.g. a SWMM-based platform) and therefore does not directly represent stormwater system assets, treatment devices or stormwater operational interventions.

Modelled Estimates of Discharges for Urban Stormwater Assessments (MEDUSA)

Modelled Estimates of Discharges for Urban Stormwater Assessments (MEDUSA; Fraga et al. 2016) is an event-driven stormwater contaminant load model that simulates the build-up and wash-off of pollutants from impervious urban surfaces (model type 1; see Section 2.1 – General model types). It was developed by the University of Canterbury for Christchurch City Council, with technical support from DHI (Chakravarthy et al. 2019).

MEDUSA is used to identify high-risk pollutant sources, calculate event-based loads and simulate the effectiveness of stormwater mitigation measures. Unlike models that primarily estimate contaminant load using catchment-level response units (e.g. FWMT), MEDUSA evaluates specific surface types (e.g. roofs, roads, carparks) to determine which contribute the greatest contaminant loads (Charters et al. 2020). In this way, MEDUSA represents a high-resolution alternative to traditional, more complex or aggregated modelling approaches. The model has been calibrated and validated using data from

several Christchurch catchments, including the Okeover Stream and Heathcote River. The key data inputs for MEDUSA include:

- Contaminant data – with a focus on estimating loads for TSS, total / dissolved copper, total / dissolved zinc and total lead.
- Meteorological data – including local climate data such as rainfall pH, intensity, duration and preceding dry days to predict loads on a per-event basis.
- Geometrical data – including roof, road and car park geometries, roofing and paving surface coverage, drainage networks, discharge points, catchment LiDAR / Digital Elevation Model (DEM).
- Management modifiers – used to simulate the impact of source reduction (e.g. green roofs, permeable pavement) and treatment options (e.g. raingardens) on contaminant loads.

MEDUSA implementation tools appear to be available. While a full review of all available web-based options was outside the scope of this investigation, a MEDUSA-based tool, which is available online, is listed below for further consideration:

- Urban Waterways MEDUSA tool[14] allows users to simulate contaminant loadings from roof, carpark and road surfaces using MEDUSA from multi- or single-rainfall events.

Road Stormwater Screening Model (RSS)

In Aotearoa New Zealand, NZ Transport Agency | Waka Kotahi uses the Road Stormwater Screening Model (RSS) to assess risks to fresh water and coastal receiving environments from road run-off (Gardiner et al. 2016; Semandi-Davies and Moores 2020). The RSS focuses on copper and zinc in road run-off and urban stormwater. It estimates relative risk by combining predicted contaminant strength with receiving environment sensitivity (RES; model type 1; see Section 2.1 – General model types). It is a steady-state screening model that represents average annual conditions at the scale of River Environment Classification (REC) sub-catchments (see Snelder et al. 2004), and it also accounts for non-road urban sources of copper and zinc. Compared with detailed stormwater network models, such as SWMM, and large regional accounting frameworks, such as Auckland's FWMT, RSS has certain advantages. It is relatively quick to implement, uses nationally available datasets (e.g. REC and road / traffic information) and produces simple relative risk categories to identify hotspots and guide interventions. A key difference from the other models reviewed is that RSS builds receiving environment sensitivity (e.g. Macroinvertebrate Community Index [MCI]-based condition bands and coastal depositional setting) directly into the risk score, whereas SWMM and FWMT typically require additional post-processing (and often site-specific ecological information) to convert flow / load outputs into a risk ranking.

In the RSS, REC groups define the spatial units used for assessing risk and provide a consistent proxy for RES. REC classifies rivers (or river reaches) at six hierarchical levels, grouping sections that are expected to have broadly similar physical and biological characteristics (e.g. hydrology, hydraulics, water quality and aquatic communities). Rivers are represented as a network of reach sections with their upstream contributing catchments, with an average reach length of approximately 700 m. Each reach is assigned a

[14] https://www.urbanwaterways.org/

class based on six factors: upstream climate, topography, geology and land cover, as well as network position and valley landform. These classes can be treated as practical management units, for example, to support targeted monitoring design, consistent reporting of environmental data and the application of specific provisions in regional plans.

The RSS version 4 (2021/22) has undergone both field testing and sensitivity analyses. This was done by comparing modelled stream risk against relative concentrations of zinc and copper measured in receiving stream environments that take run-off from major roads. For most sites, the contaminant strength predicted by the model was either higher than measured or within the same category as contaminant strength (concentration) calculated from measurements – this indicated that the model provided a conservative risk assessment. A sensitivity analysis involved changing model parameters and input data, both separately and together at the same time, to determine how these impacted risk estimates. Those results showed that the model was relatively robust. It was noted that future risk assessments need to integrate climate change (including factors such as increased rainfall intensity), as well as increasing densities of housing development (Semadeni-Davies et al. 2023).

Risk assessment framework

Unlike other models reviewed here, the RSS is supported by a River Risk Assessment framework (Gardiner et al. 2016) that translates model outputs into an actionable prioritisation tool. This framework allows the level of relative risk associated with the discharge of stormwater contaminants to receiving waterbodies to be assessed according to the combination of two attributes:

7. A contaminant strength score represents mean instream copper and zinc concentrations. For each REC reach, concentrations are estimated by dividing the annual copper and zinc loads delivered from the local and upstream sub-catchments (road traffic-derived, urban or combined sources) by the reach's estimated mean annual flow (Woods et al. 2006a). Potential combined (cumulative) effects of Cu and Zn are then accounted for using cumulative criterion units (Hickey and Golding 2002), compared against thresholds derived from ANZECC (2000) guideline values (incorporated into ANZG 2018).
8. A RES score, based on receiving environment characteristics, which reflects condition bands associated with application of the MCI. Modelled MCI scores for each REC river reach are based on a previous assessment by Cawthron, which predicted MCI scores from catchment and stream reach attributes (Clapcott et al. 2013). Based on these modelled MCI scores, each REC reach is assigned to an ecological condition band – excellent, good or fair or poor – and an RES score applied accordingly.

The RSS also includes a coast and estuary assessment framework / score (Gardiner et al. 2016), which can be used to prioritise higher-risk stormwater outlets. For each coastal outlet (including stream and river mouths), the model estimates the 'contaminant strength', in terms of mean sediment concentrations of copper and zinc by dividing the annual metal loads delivered to the outlet (from the local and upstream sub-catchments) by the estimated annual sediment load delivered to that outlet. Sediment loads are derived from the Catchment Land Use for Environmental Sustainability (CLUES)[15] model, which uses sub-catchment land use to estimate sediment delivery (Woods et al. 2006b;

[15] https://niwa.co.nz/freshwater/clues-catchment-land-use-environmental-sustainability-model

Semadeni-Davies et al. 2017, 2019, 2021, 2023). The receiving environment sensitivity (RES score then reflects the depositional level of the receiving environment. For example, outlets are classified as discharging to high-, moderate- or low-deposition environments and assigned RES scores of 5, 3 or 0, respectively; the classifications are informed by published information (e.g. measured sedimentation rates) where available.

The RSS was developed using a combination of ESRI ArcGIS and Microsoft Excel (Gardiner et al. 2016). ArcGIS is used to compile and spatially align the required input datasets and to map outputs, with the REC providing the core spatial framework. Excel is then used to calculate contaminant loads and assign relative risk scores based on contaminant strength and receiving environment sensitivity. The key data inputs RSS requires are:

- Geometrical data – including: drainage network and sub-catchments based on REC road centre-line and traffic counts from the Road Assessment and Maintenance Management database (RAMM); urban land cover, soil drainage class, location and characteristics of coastal hydrosystems (i.e. estuaries and harbours) from NIWA Coastal Explorer database; and the terminal (coastal) river segments discharging to each hydrosystem and the estimated mean annual flows for each REC stream segment.
- Ecological data – including estimated MCI scores for each REC stream segment.
- Contaminant dynamics – including sediment loads for each stream segment using the CLUES model, and copper and zinc. In terms of the latter, loads of traffic-derived copper and zinc are estimated for each road section, adjusted as necessary for traffic congestion and load attenuation (based on the road drainage and stormwater channel characteristics) and the individual section values summed for each sub-catchment.

NCC is a 'road controlling authority' and so may have access to the RSS model, potentially through a service agreement or similar. If access can be secured and the tool can be maintained at minimal cost (including any licencing, data update and support requirements), RSS may be a practical option to consider for screening-level urban stormwater risk assessment.

Model for Urban Stormwater Improvement Conceptualisation (MUSIC)

Originating in Australia and originally developed by the Cooperative Research Centre for Catchment Hydrology, the Model for Urban Stormwater Improvement Conceptualisation (MUSIC)[16] was designed to test the efficiency of different combinations of stormwater treatment options (Wong et al. 2022). MUSIC can simulate a wide range of stormwater treatment devices to identify the most effective options (i.e. such as bioretention basins, constructed wetlands, etc.) for capturing and reusing stormwater run-off, removing contaminants and reducing run-off frequency (model type 2; see Section 2.1 – General model types). The MUSIC software is available to various councils throughout Australia, and the model and associated software is owned, and can be purchased from, the eWater Group.[16]

MUSIC is well suited to treatment design and option testing; however, it is more limited for catchment prioritisation via risk assessment because it generally outputs flows and pollutant loads / concentrations

[16] https://ewater.org.au/ewater-solutions/tools/music/

rather than an integrated 'risk-to-values' score. Unlike RSS, it does not natively combine contaminant strength with receiving environment sensitivity (e.g. ecological condition bands or depositional setting) into a simple risk ranking, and it is not built around Aotearoa New Zealand-specific receiving environment frameworks (e.g. REC / MCI). As a result, applying MUSIC for prioritisation would likely require additional GIS post-processing and supplementary ecological / sensitivity datasets to translate model outputs into a comparable, decision-ready risk assessment across multiple sub-catchments.

Catchment Contaminant Annual Loads Model (C-CALM)

The Catchment Contaminant Annual Loads Model (C-CALM)[17] is a spatial decision-support tool designed for planning applications (Semadeni-Davies and Wadhwa 2014). It estimates annual contaminant loads from diffuse sources at neighbourhood to stormwater management unit (sub-catchment) scales for TSS, fine particles, and dissolved zinc and copper (integrates model types 1 and 2; see Section 2.1 – General model types). Estimated loads can then be adjusted to reflect changes in land use, contaminant mitigation measures or proposed development scenarios. C-CALM is the property of NIWA (Earth Sciences NZ) but is free of charge for non-commercial use and is intended to aid in the planning of urban stormwater treatment at the stormwater unit / sub-catchment scale. It consists of a GIS modelling interface linked to a contaminant loads model and a query library of performance rules for stormwater treatment options, such as wet detention ponds, wetlands, raingardens (i.e. bioretention), catch-pits and porous paving.

Based on workshopping with councils, C-CALM was designed to be a nationally available, GIS-based planning tool for councils and developers to compare land-use and stormwater management scenarios (Semadeni-Davies and Wadhwa 2014). Workshop participants considered detailed urban drainage models (e.g. SWMM, MUSIC) too data intensive and specialist for broad planning use and noted that MUSIC was less suitable because it does not simulate metals. The workshop participants requested a simple, intuitive spatial decision-support system that could leverage existing council GIS layers (e.g. imperviousness, land use, catchments, networks, roads, streams and treatment devices) to identify high load-contributing areas and communicate the implications of urbanisation and mitigation.

C-CALM differs from RSS, as it does not consider receiving environment sensitivity or provide a receiving environment risk scoring framework, which will potentially be a component of any stormwater network risk management plan developed for the Local Government (Water Services) Act (2025). C-CALM also differs to SWMM and FWMT in that it does not use a fully attributed stormwater pipe network (e.g. diameters, inverts, routing) and therefore does not simulate pipe hydraulics (capacity, surcharging, backwater effects). Where stormwater network layers are used, they mainly support spatial attribution and planning (e.g. assigning source areas to outlets and representing the presence of treatment devices). The main risk of this simplified approach is that results can be sensitive to the completeness and accuracy of GIS connectivity (potentially misassigning loads to the wrong outlet / receiving reach) and to assumptions about treatment performance. In addition, annual load outputs may mask short-lived, event-driven peak concentrations that can drive acute effects.

[17] https://webstatic.niwa.co.nz/static/CCALM_manual_pdf.pdf

Model review summary

Table 1 summarises the seven risk assessment model approaches reviewed, including the types of data needed and potential benefits / challenges for NCC. The key features of the models presented in Section 2.1 are:

- With the exception of MUSIC, the models are primarily screening tools intended to support risk ranking and prioritisation.
- MUSIC differed in purpose to the other models, as it is mainly used to test and compare stormwater treatment options. The other models show where to intervene (high-risk areas) and / or apply more simplistic 'performance rules' (C-CALM) or 'management modifiers' (MEDUSA) to estimate intervention outcomes.
- Similar core stormwater contaminants are used in the models (copper, zinc[18] and often TSS).
- All models depend on similar foundational data inputs (catchment boundaries, impervious surfaces / land use, rainfall and some representation of receiving environment sensitivity, etc.).
- The SWMM model had the highest stormwater network source apportionment resolution potential. Other models used sub-catchment scale or land-use type groupings.
- RSS was the only model reviewed to integrate receiving environment sensitivity and a risk assessment framework directly in its design.
- The models should not replace stormwater quality monitoring, and they require data to calibrate and confirm causal links between stormwater and receiving water quality.
- None of the models reviewed were developed specifically to meet the stormwater network risk management plan requirements of the Local Government (Water Services) Act 2025.
- Of the models reviewed, SWMM and MUSIC were not explicitly developed or parameterised for Aotearoa New Zealand.
- The SWMM model had a range of off-the-shelf GIS add-ons / software available for trial. C-CALM, MEDUSA and MUSIC may also be available, in some form, for non-commercial use.

[18] Copper and zinc are readily released into watercourses during rainfall events, and their concentrations can be toxic to aquatic life. Acute guideline values (ANZG 2018) for copper and zinc in stormwater models allow evaluation of the potential effect of these contaminants on aquatic organisms (Gadd et al. 2024). These guidelines are crucial for management of the receiving environment in Aotearoa New Zealand, especially within the context of the NPS-FM (MfE 2025).

Table 1. A selection of stormwater risk assessment models used in Aotearoa New Zealand, with input data requirements, outputs, access, and potential benefits and challenges to Nelson City Council (NCC). SWMM = Storm Water Management Model, FWMT = Fresh Water Management Tool, CREST = Coastal Receiving Environment Scenario Tool, MEDUSA = Modelled Estimates of Discharges for Urban Stormwater Assessments, RSS = Road Stormwater Screening Model, MUSIC = Model for Urban Stormwater Improvement Conceptualisation, C-CALM = Catchment Contaminant Annual Loads, LID = low impact development, US EPA = US Environmental Protection Agency, LiDAR = light detection and ranging, TSS = total suspended solids, Cu = copper, Zn = zinc, DHI = Danish Hydraulic Institute, REC = River Environment Classification, RAMM = Road Assessment and Maintenance Management database, CLUES = Catchment Land Use for Environmental Sustainability, MCI = Macroinvertebrate Community Index, WSUD = Water sensitive urban design.

Model	Brief description	Input data	Model output	Access	Benefits for NCC	Challenges for NCC
SWMM	Dynamic hydrology, hydraulics and water quality model for urban stormwater systems (event-based and continuous)	Rainfall, sub-catchments, pipe network, LID controls, pollutant build-up / wash-off parameters	Flow rates, flood depths, pipe capacity, pollutant loads, LID performance	Open source (US EPA, public domain)	Strong for flood risk, pipe capacity assessment and detailed stormwater design	High data and calibration effort; no coastal fate without coupling
FWMT	Continuous, process-based freshwater contaminant load accounting model for urban and rural catchments	LiDAR-derived sub-catchments, climate, land use, soils, wastewater, stormwater networks	Time-series flows and loads (TSS, Cu, Zn, nutrients, *E. coli*); hotspot maps	Auckland Council-owned framework (built on open US EPA models)	Provides NZ example for integrated, continuous catchment modelling	High set-up and operational cost; not directly transferable to Nelson Region
CREST	Catchment-to-coast scenario and visualisation tool linking run-off loads to estuarine and coastal fate	Sub-catchment loads, rainfall run-off, land use, coastal bathymetry, tides and winds	Connectivity matrices, coastal concentration maps, scenario outcomes	Proprietary (DHI platform, council use); current NCC application	Highly relevant for Nelson's coastal receiving environments and hotspot prioritisation	Requires specialist modelling support and reliable upstream load estimates
MEDUSA	Event-based model simulating contaminant build-up and wash-off from roofs, roads and carparks	Surface geometries, surface types, rainfall intensity, duration, antecedent dry days, rainfall pH	Event-based contaminant loads and concentrations (TSS, Cu, Zn)	Hosted research / industry tool (not fully open source)	Excellent for identifying acute run-off and source-level hotspots	Does not simulate pipe hydraulics or long-term averages

Model	Brief description	Input data	Model output	Access	Benefits for NCC	Challenges for NCC
RSS	National steady-state screening model assessing copper and zinc risk from roads	REC network, RAMM traffic data, land use, CLUES sediment loads, MCI scores	Relative risk categories for streams and coastal discharges	Agency tool (Waka Kotahi / NIWA)	Low-cost way to prioritise high-risk road corridors	Relative (not absolute) risk; limited to Cu and Zn
MUSIC	Conceptual continuous model for assessing stormwater treatment and WSUD performance	Climate, catchment areas, soils, treatment device parameters	Long-term pollutant removal performance and treatment sizing	Proprietary (eWater). Free for various Australian councils	Well suited for consent support and WSUD design	Limited metals capability and no coastal fate modelling
C-CALM	GIS-based annual contaminant load model for planning and scenario evaluation	Land use, surface composition, source yields, treatment devices	Annual loads of TSS and dissolved / particulate Cu and Zn	Free for non-commercial use (NIWA / Earth Sciences NZ)	Rapid screening tool for planning and consent support	Annual average only; lacks event dynamics and hydraulics

2.2 Available data to inform a model

A provisional data gap analysis and preliminary risk assessment were undertaken as early steps in sub-catchment and site prioritisation (Cawthron unpublished data). This work identified a range of potential information sources that could support the identification of high-risk stormwater sub-catchments. The data has informed part of this review (Table 2) and helped determine which areas of the receiving environment are more likely to be affected by poor stormwater quality (Table 3). Those minimum data, which likely identify areas that would benefit from stormwater improvements (identified in the model review above), are indicated with a tick (Tables 2 and 3).

Table 2. Summary of potential sub-catchment attributes that may affect stormwater (SW) quality and suitable representative model input data (✔), alongside the spatial datasets available to support geospatial analysis and risk assessment modelling (represented by *). Rows with ● indicate an attribute that may influence water quality during only dry-weather conditions. High = good quality, available data, moderate = data is available but has lower confidence due to low replication or inaccuracies, poor = restricted access and / or very low confidence data. Cu = copper, Zn = zinc, Pb = lead.

Catchment attribute	Rationale	Data sources	Quality	Input
Percentage of urban area / land use	More urban area increases the delivery of SW contaminants	NCC 2021; TOTSM 2024; MWLR 2026	High	✔
SW quality	SW outfall monitoring data for contaminant ground-truthing	MacNeil and Sneddon 2026	Moderate	✔
SW volume / rainfall data	More rainfall creates more run-off (calculated from rainfall data)	TDC 2026	High	✔
Percentage of 'old' pipes	Old pipes subject to wastewater infiltration to the SW network. Concrete pipework increases SW pH levels (Müller et al. 2020)	NCC 2021 (Fig 4.1)	Poor	
Unpermitted septic tanks (no.)	Potential for surface water / groundwater wastewater infiltration	NCC 2021; TOTSM 2024	Poor	
Area of roof surfaces	More roof area increases roof related contaminants e.g. trace metals (Cu, Zn, Pb)	NCC 2021; TOTSM 2024	Moderate	
Road area	More road-related contaminants, e.g. trace metals, oil and grease / hydrocarbons etc. (Müller et al. 2020)	NCC 2021; TOTSM 2024	Moderate	✔
Percentage of total impervious area (TIA)	Increased delivery of SW contaminants and heat exchange; linked to biodiversity declines (Walsh et al. 2005a)	NCC 2021; TOTSM 2024	Moderate	✔
Hydrogeology / diffuse input potential (water table depth)	Higher water tables are vulnerable to contaminated surface waters, increasing diffuse contamination to rivers and streams	MWLR 2025; NCC 2026	Poor	
Low impact design (LID) areas	Reduce stormwater contaminant inputs	NCC 2021; TOTSM 2024	High	
Hazardous Activities & Industries List	Potential for diffuse SW contaminant inputs	NCC 2021; TOTSM 2024	Poor	
Misconnections / illegal flows	SW pipes discharging during dry weather	None	Poor	●
River Environment Class (REC)*	Spatial analysis, basemaps, receiving environment	NIWA 2025	High	✔
SW drainage network*	Spatial analysis, basemaps, SW source tracing	TOTSM 2024	Moderate	✔
NCC sub-catchments and topology*	Spatial analysis, basemaps, receiving environment	NCC 2021; TOTSM 2024; LINZ 2025	High	✔

Table 3. Potential receiving environment indicators of stormwater (SW) quality for risk assessment modelling. High = good quality, available data. Moderate = data is available but has lower confidence due to low replication or inaccuracies. Poor = restricted access and / or very low confidence data / sampling programme not designed in a way that can adequately assess point source SW discharges (i.e. few urban stormwater discharges upstream of the monitoring sites). Rows with ● represents outfall specific investigations, with multiple potential indicators, that could be used to validate the model.

Indicator	Rationale	Data sources	Data quality	Input
River sediment quality	Soft sediment receiving environment conditions where adverse ecological effects could, or do, occur	Barter and Frisk 2001; Barter and Thompson 2003; Bennett 2006; Bailey and Conwell 2010; Sneddon and Elvines 2012; O'Cain 2016; Tiernan 2022	Poor (for this purpose)	
River water quality	Water quality receiving environment conditions and trends that are below the desired water quality condition. e.g. declining / improving / indeterminate	LAWA 2026; Stats NZ 2026; McArthur and Foster 2018	Poor (for this purpose)	
Macroinvertebrate Community Index trends	Urban streams exhibit low abundance and survival of sensitive aquatic species (Walsh et al. 2005a, 2005b)	Clapcott et al. 2013	High	✓
Ecological state of the coastal receiving environment	Receives contaminant inputs from the wider Nelson Region	NCC 2024 (state of the environment monitoring) and reports therein. DHI 2025 (CREST model)	High	✓
Ground-truthed / validated SW / water quality causal relationships	Outfall specific field sampling to confirm whether stormwater discharge quality measurably influences receiving river water quality. Contaminant prediction ground-truthing and model validation	Robertson and Asher 2001; Thompson and Barter 2002; Hopkins and Asher 2005; MacNeil et al. 2023	Moderate	●

2.3 Model limitations and considerations

To frame the recommendations that follow, we highlight several key considerations that will influence the reliability, completeness and regulatory relevance of stormwater risk assessment and prioritisation (and associated models) in Nelson.

Maintaining or improving monitoring efforts

Based on the conditions of the global stormwater monitoring consent, there is a risk that future monitoring may be scaled back. The current consent requires monitoring only for *E. coli*, whereas copper, zinc and TSS were identified as key contaminants in the reviewed stormwater models. While NCC is currently analysing these contaminants as additional parameters, it is important to emphasise the value of their ongoing inclusion in monitoring programmes to ensure robust and model-relevant data inputs.

In addition, the stormwater monitoring approach established under the global stormwater consent has remained largely unchanged since 2004 and has not been formally reviewed for its suitability for stormwater risk assessment. Since then, land use, the stormwater network, council objectives and the regulatory context have changed substantially. Developing and applying the risk assessment model will likely expose these limitations and help target monitoring updates so that the programme remains fit for purpose and aligned with current objectives and legislative requirements.

Uncertainty and model validation

Model predictions inevitably carry uncertainty, particularly where monitoring data are sparse or where sampling sites are not representative of wider conditions. Model reliability can only be assessed once the model is run using the available datasets and its outputs are evaluated against independent monitoring data (i.e. ground-truthed). Given the limited monitoring data available and ongoing changes in land use across the Nelson Region, the model should be treated as an adaptive tool that is progressively improved as new data become available and is subject to regular validation of its predictions.

An example of an adaptive, data-driven modelling approach is provided by Christchurch City Council's stormwater management plan for the Halswell River / Huritini (CCC 2025). This evaluation was principally informed by an existing Christchurch Contaminant Load Model (C-CLM). The C-CLM is an annual load model driven by annual contaminant loads for various road surface types (originally developed by NIWA for Auckland Regional Council). Surfaces include galvanised, zinc, aluminium, painted and other roof types, a hierarchy of road types organised by traffic volumes, paved areas and green areas. All sub-catchments were estimated to discharge a similar unit load of TSS. Zinc loads were strongly influenced by the zinc content of roof surfaces and vehicle traffic volumes, and higher copper levels from industrial sub-catchments were correlated with busier roads. An additional MEDUSA model helped to indicate potential mitigation options and point to the benefits of contaminant controls at source, but there was not sufficient specific TSS information to improve on the C-CLM. The original report states that a continuous, event-based contaminant load was proposed using the MEDUSA model, which would be expected to incorporate Christchurch contaminant discharge data and to generate

more accurate contaminant loads on an event and annual basis. The report proposed transitioning to a continuous, event-based MEDUSA or MUSIC model over time, with the C-CLM retained as a simple, practical tool to track progress and estimate the benefits of stormwater treatment investments.

New statutory requirements

The Local Government (Water Services) Act 2025 introduced new requirements for councils to adopt a structured, risk-based approach to managing stormwater networks. While this report does not constitute a stormwater network risk management plan under the Act, it provides a critical technical foundation to support NCC's development of such a plan by identifying high-risk stormwater sub-catchments, key contaminant sources and sensitive receiving environments, and by evaluating appropriate stormwater risk assessment tools.

At the time of writing, the Local Government (Water Services) Act 2025 does not prescribe specific stormwater environmental performance targets. Instead, the Act enables the future introduction of stormwater environmental performance standards by regulation. This report provides a technical foundation to support NCC's preparedness for those future standards by identifying high-risk stormwater sub-catchments, key contaminants and sensitive receiving environments where compliance efforts are most likely to be required.

Dry-weather misconnections

Some indicators of degraded river water quality may not be directly linked to stormwater discharges but instead reflect chronic or diffuse inputs such as groundwater / surface water interactions, legacy sediment contamination, or dry-weather flows from misconnections or ageing infrastructure. Recent monitoring (MacNeil et al. 2023) indicated misconnection discharges may be ongoing from some stormwater outfalls (Figure 2). These inputs, which are happening independent of stormwater discharges, can persist during long dry periods and elevate contaminant concentrations even without rainfall. Incorporating data on these dry-weather influences alongside traditional stormwater attributes would provide a more complete understanding of catchment stressors; this process could be supported through simple, routine monitoring of stormwater outlets during dry-weather conditions to detect persistent contaminant sources not captured during wet-weather sampling.



Figure 2. Evidence of possible misconnection into stormwater system discharging to Orchard Stream on 27 June 2023 (MacNeil et al. 2023). (1) Inspection of the stormwater outfall at site 3 (yellow arrow) and instream sampling locations (red arrows). (2) Evidence of persistent nutrient-rich discharge, as indicated by thick green biofilm layering the stormwater pipe (grey arrow).

3. Recommendations for model development

Identifying stormwater sub-catchments where focused, cost-effective improvements will likely positively impact receiving water quality requires a more nuanced approach than simply targeting areas with the most degraded stormwater discharges. An effective approach needs to first identify sections of degraded receiving water (rivers or estuaries) where reduced urban stormwater quality is likely to be exerting a significant and measurable influence. These locations should represent parts of the freshwater or coastal environment where contaminant loads from urban catchments accumulate, persist or interact with sensitive ecological values in receiving waters. Targeting sub-catchments that discharge to these threatened and / or degraded areas increases the likelihood that improvements in stormwater quality will translate into detectable improvements in receiving water condition.

Focusing solely on sub-catchments with the poorest stormwater quality does not necessarily guarantee measurable outcomes. Many stormwater contaminants, particularly those mobilised during rainfall, are highly variable and transient within receiving environments. Their influence may be restricted to short periods during storm events, after which concentrations rapidly return to background levels through dilution, flushing or tidal exchange. In such cases, even substantial improvements at the sub-catchment scale may only produce extremely short-lived improvements in receiving waters, many of which are detectable only during stormflow monitoring and only in the water column (Gadd et al. 2024). Furthermore, ecological responses often integrate conditions over much longer timescales. While some catchments may deliver high contaminant loads, these may not result in ecological degradation if the receiving water has high assimilative capacity, rapid flushing or limited depositional zones. Conversely, degraded estuarine or low-flow river reaches that act as contaminant sinks may respond more measurably to upstream stormwater improvements, even if the contributing stormwater is only moderately degraded.

The information drawn from this review of stormwater models will help ensure that management efforts are directed towards sub-catchments where improvements in stormwater quality are most likely to produce measurable and ecologically meaningful changes in the receiving environment. Any stormwater improvement prioritisation tool should combine information on stormwater contaminant sources and loads with knowledge of receiving environment sensitivity and degradation, as well as hydrological and geomorphic processes that determine where contaminants accumulate or affect ecological health.

The minimum data inputs to build a stormwater improvement prioritisation tool should include:

- ✓ sub-catchment boundaries and stream / flow paths
- ✓ impervious surface area (roads, roofs, carparks)
- ✓ basic land-use classification (housing, commercial, industrial, etc.)
- ✓ rainfall data (intensity, duration, antecedent dry period)
- ✓ estimated or measured contaminant loads for copper, zinc and TSS
- ✓ receiving environment ecological sensitivity (e.g. MCI, identification of depositional zones)
- ✓ basic hydrological information (topography, REC flow or catchment run-off potential)
- ✓ infrastructure (stormwater and wastewater pipe network).

NCC appears to have the required data sources available for a less complex model (e.g. MEDUSA, RSS, C-CALM, MUSIC). However, one of the key data inputs required for a stormwater model was identified as lower quality in the data review. This is the long running NCC stormwater 'first flush' monitoring programme, which has low sampling replication per land-use type (one sample per land-use type every 2 years) (MacNeil et al. 2025). Nevertheless, because the data for this programme span long periods (i.e. two decades), they may still provide valuable insights. Increased monitoring effort (per survey) over more representative stormwater catchments would likely improve the data inputs and assessment of risks.

Considerations

To support robust prioritisation and ensure the recommendations remain fit for purpose over time, we highlight the following considerations that affect the reliability, completeness and regulatory relevance of stormwater risk assessment in Nelson:

- **Maintain and strengthen monitoring:** Consent conditions currently mandate monitoring only for *E. coli*. Copper, zinc and TSS are not required but are central to the stormwater models reviewed. Continuing – and where possible expanding – monitoring for these contaminants will maintain robust, model-relevant inputs. In addition, the stormwater monitoring approach established under the global stormwater consent has remained largely unchanged since 2004. The risk assessment model will help identify the current monitoring limitations and guide updates so that the monitoring programme remains fit for purpose and aligned with current objectives and legislative requirements.
- **Uncertainty and validation:** Model predictions will always contain uncertainty, particularly where monitoring data are sparse or not representative. Confidence can only be established by running the model and evaluating performance against monitoring data (ground-truthing). Given the limited monitoring data available and ongoing changes in land use across the region, the model should be treated as an adaptive tool that is progressively improved as new data become available. The model should also be subject to regular prediction validation.
- **Dry-weather misconnections and chronic sources:** Degraded receiving water indicators may reflect non-storm inputs (e.g. groundwater / surface water interactions, legacy sediment contamination, misconnections, ageing infrastructure) that can persist during dry periods. Routine dry-weather outfall checks are recommended to identify persistent sources not captured by wet-weather sampling and to support interpretation of model outputs.
- **New statutory requirements:** The Local Government (Water Services) Act 2025 requires councils to adopt a structured, risk-based approach to stormwater network management. This report is not a stormwater network risk management plan under the Act; instead, it provides technical foundations by identifying high-risk sub-catchments, key contaminants and sensitive receiving environments, and by evaluating suitable risk assessment tools. The Act does not currently set specific stormwater environmental performance targets, but it enables future performance standards to be introduced through regulation; this work supports NCC's preparedness for those future requirements.
- **Existing models and complexity:** A Parliamentary Commissioner for the Environment report (PCE 2024) found that councils often take an ad hoc approach to stormwater risk assessment, developing bespoke models rather than adapting existing ones to regional needs. It noted that of

seventy-five models reviewed, 60% had been developed by a specific council and were seldom reused. The report also found that existing models were often not used to their full potential, with council staff describing them as too complex or expensive; these models were frequently replaced by simpler options that could be deployed quickly.

Recommended approach

The goal of this assessment was to identify stormwater risk assessment models that NCC could use efficiently to support decisions on stormwater improvements and monitoring, using currently available sub-catchment attribute data. Of the models reviewed, many are proprietary, not readily transferable to the Nelson context, or provide outputs at too coarse a resolution for robust source tracing. Several options also carry a risk of ongoing dependency on external tool developers for maintenance and updates. For these reasons, it is uncertain whether an entirely 'off-the-shelf' model would be appropriate for NCC without modification.

For any future model selected or developed for NCC, we recommend consideration of the following core functionality (with representative models shown in parentheses and a schematic in Figure 3):

- ability to **test and compare management interventions** and treatment scenarios (e.g. MUSIC)
- an **explicit risk assessment framework** that incorporates receiving environment values / sensitivity (e.g. RSS)
- capability to **extend assessment to coastal receiving environments** (e.g. RSS, or FWMT coupled with CREST)
- ability to **disaggregate contaminant generation by impervious surface type** (e.g. MEDUSA; RSS for road-related sources) to further enable targeted interventions and test land-use scenarios
- ability to **use topography and stormwater infrastructure data to trace contaminant pathways** through the stormwater network and better target improvements (e.g. SWMM; FWMT-style approaches)
- maximise usability and transparency for council staff by using model outputs that are **delivered through simple, web-based GIS tools** (e.g. ArcGIS online web maps / dashboards, as per SWMM add-ons). This would allow users to explore spatial risk patterns, compare sub-catchments and test scenarios without specialist modelling expertise.
- employ a model that uses **ongoing stormwater and receiving environment monitoring to ground-truth and validate predictions** (e.g. RSS, FWMT, MEDUSA, etc.). Noting that the current stormwater and river state of the environment long-term monitoring approaches will likely require some modification to support this functionality.
- employ a framework that is **flexible enough to incorporate new or improved predictors** over time, e.g. dry-weather misconnections, infrastructure upgrades, updated land use / imperviousness and climate change predictors.

Of the models reviewed, RSS meets several of these criteria. Notably, it was developed for Aotearoa New Zealand conditions, is available for non-commercial use, and incorporates a receiving environment risk framework using nationally available proxies. However, RSS is strongly oriented towards road run-off sources (model type 1; see Section 2.1 – General model types), and it does not represent stormwater

network topology in sufficient detail to support source tracing through NCC's pipe network (e.g. back to individual outfalls or upstream assets). It is possible that coupling with a hydrological / hydraulic model approach (model types 2 and / or 3; see Section 2.1 – General model types), such as SWMM, could complement RSS by providing the network-scale representation needed to trace pathways and target infrastructure upgrades.

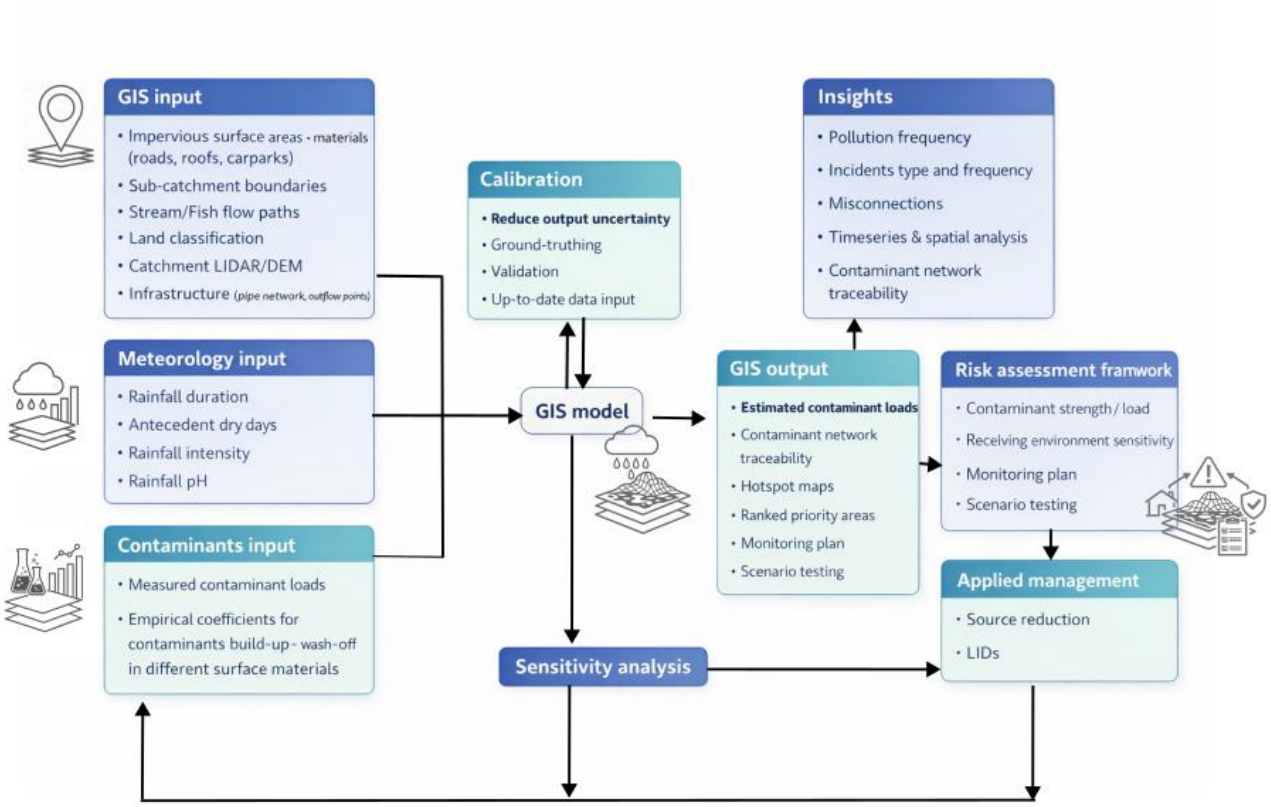


Figure 3. Representative flow diagram of the recommended model framework showing key data inputs, the risk assessment step (loading × receiving sensitivity, with confidence / uncertainty) and outputs, including a feedback loop to inform monitoring, validation and scenario testing. Adapted from MEDUSA (Fraga et al. 2016).

Next steps

1. **Confirm risk assessment objectives through NCC workshopping.** Identify NCC's stormwater risk assessment objectives and the required core functions of the model. These should be decided in light of the new Local Government (Water Services) Act 2025 and the required 'stormwater network risk management plan' development.
2. **Trial available models.** Given the range of products available online (e.g. SWMM add-ins and commercial platforms) with free trials, and that some tools may be available for non-commercial use (e.g. RSS), a sensible next step is to confirm access and licencing requirements and undertake a short, targeted trial of the most promising options. This may identify an 'off-the-shelf' solution

suitable for NCC; if not, the trials will still provide practical insights into model set up, data requirements and functionality to inform any subsequent bespoke model development.

3. **Evaluate a custom solution.** If existing 'off-the-shelf' solutions do not provide all required functionality, a custom solution should be evaluated that integrates the most relevant components of available models for NCC's needs (e.g. Figure 3). This evaluation should include a comparison of costs, functionality and resourcing requirements relative to off-the-shelf options, including development, implementation and ongoing maintenance.

Concluding remarks

This review demonstrates that effective prioritisation of stormwater improvements in Nelson sub-catchments requires a shift from focusing only on stormwater discharge quality to a more integrated, risk-based approach. This new approach should explicitly consider receiving environment sensitivity, contaminant transport processes and the likelihood of achieving measurable ecological improvements. The highest value interventions for NCC are likely to occur where urban stormwater is discharged to environments that act as contaminant sinks or support sensitive ecological values, rather than locations where stormwater discharge contaminant concentrations are highest. NCC is well positioned to implement a fit-for-purpose screening-level risk assessment using largely existing datasets. However, the value of this approach will depend on maintaining and strengthening monitoring for relevant contaminants, addressing uncertainty through validation and ground-truthing, and explicitly incorporating dry-weather misconnections and other chronic sources. The findings highlight that stormwater risk assessment should be treated as an adaptive decision-support framework. This framework should be able to guide investment, monitoring and compliance over time, supporting readiness for emerging statutory requirements under the Local Government (Water Services) Act 2025 and maximising the environmental return on NCC's stormwater improvement efforts.

4. References

[ANZG] Australian and New Zealand Governments. 2018. Australian and New Zealand guidelines for fresh and marine water quality. Canberra: Australian and New Zealand Governments and Australian state and territory governments. https://www.waterquality.gov.au/anz-guidelines

Auckland Council. 2021. Freshwater management tool: report 1. Baseline data inputs. Auckland: Auckland Council. FWMT Report 2021/1. https://www.knowledgeauckland.org.nz/media/2463/fwmt-report-1-baseline-data-inputs-auckland-council-2021.pdf

Auckland Council. 2024. Healthy Waters stormwater network discharge consent monitoring and evaluation strategy, version 3.4. Auckland: Auckland Council.

Auckland Council. 2026. Freshwater management tool version 1.0 – Healthy Waters & Flood Resilience. Auckland: Auckland Council. https://www.aucklanddesignmanual.co.nz/content/dam/adm/adm-website/developing-infrastructure/freshwater-management--tool/Freshwater%20Management%20Tool%20v1%20Edited%2009-04-2026.pdf

Bailey M, Conwell C. 2010. Sediment contaminant levels in Nelson area catchments: 2010. Nelson: Cawthron Institute. Cawthron Report No. 1732. Prepared for Nelson City Council.

Bambic D, Stephens T, Grant C, Porter T, Brown N, Clarke C. 2019. Current and future state of Auckland's watersheds: stage 1. Freshwater Management Tool. https://www.aucklanddesignmanual.co.nz/content/dam/adm/adm-website/developing-infrastructure/freshwater-management--tool/conference-papers/stormwater-(water-nz)/2019-C-1%2010-04-2026.pdf

Barter P, Frisk S. 2001. A review of sediment contaminant levels in Nelson area catchments. Nelson: Cawthron Institute. Cawthron Report No. 627. Prepared for Nelson City Council.

Barter P, Thompson S. 2003. Sediment contaminant levels in Nelson area catchments: 2003. Nelson: Cawthron Institute. Cawthron Report No. 848. Prepared for Nelson City Council.

Bennett C. 2006. *S*tream sediment contaminant levels. Nelson: Cawthron Institute. Cawthron Report No. 1206. Prepared for Nelson City Council.

Campos C, Morrisey D, MacNeil C, Johnston O. 2021. Urban stormwater improvement strategy for Nelson. Nelson: Cawthron Institute. Client Draft Report No. 3679. Prepared for Nelson City Council.

Chakravarthy K, Kumar H, Watters J, Stevenson M, Charters F, Cochrane T. 2019. Identification, prioritization, and mitigation – a three step process for stormwater quality management. Wellington: Water New Zealand. New Zealand Stormwater Conference & Expo 2019 conference paper. https://www.waternz.org.nz/Article?Action=View&Article_id=1706

Charters FJ, Cochrane TA, O'Sullivan AD. 2020. Predicting event-based sediment and heavy metal loads in untreated urban runoff from impermeable surfaces. Water. 12:969. https://doi.org/10.3390/w12040969

[CCC] Christchurch City Council. 2025. Huritini-Halswell River Stormwater Management Plan. Christchurch: Three Waters & Waste Unit, Christchurch City Council. TRIM Ref 22/40920.

https://ccc.govt.nz/assets/Documents/Services/Stormwater-drainage/Management-plans/Huritini-Halswell-Stormwater-Management-Plan-2025.pdf

Clapcott J, Goodwin E, Snelder T. 2013. Predictive models of benthic macroinvertebrate metrics. Nelson: Cawthron Institute. Cawthron Report No. 2301. Prepared for Ministry for the Environment. https://environment.govt.nz/assets/publications/Files/mfe-predictive-models-benthic-macroinvertebrate-metrics-2013.pdf

DHI. 2025. Nelson Haven – Coastal Receiving Environment Scenario Tool. Auckland: DHI New Zealand. Report No. 44802095/01, Rev. Final 1.1. Prepared for Nelson City Council.

Fraga I, Charters F, O'Sullivan A, Cochrane T. 2016. A novel modelling framework to prioritize estimation of non-point source pollution parameters for quantifying pollutant origin and discharge in urban catchments. Journal of Environmental Management. 167:75–84.

Gadd JB, Hickey CW, Snelder AH. 2024. Acute copper and zinc water quality guideline values for Aotearoa: technical report of the derivation including bioavailability model evaluation. Auckland: Hydrotoxy Research. Prepared for Ministry for the Environment. https://environment.govt.nz/assets/publications/Freshwater/accute-copper-and-zinc-water-quality-guideline-values.pdf

Gallo F, Fossi C, Weber R, Santillo D, Sousa J, Ingram I, Nadal A, Romano D. 2018. Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. Environmental Sciences Europe. 30(1). https://doi.org/10.1186/s12302-018-0139-z

Gardiner LR, Moores J, Osborne A, Semadeni-Davies A. 2016. Risk assessment of road stormwater runoff. Wellington: NZ Transport Agency. Research Report 585. https://www.nzta.govt.nz/assets/resources/research/reports/585/585-risk-assessment-of-road-stormwater-runoff.pdf

Hickey CW, Golding LA. 2002. Response of macroinvertebrates to copper and zinc in a stream mesocosm. Environmental Toxicology and Chemistry. 21(9):1854–1863. https://doi.org/10.1002/etc.5620210913

Hopkins S, Asher R. 2005. Compliance monitoring at the Collingwood Street stormwater outfall. Nelson: Cawthron Institute. Cawthron Report No. 1098. Prepared for Nelmac.

Kpodonu T, Stephens T, Brown N, Tuckey B, Chakravarthy K. 2022. Advances of integrated modelling from sea-to-mountain. Wellington: Water New Zealand. Stormwater Conference & Expo 2022 conference paper. https://www.aucklanddesignmanual.co.nz/content/dam/adm/adm-website/developing-infrastructure/freshwater-management--tool/conference-papers/stormwater-%28water-nz%29/2022-A-1.pdf

Larned ST, Whitehead AL, Snelder TH, Fraser C, Yang J. 2018. Water quality state and trends in New Zealand rivers: analyses of national data ending in 2017. Christchurch: National Institute of Water and Atmospheric Research. NIWA Client Report 2018347CH. Prepared for the Ministry for the Environment.

LAWA. 2026. Land, Air, Water Aotearoa. River quality. [accessed 1 March 2026]. https://www.lawa.org.nz/explore-data/river-quality

Lee JH, Bang KW, Ketchum LH, Choe JS, Yu MJ. 2002. First flush analysis of urban storm runoff. Science of The Total Environment. 293(1–3):163–175. https://doi.org/10.1016/s0048-9697(02)00006-2

[LINZ] Toitū Te Whenua | Land Information New Zealand. 2025. Elevation data (LINZ Data Service) [digital elevation models and point-cloud datasets; web and API access]. [accessed February 2026]. https://www.linz.govt.nz/products-services/data/types-linz-data/elevation-data/access-elevation-data.

MacNeil C, Campos C. 2022. Stormwater quality monitoring programme for Nelson urban areas: scoping study of three high-risk catchments. Nelson: Cawthron Institute. Cawthron Advice Letter 2252. Prepared for Nelson City Council.

MacNeil C, Campos C, Tremblay L. 2023. Stormwater quality improvement programme: Baseline survey at sites in the Orchard Stream. Nelson: Cawthron Institute. Cawthron Advice Letter 2354. Prepared for Nelson City Council.

MacNeil C, Sneddon R, Falk H. 2025. Nelson stormwater monitoring 2024/2025: sampling of three catchments. Nelson: Cawthron Institute. Cawthron Report 4149. Prepared for Nelson City Council.

[MWLR] Manaaki Whenua | Landcare Research. 2025. S-map – New Zealand's national digital soil map. [accessed 1 February 2026]. https://smap.landcareresearch.co.nz/

[MWLR] Manaaki Whenua | Landcare Research. 2026. LCDB v.6.0 – Land Cover Database version 6.0, Mainland, New Zealand [land cover spatial dataset]. [accessed 1 February 2026]. https://lris.scinfo.org.nz/layer/123148-lcdb-v60-land-cover-database-version-60-mainland-new-zealand/

McArthur K, Foster C. 2018. Whakatū Nelson freshwater sub-catchment summary of current state, values and issues requiring a plan response: a report to support the development of the Nelson Plan. Report no. 2018/129. Prepared for Nelson City Council.

[MfE] Ministry for the Environment. 2025. National Policy Statement for Freshwater Management 2020. [amended December 2025]. Wellington: Ministry for the Environment. https://environment.govt.nz/publications/national-policy-statement-for-freshwater-management/

Müller A, Österlund H, Marsalek, J, Viklander M. 2020. The pollution conveyed by urban runoff: a review of sources. Science of the Total Environment. 709:136125. https://doi.org/10.1016/j.scitotenv.2019.136125

[NIWA] National Institute of Water and Atmospheric Research. 2025. River Environment Classification, v.2.0 (REC2) [river classification spatial dataset]. [accessed 1 February 2026]. https://niwa.co.nz/freshwater/river-environment-classification-2

[NCC] Nelson City Council. 2004. Nelson Resource Management Plan 2004. https://www.nelson.govt.nz/1your-council/resource-management-plans/eplan-view-the-interactive-resource-management-plans

[NCC] Nelson City Council. 2018. Nelson City Council blanket consent for entire Nelson District reticulated system. Full and updated conditions for Resource Consent RM075499 dated 19 February 2009; as varied by RM075499V1 dated 3 December 2018. Expires 19 February 2044.

[NCC] Nelson City Council 2020. Draft Nelson Plan 2020. https://shape.nelson.govt.nz/nelson-plan/draft-nelson-plan-documents

[NCC] Nelson City Council. 2024. Nelson City Council state of the environment report 2019–2023. Nelson City Council. https://www.nelson.govt.nz/repository/libraries/id:2r883m1me1cxbyryo0mp/hierarchy/6Environment/NCC%20State%20of%20the%20Environment%20Report%202019-2023%20%281%29.pdf

[NCC] Nelson City Council. 2026. Soil mapping (Our soils – sustainable land management). [accessed 1 February 2026]. https://www.nelson.govt.nz/6environment/rural-hub/sustainable-land-management/our-soils/soil-mapping

O'Cain M. 2016. Sediment contaminant levels in Nelson area catchments: 2016. Christchurch: Davis Ogilvie & Partners Ltd. Report No. 35241; Project No. NN35241. Prepared for Nelson City Council.

[PCE] Parliamentary Commissioner for the Environment. 2024. A review of freshwater models used to support the regulation and management of water in New Zealand. Wellington: Parliamentary Commissioner for the Environment. https://pce.parliament.nz/media/4ttfvgwj/a-review-of-freshwater-models-used-in-the-management-and-regulation-of-water.pdf

Palmer M, Ruhi A. 2019. Linkages between flow regime, biota, and ecosystem processes: implications for river restoration. Science. 365(6459). https://doi.org/10.1126/science.aaw2087

Robertson B, Asher R. 2001. Nelson Haven stormwater discharge monitoring: Neale Park and Wood stormwater discharge, Nelson Haven monitoring. Cawthron Report No. 691, prepared for Nelson City Council, Cawthron Institute, Nelson.

Semadeni-Davies A, Gadd J, Hyde C. 2021. Road Stormwater Screening Model V.4: customising stormwater treatment, model validation and sensitivity analysis. Wellington: National Institute of Water and Atmospheric Research. NIWA Client Report. Prepared for Waka Kotahi | NZ Transport Agency.

Semadeni-Davies A, Gadd J, Moores J, Jayaratne R, Grieg D. 2023. Introducing version 4 of the road stormwater Screening Model. Wellington: Water New Zealand. Stormwater Conference & Expo 2023 conference paper. https://www.waternz.org.nz/Resources/Attachment?Action=Download&Attachment_id=6177

Semadeni-Davies A, Moores J. 2020. Development and application of the Road Stormwater Screening Model V.3: guidance and national application. Wellington: National Institute of Water and Atmospheric Research. NIWA Client Report. Prepared for Waka Kotahi | NZ Transport Agency.

Semadeni-Davies A, Moores J, Osborne A, Gardiner LR. 2017. NZTA road stormwater screening model RSS v2 user guidance. MWH (Stantec) and NIWA. Prepared for NZ Transport Agency. NZTA Contract No 16-270.

Semadeni-Davies A, Wadhwa S. 2014. C-CALM 2.0 user manual: Catchment Contaminant Annual Load Model. Auckland: National Institute of Water and Atmospheric Research. NIWA Client Report No. AKL2014-026. https://webstatic.niwa.co.nz/static/CCALM_manual_pdf.pdf

Sneddon R. 2010. Nelson City stormwater monitoring programme: 2010. Nelson: Cawthron Institute. Cawthron Report No. 1753. Prepared for Nelson City Council.

Sneddon R, Elvines S. 2012. Sediment contaminant levels in Nelson area catchments: 2012. Nelson: Cawthron Institute. Cawthron Report No. 2116. Prepared for Nelson City Council.

Snelder T, Biggs B, Weatherhead M. 2004. New Zealand River Environment Classification user guide. Wellington: Ministry for the Environment. NIWA publication ME1026.

Stats NZ. 2026. Statistics New Zealand. River water quality: Macroinvertebrate Community Index. [accessed 1 March 2026]. https://www.stats.govt.nz/indicators/river-water-quality-macroinvertebrate-community-index

[TDC] Tasman District Council. 2026. Environmental data: rainfall data. [accessed 1 February 2026]. https://www.tasman.govt.nz/my-region/environment/environmental-data/rainfall

Thompson S, Barter P. 2002. Baseline environmental monitoring at the Collingwood Street stormwater outfall. Nelson: Cawthron Institute. Cawthron Report No. 756. Prepared for Nelson City Council.

Tiernan F. 2022. Stream sediment survey 2022: state of the environment monitoring report. Envirolink Ltd. Prepared for Nelson City Council.

[TOTSM] Top of the South Maps. 2024. Nelson City Council, Tasman District Council & Marlborough District Council web-based GIS portal. [accessed 1 April 2026]. https://www.topofthesouthmaps.co.nz

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP. 2005a. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society. 24:706–723.

Walsh CJ, Fletcher TD, Ladson AR. 2005b. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society. 24:690–705.

Wong TH, Fletcher TD, Duncan HP, Coleman JR, Jenkins GA. 2002. A model for urban stormwater improvement conceptualisation. International Congress on Environmental Modelling and Software. 122. https://scholarsarchive.byu.edu/iemssconference/2002/all/122

Woods R, Elliott S, Shankur U, Bidwell V, Harris S, Wheeler D, Clothier B, Green S, Hewitt A, Gibb R, et al. 2006b. The CLUES Project: predicting the effects of land-use on water quality – Stage II. Hamilton: National Institute of Water and Atmospheric Research. NIWA Client Report HAM2006-096.

Woods R, Hendrikx J, Henderson R, Tait A. 2006a. Estimating mean flow of New Zealand rivers. Journal of Hydrology (NZ). 45(2):95–110. https://scispace.com/pdf/estimating-mean-flow-of-new-zealand-rivers-5cjvkt2c5h.pdf

WSP. 2020. Stormwater policy and plan provisions: stocktake and assessment. Christchurch: WSP New Zealand Limited. https://environment.govt.nz/assets/Publications/storm-water-policy-and-plan-provisions.pdf

Declaration of AI-assisted technologies in the writing process

During the preparation of this work the authors used Copilot (with Cawthron enterprise data protection) in order to improve the readability and language of the manuscript. The icons shown in Figure 3 were developed using Copilot. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published report.

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