Submissions for the Ihutai-Estuary and Coastal draft Stormwater Management Plan

Submission ID	First name	Last name	Organisation	Do you have any feedback on this plan's proposed goals?	Do you have any other comments on this plan?
45006	Juliet	Neill		The goals are laudable, and more can be done regarding stormwater at source.	To help solve the problem of stormwater, plus help people retain roof water for drought situations, please encourage people to have their own rainwater tanks for gardening purposes and non-drinking water. Also, please find a way to encourage people to have their own water reticulation schemes for grey water. These two actions could divert a lot of water from reaching the storm water system in the first place, and help green the city.
45007	Toni	Harris-Daw		How about dredging the Avon / Heathcote rivers, clearing the liquefaction the rose the riverbed so that they can hold more water and stop flooding the city areas, along with Flockton Street etc, also Southshore.	Form a decent channel in the Estuary.
45120	Pat	McIntosh		Goal 1. Regarding goals for sediment discharges, I do not agree with accepting 5-10% non compliance. This sets the bar much too low. The goal should be zero consented construction activities reported non compliant. Non compliance should be considered non-negotiable. Compliance should be expected, supported and monitored. By allowing yourselves a degree of non-compliance you are obviating the effect of the regulations.	
45264	Redcliffs	Residents Association	Redcliffs Resident Association	[see attached]	[see attached]
45267	Felicity	Blackmore	Christchurch International Airport Ltd	[see attached]	[see attached]
45268	Tim	Hobbs		I live in Sumner and have done for the last 30 years and while I respect and approve of your desire to have clean storm water, I think we spend too much tax on something that has been happening for years. Maybe a subsidy for different roofing - no zinc.	Will reducing the copper content in vehicle breaks reduce their effectiveness? If not then go ahead with our plans. The crux of the problem is there are too many vehicles! When I was a child, no fellow students owned a car and most families had only one car. In my time in Sumner, flooding is not an issue and if my friends on the esplanade get hit by a tidal wave then perhaps they should not have bought there! Maybe the North-West where I am from.
45499	Susan	Carbines	South Shore Residents Association (SSRA)	The goals about improving storm water outflow quality are admirable but we are concerned that there are not goals pertaining to improving the efficiency of the path of the stormwater water	This plan seems be primarily focused on the quality of the storm water ie reducing contaminates. We are unclear who is responsible for the maintenance, repair and improvement of the storm water system. Is this within the SMP scope?. If it is, then there are not clear goals and tasks associated with this. If it is not within the SMP scope then it would be helpful to see how this plan relates to other plans, so we have a full picture. SSRA would suggest that there is a diagram that shows the SMP and how it relates to other plans and specifically what aspects of work each is responsible for. Eg- district plan

					– building site management, LDRP etc. You need to indicate with more clarity what this plan is responsible for and equally what it is not. This is the Coastal plan. As coastal we get water from all other areas via the rivers. SSRA understand that there are 7 plans. It would be helpful to see the other 7 plans and how they are being managed. SSRA would like to understand what aspects of the Coastal SMP will be generic and carried over to other plans. It would be helpful if you could indicate which items are plan specific and which are plan general. SSRA would suggest for balance you need a section that includes a) How the CCC are managing the compliance of CCC own businesses in the Coastal area- walking the talk b) How they are managing the compliance of their own infrastructure. Clearing of drains, improving stormwater flow etc c) Indicate what the public can do to help- subsidies for roof water collection tanks, encouragement of storm water self-management via on site sumps where appropriate. If the scope of the SMP is the functionality of the storm water system, then the SSRA wish to indicate that our stormwater system does not function efficiently at present. We do believe there are newly designed one-way valves being installed at some point. As these will be new and untested, we would like to suggest theses are monitored to check efficiency and to ascertain what ongoing maintenance and care they would require We would like the CCC to consider in future a more permanent pump solution and find a better engineered out flow system for beach suburbs in general. There are too few water grates along the beach(East) side of rocking horse road. From the end(south) of RHR the first grate is outside 191a, which is well North of Mermaid (over 300 meters) and this contributes to very large volumes flowing to a single collection point. At times the water volume collected from such a distance is more than this single grate can cope with. More grates at a closer distance would result in less build up. Thank you SSRA
45577	Rosemary	Neave		I support the submission of the Redcliffs Residents Association on this matter. I live in Redcliffs and work actively with them to restore, manage and develop Te Awa Kura - Barnett Park.	
45696	Bebe	Frayle	Waitai Coastal-Burwood Community Board	[see attached]	[see attached]
45972	Charlot	Hudson	Sumner Community	In Sumner the issues are both from rainfall/storm water flooding and tidal flooding. There are management issues of the beach stormwater drains on Sumner beach needing to be dug out in advance of predicted storms and high tide events. We believe some investigation needs to be initiated to make the	We do strongly support management of contaminants in construction, road works, roofing and hill side earthworks. We would be happy to assist with an communications campaign in Sumner through our local networks.

			Residents' Association	clearing of the beach storm water outlets more efficient. In addition the management of tidal flooding is a priority in Sumner. The seawall needs maintenance - especially towards Cave Rock end of the esplanade. managing the seawall protection in addition to more efficient passage for the storm water drains will help protect Sumner from future flooding events.	
45990	Peter	Foster	P&F Global Ltd – Kaitaia Office	Great goals	A friend who lives in this area brought my attention to the Ihutai-Estuary and Coastal Draft Stormwater Management Plan Draft and I felt that it was an opportunity to bring to attention that the persistance of policy makers not to change away from traditional products is hindering more resilient, better environmentally friendly options and economical solutions. Concrete pipes are often not the best solution for stormwater management: in marine/coastal soil or peat types, to protect stream fauna and aquatic life, and in seismic prone areas. HDPE is a more sustainable and seismic resilient material and easier on the environment than concrete. Check these reports: https://www.nzgs.org/library/nzgs20_roberts3/ Quote: "In 2014 Whangarei District Council identified problems with buried pipe work in a development in Ruakaka as concrete within the storm water system had begun to suffer chemical corrosion. Investigations into the cause of the corrosion identified the presence of acid sulphate soils. Extensive earthworks and lowering of the water table occurred during development. The continual draining of the site through subsoil drains caused sulphides in the soils to react with oxygen and release sulphuric acid. The acid then corroded the concrete pipes (Whangarei District Council, 2017). The local press have reported that this has resulted in a claim by Whangarei District Council in the order of $8 million against the designer and contractor (NZ Herald, 2016)." https://pandfglobal.com/news/safe-and-sustainable-pipe-systems/ Quote: "A US paper Environmental Benefits of HDPE Pipe, produced by the Plastics Pipe Institute, details HDPE's growing reputation as "the greenest pipe available". The paper is focused on the use of HDPE pipes in municipal water and wastewater systems and talks about its wide use as a "sustainable, low-cost, leak-proof alternative to other piping". The paper details multiple benefits of HDPE pipes and their performance in relation to alternative pipe materials." http://resources.quakecentre.co.nz/wp-content/uploads/2020/02/3WaterResilience_Simplified-Assessment-Method_Final.pd f Check page 15 part way down the chart "Gravity Network...."
45992	Andrea	Davis	Andrea Davis Landscapes	The first five goals about sediment and contaminants caused by human waste and building materials is applauded, my feedback is on goal 6 which relates to storm water runoff and surface flooding. The Greater New Orleans Urban Water Plan and the Living with Water projects which Slow, Store and Use and remove when the storm is over. go to this link https://scenariojournal.com/strategy/living-with-water/	If you pass this plan will your building consent approvals have the teeth to not allow copper cladding on houses next to the water. ie the Cass Bay massive house fully clad in Copper, how will this not be repeated? Will we start to see the use of incentives with rebates for those who use green roofs and reduced house sizes and permeable driveways, will the roading units install bioswales to filter and store rain water? [see attached]

				[see attached]	
46010	Annabelle	Hasselman	Ōpāwaho Heathcote River Network	[see attached]	[see attached]
46019	Ashley	Rule	Cliff Street Residents		We understand that the Stormwater Management Plan, when completed, addresses only discharges from Council owned infrastructure. The Council requires building sites to put in place erosion and sediment control measures to manage on-site erosion and sediment. My submission is that the Council is discharging significant amounts of sediment from sub divisions and building sites into the Ihutai-Estuary through accepting and consenting poorly designed sediment containment on these sites.  This, and a lack of monitoring and overseeing compliance are leading to heavy silt loads entering the estuary in even modest rainfall. As an example, there are two Council pipes discharging stormwater from Cliff Street, Redcliffs, into the Avon Heathcote Estuary/Ihutai from the Christchurch Yacht Club car park. Sediment is is entering these pipes via surface runoff form the consented subdivision at the end of Cliff Street where development activity underway has left extensive areas of unprotected loess and poorly consolidated volcanic ash exposed to surface water flows from the hillsides above. At the downhill margin of part of the subdivision is a narrow strip of youthful shrubs widely spaced and with some sort of matting. Neither this presumed sediment detention arrangement nor the silty flows down the sealed driveway prevent accumulations of silt into the Council owned stormwater pipes discharging into the Estuary or the accumulation of silt in gutters, across the road, footpath and into driveways.  Photos of hillside sediment runoff into the estuary on 12th February 2022 at the Christchurch Yacht Club Car Park, Main Rd Redcliffs, from Cliff Street drains. The Council requires building sites to put in place erosion and sediment control measures to manage on-site erosion sediment. If the plan stipulated standards of water quality in place at the source, this would be easier to

					force compliance rather than focusing on a design which may not produce acceptable water quality and places the onus on the developer. We would like to see the plan: • Dictate stormwater quality standards for runoff prior to it entering the Council system • Increase enforcement and monitoring of sites • Give the Council recourse, after consent, if the quality of the runoff water is not to a required standard prior to entering the Council infrastructure. From Cliff Street residents: Ashley and Meg Rule. Marion Archer. Andrew Davidson. Matt Sawyer. Dean Smith. Martin Ward
46024	Nicolle	Vincent	New Zealand Steel Limited	[see attached]	[see attached]

Redcliffs Residents Association

21 March 2022

Submission on the Ihutai-Estuary and Coastal Draft Stormwater Management Plan

The Redcliffs Residents Association commends the City Council for developing this plan and ask for it to be strengthened and implemented without delay to reduce the sediment and contaminant release from our hillsides and walking tracks, and subdivisions resulting in siltation in the waterways and the estuary.
Our principal concern is the control of sediment run off which is an environmental problem at both source and destination and one that also concerns groups of property owners on slopes below the roads and in some lower lying streets.

In particular we support:

1. “Possible ways to control contaminants” (pages 10 and 11). This table sets out the contaminants of concerns for this management plan and their sources, and lists controls. We comment on two sources and advocate for the inclusion of a third.

   1.1 “Sediment”. (from construction and excavation sites). The document notes that “The Council requires building sites to put in place erosion and sediment control measures to manage on-site erosion sediment.”, and comments that “This has been a difficult and often poorly managed on-site. However, erosion and sediment control measures are now being regularly checked by building inspectors.”

   It is pleasing to see that the Council recognises that this issue has been poorly managed in the past and the Association has received complaints from residents on this matter which have been relayed to Council staff. However, we are not confident that the requirement for sediment control measures to manage on-site erosion and sediment is actually being implemented which suggests that Building Inspectors may not be enforcing these requirements.

   1.2 “Port Hills sediment”. (from slips, underground tunnelling, bank erosion). The possible controls identified are to “Fence and vegetate unstable valleys, slips and watercourses”.

   We strongly support this approach and advocate for additional measures; to create local detention structures like dams, ponds, and wetland areas to intercept flood flows and silt runoff.
   1.3 Missing source. In addition to the two sediment sources above which are listed in the table on pp10/11, there is one further important source of sediment discharge. It is from existing poorly designed and operating disposal systems or ones that have failed completely. The dispersal system servicing parts of Craigieburn Lane is an example of the latter. There are others that we can show you.
   The omission of this source of contaminants is a significant gap in the draft plan and we ask for it to be included in the final plan with suitable and effective controls.

[redacted]

2. Goal 1.4 “To have less than 10 percent of all consented construction activities on the Port Hills reported non-compliant due to sediment discharges – by 2025” (page 12).

   We support this goal but urge the final plan to identify serious and persistent offending sites to be targeted first with enforcement of controls set in rules and consent conditions. One such persistent source of silty discharges in Redcliffs is the Emily Heights Subdivision.

3. Goal 1.5 “To investigate ways to reduce the environmental effects of sediment discharges – by 2022” (page 12).

   The plan should note that priority would be given locations where greatest environmental damage is currently underway in particular those ones where the discharge plumes from major single point stormwater discharge points enter the estuary.
   Monitoring in erosion prone areas is needed also to respond to discharges from post construction works such as irrigation systems which can result in erosion.

The following two recommended actions for the **Surface Water Improvement Plan** flowing from these goals (1.7 and 1.8) are supported with qualification.

4. Goal 1.7 to “Plant severely eroding natural areas of the Port Hills from Sumner to Hoon Hay Valley.” (page 12).

   We request that this approach be more flexibly applied to not just severely eroding but areas where erosion poses greatest risk of ecological/environmental damage or its reduction or elimination gives greatest ecological/environmental benefit based on ecological assessment. The area addressed should include as much of the catchment above these locations as possible.
5. Goal 1.8 to “Put in place best-practise sediment controls on Port Hills roads and tracks – by 2025” (page 12).

   Once again, a priority should be given locations where greatest environmental damage is currently underway in particular those ones where the discharge plume from major single point stormwater discharge points enter the estuary.
6. Goal 6. “To limit the quantity of stormwater from all new development sites to pre-development levels, and minimise stormwater increases from re-development sites through consent conditions”.

   This is a commendable Goal but one that requires a much greater commitment from Council in monitoring and enforcement than it has shown in the past. Progress on this Goal requires more resourcing of consent (and rule) monitoring and enforcement.
   Operational funds need to be allocated for these activities in the Annual and Long Term plans to help ensure this Goal can be met.

7. Two missing Goals. We believe the plan needs to have added two further goals if its overall objectives are to be met.

   7.1 To identify, redesign and implement new stormwater disposal systems where existing ones are discharging silty sediment and or creating under runners.
   This self-evident Goal should be high on the Council’s list and its implementation will help ensure rapid progress is made to address current silty flows into waterways and the estuary.

[redacted]

7.2 To approve only those stormwater collection and disposal systems for new developments that do not result in overground or under runner flows onto neighbouring land. Design standards for individual or group stormwater discharges on the hill suburbs in the past have included flow dissipaters and spreaders, and velocity checking structures many of which have failed by erosive overflow and downslope channelling. The continuing failure of these designs brings into question their efficacy and the sense of them being approved by the City Council for use by developers.

8. Absent from this draft plan is mention of the infrastructure carrying the stormwater from land to sea (estuary). Regular checks and routine maintenance have not been a strong feature of the Council's management of the discharge structures and in the particular hinged flaps at the pipe terminals have been held open by debris resulting in salt water intrusion into residents garden.

   Climate change induced sea level rise will reduce the effectiveness of some of these outfall structures and assessment of resilience to this certainty needs to be on the Council's agenda together with an improved monitoring programme.

In summary we seek:

1. more targeted attention on reducing the source and destination impacts of actual and potential silty discharges from already consented subdivisions, Council owner hillside land and walking tracks,
2. Improved design of stormwater discharge arrangements for new activities of all types,
3. Repair and replacement of existing stormwater systems that are failing to contain silty runoffs and under runners, and
4. Innovation in silt runoff interception through use of valley floor detention structures.

[redacted]

[redacted]

Christchurchairport.co.nz

21 March 2022

Christchurch City Council
53 Hereford Street
Christchurch

CHRISTCHURCH CITY COUNCIL IHUTAI-ESTUARY AND COASTAL DRAFTDRAFT STORMWATER MANAGEMENT PLAN

Submitter: Christchurch International Airport Limited (*CIAL*).

Introduction

1 Thank you for the opportunity to comment on Ihutai-Estuary and Coastal Draft Draft Stormwater Management Plan.

2 CIAL supports three key purposes of the plan:

2.1 To meet the targets for lowering stormwater contaminants under the Comprehensive Stormwater Network Discharge Consent (CSNDC)

2.2 To propose extra targets for lowering stormwater contaminants above and beyond the CSNDC

2.3 To describe the ways stormwater discharges will be improved over time to meet environmental objectives.

3 CIAL also recognise the main issues for the Ihutai-Estuary and Coastal Draft is water quality and ecological health and flooding risks.

Bird Strike Risk

4 Bird strike is when a bird or flock of birds collide with an aircraft. This can cause damage to the aircraft, which compromises safety and, in many instances, forces an emergency landing.

5 Bird strike risk is increased by flocks of birds flying across flight paths between different parts of the city. Birds fly across the city every day between roosting areas, feeding areas, areas of standing water.

6 The more activities / sites near the airport that attract birds, the more likely it is that birds will fly across flight paths between these activities / sites and increase the risk that bird strike will occur at the Airport. Any new activities or habitats which will attract birds should be managed to ensure that they will not increase bird strike risk at the Airport.

7 CIAL would like to highlight the risk of bird strike is applicable to an area greater 3km, activities that have the potential to impact bird strike risk extend out to 13km radius of the runway thresholds. 13km radius is the "shared" airspace and is the area which both Aircraft and birds occupy, hence creates potential for bird strike.

8 The International Aviation Authority states "typically a 13km (or 7NM) circle is considered a large enough area for an effective wildlife management plan. It also recommends "For any new off-airfield developments being proposed that may attract birds or flight lines across the airport, it is important that the airport operator be consulted and involved in the planning process to ensure that its interests are represented[1]

9 Activities which may result with a change to the existing environment including the potential to change behaviours of bird flight paths for CIAL high risk species require specific assessment, this includes the creation of new water bodies.

10 The planning framework in the Christchurch District Plan specifically, strategic objective 3.3.12, policy 6.7.2.1.2, and policy 8.2.3.4 provides for the assessment of birds strike risk outside of the 3km bird strike risk management area.

11 CIALs would like to engage with CCC on the creation of new water bodies which have the potential to change the risk of bird strike within a 13km radius of the runway thresholds.

Dated 21 march 2022

Felicity Blackmore

Environment and Planning Manager

[redacted]

[1] ICAO (2020). Airport Services Manual. Part 3. Wildlife Hazard Management. Fifth Edition.

SUBMISSION TO:	Christchurch City Council
ON:	Ihutai-Estuary and Coastal Draft Stormwater Management Plan
BY:	Waitai Coastal-Burwood Community Board
CONTACT:	Bebe Frayle Chairperson, Submissions Committee [redacted]

1. INTRODUCTION

The Waitai Coastal-Burwood Community Board appreciates the opportunity to make a submission to the Christchurch City Council on the Ihutai-Estuary and Coastal Draft Stormwater Management Plan.

The Board wishes to be heard in support of this submission.

In preparation for this submission, the Board hosted a Resident's Association Forum to get feedback from the residents in our Wards on this plan. The feedback we received is reflected in this document.

2. SUBMISSION

Do you have any feedback on this plan's proposed goals?

Goal 1 – 4
The Board recognises the importance of controlling contaminants entering our waterways and stormwater system, and supports the mitigations described in the plan.
We note that some of the mitigations involve changes that residents may be asked to make (e.g. painting their roof or changing brake pads). The Board recommends that the Council consider providing a subsidy for this, or preferrably, advocating for a central government subsidy to assist with the financial impact of these mitigations.

While we understand that reduction/removal of contaminants is important, it is not the most pressing concern our residents have around Ihutai Estuary stormwater issues – earthquake legacy issues are far more important. Until these are resolved, it is difficult to focus on other matters.

Goal 5
Engaging with residents and providing them with information about what they can do to help mitigate stormwater contamination is a good first step. The Board sees this as a starting point for a conversation about the importance of cleaning up our waterways.

Because this issue impacts on our Coastal residents more than it might on other suburbs, there is a concern that residents in other parts of the city will be less concerned about issues that are not happening in their area. The education needs to stress that stormwater management requires a city-wide response, it's not just an issue for riverside or coastal communities to deal with.

Goal 6
The main feedback from our residents on the management plan is that it is important for the Council to focus on resolving our earthquake legacy issues FIRST before any other actions are taken in relation to stormwater and Ihutai Estuary management.

The remediation required to deal with damage from the earthquakes, and mitigations required for stormwater management need to be treated as separate issues. It is good to see that the management plan acknowledges the work that has recently begun on coastal hazards adaptation planning (CHAP). It is important that these processes proceed in tandem.

A comment from the Resident's Association Forum summarises this concern well:
As a matter of principle, we need to distinguish between flood risk and protection as a result of climate change (CHAP) and flood risk and protection resulting from the 2011 earthquakes. Returning the stormwater and drainage network to the same functionality as before the earthquakes needs to be the baseline, the datum, for any discussion that CCC has with its community in respect to CHAP. First fix the damage from the earthquakes, and then let's deal with the impact of climate change.

As our Wards are the receiving environment for stormwater across the city, resolving existing earthquake issues, and providing top-quality stormwater infrastructure and maintenance in our Wards is essential.

As noted in the Resident's Association Forum:
Most stormwater in metropolitan Christchurch eventually ends up in the estuary; when it rains in Sydenham or the CBD, it will end up in the estuary.

The Resident's Association Forum also raised the issue of equity, one person commenting that:
It would be inequitable for coastal communities if stormwater from extreme weather events is simply disgorged into the estuary from the other metropolitan catchments. This is a metropolitan-wide issue that needs to be shared and managed across the city — whether environmentally through, for example, the development of swales and floodplain along the OARC or additional storage capacity in other metropolitan catchments.

Do you have any other comments on this plan?

It would be good if this management plan was more specifically linked to the other management plans, given the concerns about our Board area being the receiving environment for stormwater from other parts of the city.

Funding – it is noted that the management plan will be funded through the Long Term Plan. It is important that this important work is given priority in the Long Term Plan, and that the funding is not pushed out as is often the case with this kind of work – it has no immediate tangible benefit so is an easy target for deferment.

Bebe Frayle
Chairperson, Submissions Committee
WAITAI COASTAL-BURWOOD COMMUNITY BOARD

5 April 2022

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Open access

Is green infrastructure a viable strategy for managing urban surface water flooding?

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ABSTRACT

Green infrastructure strategies are often cited as best practice for urban water management; however, limited research has been undertaken to compare intervention effectiveness during moderate to extreme intensity rainfall events which are typically responsible for surface water flooding. This research responds to this through applying a cellular automata-based rapid scenario screening framework to predict the flood management performance of green infrastructure strategies across an urban catchment in Melbourne City Centre (Australia). Key findings indicate an intensive application of green infrastructure could substantially reduce flood depth and velocity in the catchment but that residual risk remains, particularly during extreme flood events. The best performing intervention strategy in the study area was found to be catchment-wide decentralised rainwater capture. The research also evidences the utility of rapid scenario screening tools to complement existing flood modelling approaches through screening management strategies, exploring scenarios and engaging a wide range of multi-disciplinary stakeholders.

ARTICLE HISTORY

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KEYWORDS

Decision support, urban flooding, stormwater runoff, SuDS, water sensitive urban design

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Introduction

Intensive development in urban centres can result in them becoming particularly susceptible to flooding during intense rainfall, which can lead to extensive damage and disruption. Engineers, architects and planners must, therefore, manage surface water runoff in urban areas to minimise a population's exposure to flooding hazards. Runoff is influenced by a number of factors, including the volume and intensity of rainfall, the percentage of impermeable area and availability of space and infrastructure to manage exceedance via storage and conveyance (Chocat et al. 2007; Butler et al. 2018). These factors are predicted to worsen in response to climate change, rapid population growth and ageing drainage infrastructure (Ana and Bauwens 2010; Howard et al. 2010; IPCC 2014). Historic and contemporary approaches towards flood risk management have focussed on capturing and conveying runoff within piped systems. However, the expense and complexities of expanding subterranean infrastructure, in combination with the need to apply more cost-effective, resilient and sustainable management techniques, has resulted in increasing interest in the use of alternate interventions, such as green infrastructure.

Green infrastructure is frequently cited as a desirable method with which to manage surface water and build resilience in urban environments (Balmforth et al. 2006; Environment Agency 2007; Duffy et al. 2008; Wong and Brown 2009; Woods Ballard et al. 2015; Bowen and Lynch 2017). Terminology describing such approaches varies, including a range of synonyms such as Water Sensitive Urban Design (WSUD), Sustainable Drainage Systems (SuDS), and Best Management Practices (BMP). In this paper, green infrastructure is applied as a generic term for drainage interventions which manage surface water by mimicking natural hydrologic processes, for example, infiltration and retention (Fletcher et al. 2015). Examples of such interventions include green roofs, rainwater capture, rain gardens and permeable paving, among many others (Woods Ballard et al. 2015). Despite established inclusion of green infrastructure within academic, government and commercial discussion, several gaps regarding application in cities are still apparent (Pitt 2008; Burns et al. 2015b; Schubert et al. 2017). This paper responds to two of these gaps, namely, the application of a rapid and quantitative analysis to screen and identify suitable interventions for a given context, and the ability of these interventions to manage a range of rainfall events.

Quantitative comparison of green infrastructure flood-mitigation performance can be constrained by the high time and computational cost of hydrodynamic modelling required for context-specific analysis of the many permutations for intervention types and locations possible within an urban environment (Elliott and Trowsdale 2007; Hunter et al. 2008; Mikovits, Rauch, and Kleidorfer 2015; Löwe et al. 2017). Restrictions on time, budget and data can lead to decision-makers considering only tried and tested interventions, resulting in institutional inertia and stifling innovation (Cettner 2012; O'Donnell, Lamond, and Thorne 2017). A range of alternative selection processes have been proposed to respond to this gap; however, these typically increase speed through sacrificing simulation of flood dynamics in favour of faster and simpler qualitative analysis or subjective expert-led judgement (Ellis et al. 2004; Makropoulos et al. 2008; Young et al. 2010). Recent developments in the field have proposed the application of novel rapid scenario screening frameworks to achieve computationally efficient intervention assessment whilst still simulating flood routing to generate quantitative outputs (Ghimire et al. 2013; Guidolin et al. 2016; Webber et al. 2018a).

This study advances previous research through the application of a rapid scenario screening framework to a real-world case study in collaboration with multi-disciplinary stakeholders and planners. The aim of the paper is to evaluate the effectiveness of green infrastructure strategies to reduce flooding during intense rainfall events in urban areas. The paper is structured through introducing the framework and then describing how a range of strategies are co-designed with catchment stakeholders and examined using a case study in the City Centre of Melbourne, Australia. Results and discussion explore how green infrastructure interventions can be implemented to manage flooding across a range of rainfall events.

Materials and methods

Evaluating many strategies using a rapid scenario screening framework

The viability of green infrastructure to manage urban flooding was tested using the rapid scenario screening framework presented in Webber et al. (2018a) and validated in Webber et al. (2018b). The framework applies a simplified representation of catchment land use and flood interventions alongside a computationally efficient cellular automata flood model 'CADDIES'. CADDIES achieves fast simulation speeds through modelling 2D runoff using simplified routing rules across a regular cellular automata grid (Ghimire et al. 2013; Guidolin et al. 2016; University of Exeter 2017). The grid is composed of individual cells in which parameters specify surface elevation (m), water input (mm/h), water output (mm/h) and the velocity of water runoff across the cell surface (via Manning's n). Spatial and temporal adjustment of these parameters across the grid controls water movement and is used as a simplified representation of land use, interventions and rainfall (Figure 1).

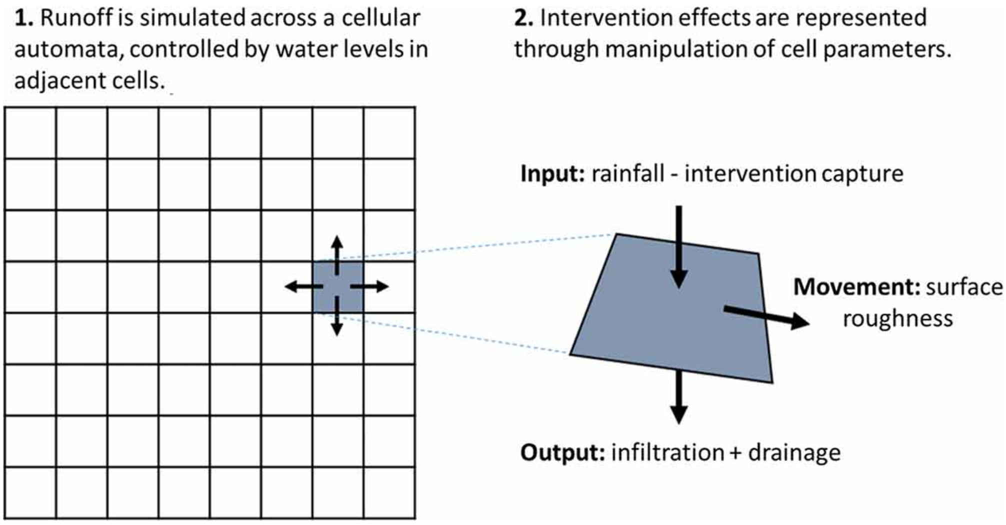

Figure 1. Runoff simulation using cellular automata, adapted from (Webber, Fu, and Butler 2018c).

The advantage of this approach is a speed increase versus traditional modelling techniques, enabling development and analysis of many interventions and rainfall scenarios (Liu et al. 2018). Previous research has identified comparable accuracy with a 5 to 20 time speed increase using CADDIES compared with other models such as Infoworks ICM (Gibson et al. 2016; Wang et al. 2018). This speed increase occurs at a trade-off versus the representation of several underlying physical processes, notably through: including representation of the piped drainage system through a cell output rate rather than detailed representation through a coupled 1D simulation; and representing interventions through cell water balance (input/output rates) and roughness parameters. Previous studies have validated these simplifications as suitable for the purposes of initial catchment screening, applicable in the early stages of flood management using easy to access data (Webber et al. 2018b). It is envisaged that this style of catchment screening is used for scenario exploration across multi-disciplinary stakeholders and to steer later flood management actions, including prioritising data collection and steering future detailed modelling using hydrodynamic 1D-2D models. Simplified model development and fast analysis is advantageous for this application of engaging stakeholders, collaboratively developing and then screening the potential of many green infrastructure scenarios in an urban catchment using accessible and inexpensive data sources.

The framework is applied in four stages: characterising the study area, representing interventions, simulating scenarios and analysing intervention performance.

Characterising study area and rainfall

The study catchment is a 4.4 × 3.4 km area in the City Centre of Melbourne, Australia (Figure 2). The catchment is intensely urbanized and constitutes a major hub of commerce, entertainment and governmental function in Melbourne. Surface water flooding in the catchment is of concern due to large historic floods in 1972 and 2010. During both of these events, surface water flows faster than 2 m/s flowed down the catchment’s main street before ponding in front of the central railway station.

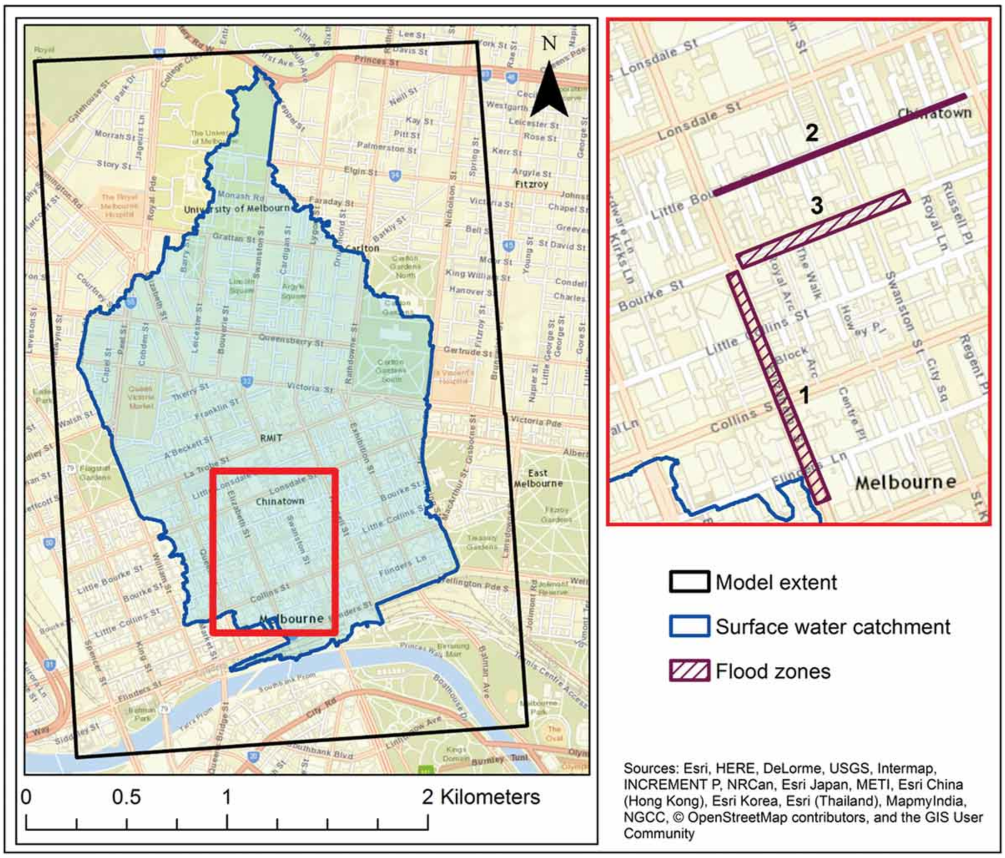

Figure 2. Identifying the study catchment and areas of investigation in Melbourne, Australia.

Buildings are typically of high rise commercial and residential structures, several of which are recognised with national heritage status. Significant infrastructure sites are located in the catchment, including a major railway station, local government offices and transport connections across the city. The highest risk area in the catchment is located in the south of the study area. This corresponds to the low point on one of the city's busiest streets, which is built on top of a natural creek. The north of the catchment includes urban parkland, national heritage sites, hospitals and the campus' of several large universities. The 'upper catchment' described in this paper refers to the region north of La Trobe Street. The south of the study catchment is bordered by the Yarra River. It should be noted that this is a highly engineered and canalised channel which is at a significantly lower elevation than the rest of the catchment, and as such fluvial flooding and interactions between surface water and the river are unlikely and, as such, are not included in this study.

Catchment elevation was represented using a 1 m resolution DEM model (10 cm vertical accuracy), which was derived from LiDAR survey. Land use was characterised into eight specifications, representing urban spaces, buildings, vegetation and transport infrastructure (Table 1). Surface roughness was attributed based on specifications for Manning's n coefficient from literature (Arcement and Schneider 1989; Hamill 2001; Syme 2008; XP Solutions 2017; Butler et al. 2018). Buildings were represented using a high Manning's n coefficient to represent water being held up within the structure (Syme 2008). Infiltration was specified based on typical rates of clay soils from the region (City of Melbourne 2018).

Table 1. Land use parameterisation in the study catchment. The geospatial data for the land use categories were sourced from the city (Kunapo et al. 2018). (Table view)

Land use type	Roughness(Manning's n)	Cell output rate (mm/h)*
Residential high density space	0.350	15
Buildings	0.400	15
Cemetery	0.100	1

Land use type	Roughness(Manning's n)	Cell output rate (mm/h)*
Minimal vegetation	0.040	1
Moderate vegetation	0.060	1
Heavy vegetation	0.090	1
Roads and pavements	0.020	15
Railway	0.125	15

*Higher rates associated with impervious surfaces represent losses due to the underground surface drainage system.

The underground surface drainage system was represented through adjusting the cell water balance through increasing the output rate in areas assumed to be drained by the piped system. This included residential high-density space, buildings, railway, roads and pavements. A rate of 15 mm/h was applied to represent a system designed to convey the average intensity of an 18% AEP, 2-h event, specified by stakeholders as a conservative estimate of the system's flow capacity based on design standards in the city. The rate was specified as it is equivalent to the average intensity of the design standard event as specified by the Australian Bureau of Meteorology (http://www.bom.gov.au/water/designRainfalls/ifd/, Ball et al. 2016).

It should be noted that the approach of applying a uniform infiltration rate across the drainage catchment is suitable for a catchment-wide application and evaluation of flood risk downstream of the contributing area; however is not likely to be suitable for evaluating highly localised flooding where a small contributing area is likely to be heavily influenced by local variation in drainage capacities. Consideration of finer resolution representation of drainage through variation depending on the trunk capacity in sub-catchments was not possible for this assessment due to incomplete data regarding the pipe network in the area. This simplified representation of drainage systems facilitated rapid screening of interventions and was able to simulate overland flooding due to the rain intensity during extreme rainfall events exceeding pipe capacity. It should be noted that this trade-off between model complexity and speed is only suitable for initial strategic comparison and not for the detailed design of options.

Validation using records from the 1972 flood event

To validate the simple representation of the catchment's underground surface drainage system, predicted model outputs from a large rainfall event were compared against available observational evidence including photographs and anecdotal information. The flood model was driven using the hyetograph of the 1972 event, one of the most intense on record where rainfall intensities exceeded 100 mm/h for approximately 20 min. The model predicted localised flooding deeper than 1 m, which compared well with photographs depicting flood waters exceeding the height of cars (e.g. http://marvmelb.blogspot.com/2014/02/the-great-flash-flood-of-72.html). This high-level validation builds confidence that the flow routes and approximate depths are acceptable to use for an initial and relative assessment, aimed at high-level option comparison.

Design rainfall generation and identification of a 'catchment critical event'

Engineers typically base designs for surface water management systems on a critical duration event where all upstream areas are contributing rainfall to a specific location. This approach is not possible when considering flood hazard across an entire catchment due to the spatial complexities and differing intensities generated from a range of rainfall profiles. The study overcame this restriction by taking advantage of simulation speeds to analyse a range of rainfall profiles and compare maximum flood depths to identify a 'catchment critical event'. A total of 30 rainfall events were assessed, including five different frequencies (18%, 10%, 5%, 2% and 1% AEP) across six different durations (30, 60, 120, 180, 270 and 480 min).

Design rainfall was derived using methods outlined in Australian Rainfall and Runoff (Ball et al. 2016). This analysis identified peak flooding during the 1-h rainfall profile for all annual exceedance probabilities; therefore, this was used for analysing intervention effectiveness.

Throughout the paper, the likelihood of design rainfall is described in terms of annual exceedance probability (AEP). This terminology was selected to address potential ambiguity for multi-disciplinary stakeholders unfamiliar with hydrology, due to misconceptions regarding implied periods of 'safety' between event recurrences when presenting findings using return periods, i.e. '1 in X year'. This is important for a study partially responding to the need for decision-support suited to stakeholders of varied training and professional backgrounds.

Developing and representing intervention strategies

The research team collaborated with the catchment's local government to devise potential surface water management strategies which could be applied within the area. This involved a series of workshops with key organizational staff from a range of departments, including engineering, environmental management, and urban planning. Workshop participants identified a range of strategies, which included specific sites for green infrastructure retrofit along with the possibility of broad implementation of interventions across the entire catchment.

Translation of the strategies into the flood modelling framework involved editing the rainfall input, output and roughness data for all relevant cells within the study catchment (Figure 1, Webber et al. 2018a; Webber et al. 2018b). The effect of each strategy is applied uniformly across every cell specified. A percentage of catchment treated is described for each strategy to indicate the scale and scope of the intervention. The following section outlines each of the scenarios examined, describing the adjustments to cell parameters and extent of the intervention effect relative to the total area of the catchment. A summary of all strategies is presented in Table 2.

Table 2. Intervention scenarios applied to the catchment. (Table view)

Intervention	Distribution (% of study area)	Roughness (Manning's n)	Infiltration (mm/h)	Rainfall capture (l per cell)
Base case model	n/a	Land use	Land use	n/a
Green roofs on all buildings	39.4	Land use	Land use	10.00
Green roofs in the upper catchment	7.8	Land use	Land use	7.50
Rainwater capture tanks on all buildings	39.4	Land use	Land use	25.00
Rain gardens across all impermeable spaces*	43.5	Land use	Land use	7.00
Tree pits in the upper catchment*	43.4	Land use	Land use	0.12
Permeable paving across all impermeable spaces*	43.5	Land use	Land use (plus 1.0)	10.00
Rainfall storage in the university campus	6.6	Land use	Land use	3.30
Rainfall storage in university buildings	0.3 (zone 1) 0.7 (zone 2)	Land use	Land use	46.00 (zone 1) 10.00 (zone 2)
Enhanced catchment storage	15.6 (zone 1) 52.2 (zone 2)	Land use	Land use	8.10 (zone 1) 4.50 (zone 2)

Intervention	Distribution (% of study area)	Roughness (Manning's n)	Infiltration (mm/h)	Rainfall capture (l per cell)
Increase park space	0.9	0.040	1.0	100.00
Pipe duplication	17.1	Land use	30.0	n/a

*Intervention capture rates averaged over all cells; therefore, underlying land-use parameters are used to represent infiltration and roughness.

Base case

The base case represented a business-as-usual scenario where the catchment was simulated as described in 'characterising study area and rainfall', with no interventions applied. This was used as a comparative baseline to measure the performance of each intervention strategy against.

Green roofs applied across the entire catchment

This scenario represented retrofitting green roofs on all buildings within the catchment. Application across all roofs constituted 39% of the total catchment area. This was deemed to be an aspirational strategy, achievable in the medium to long term through changes in city-level planning. Green roofs were modelled through editing input hyetographs to represent capturing rainfall within a cell. Each m^2 of a green roof captured 10 l of rainfall, based on a review of the green roof literature (Mentens, Raes, and Hermy 2006; Stovin, Vesuviano, and Kasmin 2012; Woods Ballard et al. 2015). Such levels of rainfall retention represented a conservative estimate, irrespective of antecedent conditions, taking into account a range of typical values associated with varying roof slope, substrate storage capacities and climates.

Green roofs applied across the upper catchment

This was a more cautious strategy devised by the local government, enabling the study to investigate a range of green roof values and to accommodate strategies suggested by multiple stakeholders. The scenario only added green roofs to specific buildings in the upper catchment, representing 8% of the total catchment area. Rainfall capture with this intervention was further limited to a more conservative 7.5 l per m^2 of the green roof.

Rainwater capture tanks applied across the entire catchment

Rainwater capture tanks were applied across all buildings in the catchment. It was assumed that rainfall would be captured on roof surfaces and transmitted through the downpipe to storage tanks within each building. This constituted 39% of the total catchment area.

A storage capacity of 2500 l per 100 m^2 of roof space was applied across all buildings. This value represents an estimate for rainwater capture supported by literature and common practice (Burns et al. 2012; Hamel and Fletcher 2014; Schubert et al. 2017). It was assumed that the entire capacity was available for storage, attributed to real-time control operation draining the tank in preparation of a predicted rainfall event, and that the downpipe would not throttle water into the tank (Xu et al. 2018).

Rain gardens distributed across the entire catchment

Rain gardens were applied across impermeable areas within the catchment. A 2 m^2 garden was specified to drain 100 m^2 of impermeable catchment. The rainfall capture effect was represented through a uniform application of this capture capacity across all contributing cells, representing 43% of the total catchment area.

Rainfall is captured in rain-gardens through surface ponding and infiltration into porous filter media. Surface ponding was specified to a depth of 200 mm of water across the 2 m^2 surface (equating to 400 l of storage). The filter media were assumed to be 500 mm deep with a porosity of 0.4, but an effective porosity of 0.30 to account for likely antecedent soil moisture. Therefore, each rain-garden had a total storage capacity of 700 l (400 l at the surface and 300 l within the filter media). The filter media were lined and assumed to flow into the surface water sewer system, so no allowance for infiltration was included within the intervention. The value of 700 l was applied uniformly across all cells in the 100 m^2 catchment to generate a representative average capture effect of 7 mm of rainfall per m^2.

Tree pits distributed across the upper catchment

The effect of locating 1000 tree pits across the upper catchment was modelled through assuming the storage capacity of a 1 m^2 tree pit to be 350 l, using the same assumptions as for rain gardens (above). This capacity was multiplied by 1000 and then applied as a uniform capture volume of 0.12 l/m^2 across the entire upper catchment, which constituted 43% of the total study area.

Permeable paving distributed across the entire catchment

Permeable paving was modelled through assuming all impermeable areas within the catchment, constituting 44% of the study area, could runoff to a permeable paving unit. Typical paving structure comprises 200 mm depth gravel with a porosity of 0.5 (Melbourne Water 2005; Yong et al. 2011; Mohammadinia et al. 2018). This equates to 100 mm of interception across each 1 m^2 paving unit. It was assumed that each permeable paving unit served 10 m^2 of contributing area; therefore, this effect was averaged and distributed evenly, represented through 10 mm captured from each contributing cell. An ongoing infiltration rate of 1 mm/h was based on a typical permeability of the underlying clay catchment.

Enhanced catchment storage

The local government was interested to test the potential combined effect of large-scale distributed storage applied across the entire catchment. This scenario represented the possible effects of a collaboration between all property planners and owners (both public and private) in the catchment. It was assumed storage would be implemented through a wide application of sustainable drainage features, which may also offer additional benefits to the city.

Previous investigations by the local government found that a value of 4.5 l/m^2 could be achieved across the catchment and an enhanced storage capacity of 8.1 l/m^2 would be possible in strategically targeted areas of the upper catchment. This is a strategic development zone within the city centre where extensive works are currently being planned in collaboration with major landowners. No detail could be provided regarding locating sites at this early stage of option analysis; therefore, this intervention was modelled through capturing rainfall landing within each cell of the catchment. Standard storage capacity was applied across 52% of the total catchment area and the enhanced capacity was applied across a further 16% of the catchment area.

Storage at a major university campus

Further storage was considered across the City's major university campus in the north of the city centre. A total of 1.5 Ml of storage was proposed, achievable through intensive application of surface water control measures such as permeable pavement, rain gardens and rainwater capture across the campus. Storage was implemented in the modelling framework using an assumption of uniform capacity across the entire campus, which constituted 6.6% of the total catchment area. The effect over this area was estimated to be 3.3 l/m^2.

Storage at university buildings integrated within the city centre

Similar storage was proposed across the other university in the catchment. These buildings are located across multiple sites clustered in the north of the city centre. It was proposed that 1 Ml could be captured on roofs of campus buildings the northern subset and 0.5 Ml could be captured on roofs in the southern distribution. This was modelled through capture volumes of 46 l/m^2 in the north (0.3% of the total catchment area) and 10 l/m^2 in the south (0.7%).

Park expansion at city squares

The local government proposed expanding the pervious area of three major parks in the catchment. The parks were expanded across the roads to increase the park space up to 0.9% of the total catchment area. Each 1 m^2 section of park space was specified to capture 100 l of rainfall, with a continuing rate of 1 mm/h infiltrating into the underlying clay soil. Roughness was attributed a uniform Manning's n coefficient of 0.040 to represent minimal vegetation coverage across the square.

Increasing drainage capacity in the strategic sub-catchments

A 'grey' intervention proposed was to increase the drainage capacity in two key areas through duplicating current pipes in two surface water drainage sub-catchments, representing 17% of the catchment area. Limited data exist regarding the pipe capacities, so a high-level assumption was used to represent the scenario where the drainage rate used in the analysis was doubled to 30 mm/h output per cell across both areas.

Simulating scenarios

In total, 60 simulations were executed, which consisted of the 12 intervention scenarios across the five rainfall magnitudes. Simulation was undertaken using CADDIES run on an 'Nvidia Tesla K20c'. Average simulation time for each scenario was 2.1 h at a minimum model time step of 0.01 s.

Analysing intervention performance

Areas of investigation

Intervention performance was assessed in three zones across the catchment. These were selected through correlating flood ponding and conveyance routes during the base case scenario with expertise and observations from local government. Each transect corresponded to a major road within the catchment and was corroborated as areas of interest through historical flood observations (Figure 2).

Using peak flood depth as a flood hazard metric

Performance of interventions was assessed using peak flood depths in cells within each transect identified in Figure 2. Peak values were chosen for analysis as these represent the worst-case flooding and allow one image to effectively communicate overall flood hazard to stakeholders.

Results

For brevity, not all results appear in the paper. The 5% AEP event is presented to represent flooding during a design standard event and the 1% AEP event is used to present a low probability flood scenario, such as the 1972 event (Ball et al. 2016). Where discussion references the performance of interventions across other events, further results are available in the supplementary information.

Catchment flood characteristics

Surface water flooding was observed during the 1-h rainfall event in all scenarios and at all exceedance probabilities. Analysis of the distribution of peak flood depths per simulation indicates that the deepest mean and maximum peaks are observed in the base case scenario for all transects and during all return periods, demonstrating that no intervention had a negative effect on flooding within the study area.

Intervention performance during the 5% AEP event

The majority of interventions reduced flood depth across the three transects during the 5% AEP rainfall event. Figure 3 shows the distribution of peak flood depth across all cells for all strategies in each of the three transects. All scenarios are presented within this graph so they can be evaluated in terms of their relative flood reduction effect. The peak flood depth metric is used to provide an absolute reference point to assist in communicating effectiveness to a wide range of stakeholders. It should be noted that as a high-level scenario exploration tool it is most appropriate for these depths to be compared relatively and further detailed modelling with additional data is required to develop these results into values appropriate for full design.

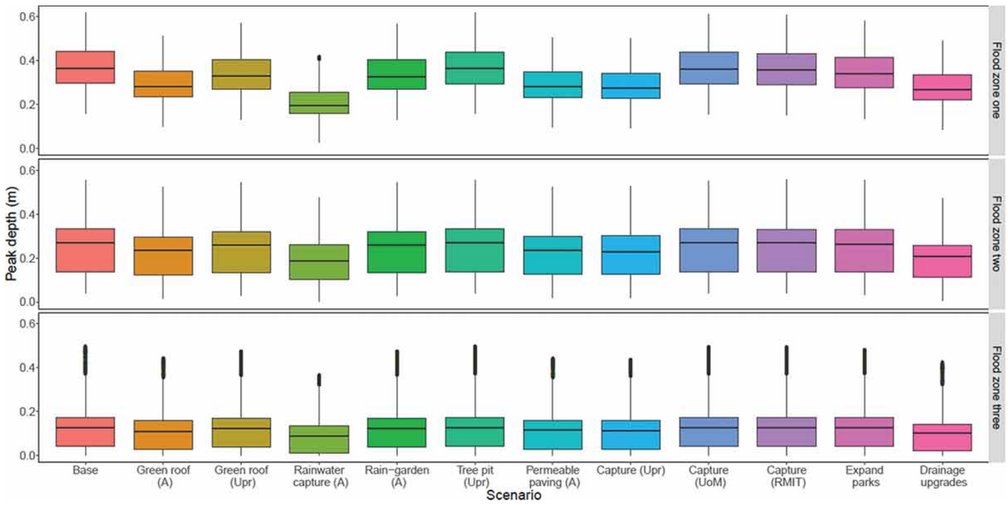

Figure 3. Comparison of peak flood depth distribution for all transects in the 5% AEP event.

The maximum mean peak depth in the base case scenario, approximately 0.38 m, was observed in Zone One. The deepest peak flood depth, over 0.61 m, was also identified in this zone. Zone One is located at the furthest downstream point of the catchment and will have the largest contributing area when flows exceed the drainage capacity. Flooding across the other zones was on average shallower, due to smaller contributing areas.

The largest reduction in peak depth was observed in Zone One, where several strategies reduced the mean peak flood depth by 25% to 50%. The most effective interventions were those applied across large areas of the catchment, including rainwater capture, green roofs, permeable paving and the introduction of enhanced storage in the upper catchment. Rainwater capture was consistently the most effective intervention, reducing the mean peak flood depth to less than 0.2 m in Zone One and Two, and to less than 0.1 m in Zone Three. The strategy of increasing drainage capacities also results in reducing flood depths. Tree pits and capturing runoff at the city's universities demonstrated a negligible reduction in flood depth versus the base scenario. It is suggested that, in this instance, these interventions only capture enough rainfall to delay the timing of the flood peak, rather than reduce peak magnitude.

Interventions demonstrate similar performance rankings in each zone. The most effective performances were observed in Zone One with similar, albeit a smaller range of, values exhibited in the other study areas. No interventions completely eliminated flooding; however, rainwater capture does remove all flooding from certain cells in Zone Two, a benefit which is not present in the base scenario. All interventions demonstrated cells with no flooding in Zone Three.

Intervention performance during the 1% AEP event

Deeper flooding is observed across all scenarios during the 1% AEP event (Figure 4). Intervention performance generally approaches the base case scenario, with less variation in performance relative to lower return periods. Ranking of interventions remains consistent, but less apparent.

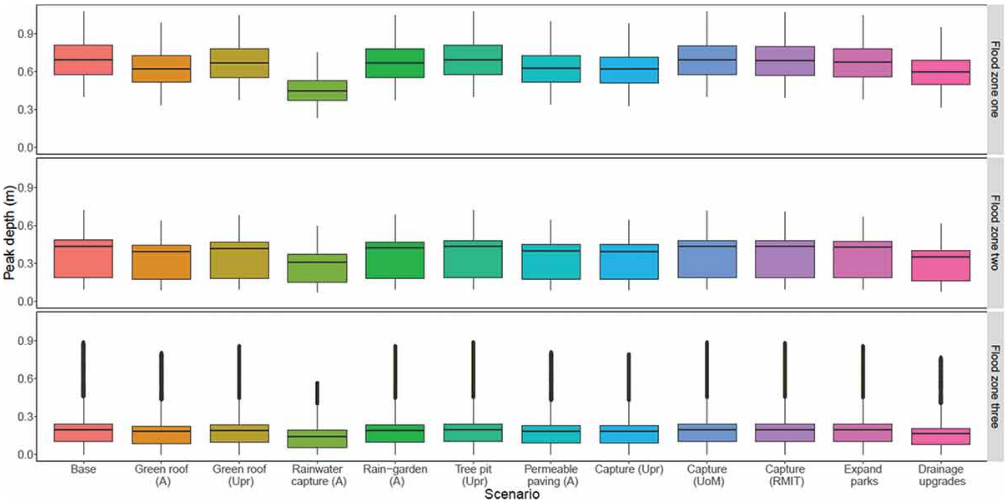

Figure 4. Comparison of peak flood depth distribution for all transects in the 1% AEP event.

No interventions worsen flood depths; however, tree pits and capturing 1.5 Ml at the University of Melbourne and RMIT campuses show negligible differences to the base case across all transects. Other strategies based on a defined capture volume, such as green roofs in the upper catchment, rain gardens and park expansion also have little impact on flood depths. Limited performance is attributable to rainfall exceeding capture capacities during the event and therefore interventions leading to a delay, rather than reduction, in peak runoff volume. This effect is partly mitigated by strategies applied across the whole catchment or large areas, such as rainwater capture, green roofs, enhanced catchment storage and permeable paving which capture sufficient volume to reduce peak depths. Strategically targeted and intensive options such as increasing drainage capacities also demonstrate an improvement versus the base case.

Interventions flood reduction performance was less apparent in Zones Two and Three. It is suggested that this is due to the transects chosen, which receive input from smaller areas of the catchment, reaching their respective time of concentration faster after rainfall volume exceeds capture capacities.

Analysis of depth distribution is a useful tool for identifying strategic performance trends during decision support. However, it is also important for decision-makers to consider the location of flooding, in order to conceptualise and manage risk. Figure 5 presents a visualisation of peak depths in the base case scenario during the 1% AEP event (panel A) with a comparison of the reduction in flooding created by the application of the most effective intervention, rainwater capture (panel B).

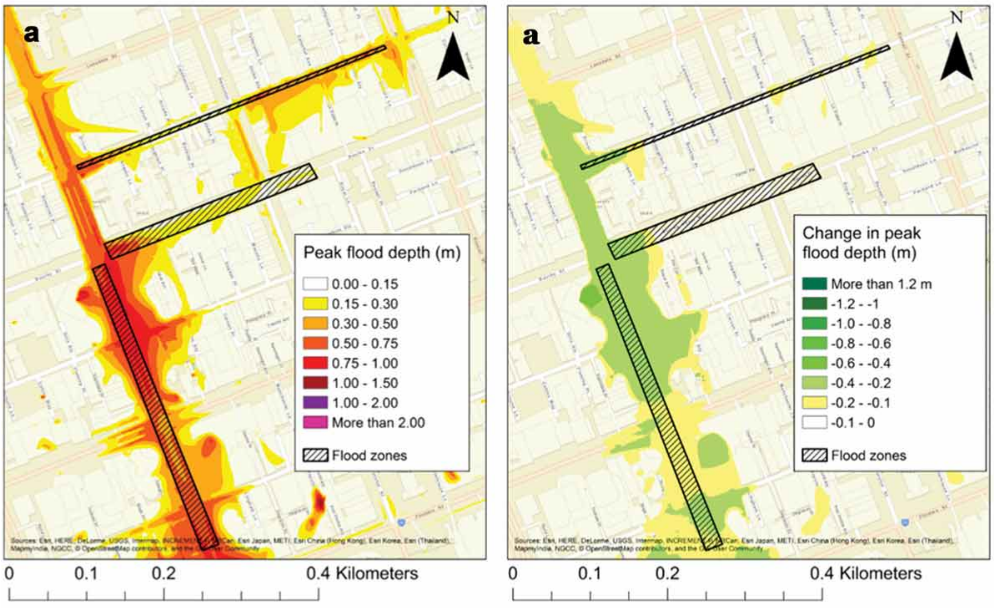

Figure 5. Effect of catchment scale rainwater capture on peak flooding during the 1% AEP event. (a) Base case and (b) Difference in peak floods using rainwater capture.

This figure shows that rainwater capture reduces peak flood depths by 0.2 to 0.6 m across the entire width of Zone One along approximately 300 m of the transect. This demonstrates a substantial public safety and damage reduction improvement versus the base case scenario.

Discussion

Green infrastructure to manage surface water

Many interventions reduced peak flood depths, and no strategy performed more poorly than the base case approach. Of particular note were interventions applied as part of a decentralised and catchment-wide strategy.

The apparent limited performance of certain localised or independent interventions should be considered in the context of an incremental development step towards a larger catchment management approach. In addition to this, although local strategies may not reduce the peak depth in the downstream catchment, their local effect and delaying flood peaks may facilitate more effective movement around areas of severe flooding which are consistent with large rainfall events.

A reduction in peak flood depth will likely correlate with a decrease in flood damage costs (Penning-Rowsell et al. 2005; Hammond et al. 2015). Reduction in flood volume will also reduce the duration of flooding, which in turn will reduce the disruption and hazard exposure to the general public. Delaying the occurrence of peak flood depths will also provide an opportunity for additional warning time, enabling more effective application of flood resilience measures and early warning systems, potentially providing safer emergency evacuations of the at-risk areas and allowing diversions to limit disruption in a key economic hub of the city (Parker, Priest, and McCarthy 2011).

No interventions completely prevented surface water flooding in the zones studied during any rainfall event. This is likely due to a very high capacity of storage and conveyance systems required to capture runoff from the large contributing area in combination with the high intensity of rainfall predicted during short duration events. Despite this, many strategies demonstrated a reduction in flood depth within the flood zones studied. Many interventions also created safe areas, where water levels were reduced to either zero or very low values. Safe areas prevent damage in the locality, but also have a far wider reach in minimising disruption and consequences through establishing evacuation routes which can provide the public with an opportunity to minimise hazard exposure.

Application of frameworks such as this which facilitate analysis of many simulations may have a role in iteratively combining smaller local strategies to project the impact of combined future projects and develop towards greener urban catchments. This mode of analysis could also provide useful in identifying tipping points, where the combined effect of interventions will reduce rather than delay the peak flood and limit the requirements for financially and environmentally expensive subsurface drainage upgrades.

Effect of AEP on green infrastructure performance

Fast analysis of strategies enabled evaluation of performance across multiple rainfall AEP scenarios. This analysis has identified a clear trend where, as events become more intense (i.e. AEP decreases), intervention performance to reduce peak flood depth and velocity become less effective. It should be noted that this finding is made relative to the peak values and does not include the intervention effect on hazard duration. However, in the case of surface water flooding, the peak depth rather than flood duration is likely to be the controlling factor in flood damage (Penning-Rowsell et al. 2005).

The reduction in intervention performance during more intense rainfall is attributed to strategies reaching capacity and then ceasing to reduce the flow rate versus the base case scenario. This pattern of interventions becoming less effective at reducing peak values during high-intensity events is observed during the 1% AEP event, where differences between interventions were negligible.

Assessing the response of green infrastructure to changing rainfall intensities is significant as it informs understanding the effective flood management beyond design standards. Green infrastructure is frequently cited as a desirable method with which to manage surface water and build resilience in urban environments (Wong and Brown 2009; Woods Ballard et al. 2015; Bowen and Lynch 2017). Finding that performance of certain interventions reduces in response to high-intensity rainfall indicates that resilience of interventions needs to be assessed in relation to a range of events when building urban resilience, particularly in light of increasing intensity and frequency of future hazards (Howard et al. 2010; IPCC 2014).

Supporting practical application of green infrastructure through collaborative strategy screening

It is imperative that catchment stakeholders understand the performance of flood management techniques in order for benefits to be applied to cities (Pitt 2008; Burns et al. 2015a; Schubert et al. 2017). Historic approaches have been limited by restrictions on time, budget and data which can lead to decision-makers considering only tried and tested interventions, resulting in institutional inertia and stifling innovation (Cettner 2012; O'Donnell, Lamond, and Thorne 2017). This research sought to develop the application of new methods to address this institutional barrier through collaborating with key personnel from the local government to devise intervention strategies. There is thought that such civic experimentation can change standard practice (Karvonen 2011), and in this case, could increase the capacity of the local government to implement green infrastructure. This is particularly important because case study results suggest that substantial reductions in flood risk are made possible when green infrastructure is applied across large areas of a catchment, requiring buy-in and communication between many stakeholders. Rapid analysis using the framework enabled a series of workshops in quick succession, in which stakeholders could communicate and test strategies with fast feedback upholding a collaborative momentum.

Achieving high levels of green infrastructure implementation will likely take time and trusting partnerships between those involved (Burns et al. 2015a). Planners, therefore, need to develop and articulate aspirational strategies which gradually implement actions towards catchment-wide surface water flood management. It is important to note that although the more localised interventions appear less effective, these will play a vital role in achieving larger scale ambitions. Communicating that substantial outcomes could take time will be an important part of stakeholder consultation efforts.

Limitations and future research

The approach applied constitutes a fast process which appears very well suited to intervention screening and to facilitating collaboration between catchment stakeholders. The tool is subject to several limitations which need to be recognised during implementation and evaluated when applying findings to direct further flood management actions.

The main limitation is the simplified inclusion of the underground drainage network. The constant infiltration approach is able to represent the recession process (Wang et al. 2018), but is unable to simulate hydraulic events such as downstream pipe surcharge or throttling (Webber et al. 2018b). Therefore, application of results should be used to direct and prioritise requirements for further detailed modelling which incorporates the sub-surface system. It should be noted that aside from speed, a further benefit of this simplified representation is that only limited understanding of a drainage network is required for setting up and screening models to examine the surface water runoff. This is of particular importance where components of the drainage system may be unknown: A common problem in many urban areas.

A further useful addition to the framework would be the inclusion of the multiple benefits associated with each intervention. Current literature regarding assessment of cost-effectiveness within this framework is available (Webber, Fu, and Butler 2019) however inclusion of cutting edge additional benefit measurement techniques would provide a greater opportunity for application as an integrated decision support framework able to manage resilience and sustainability (Guswa et al. 2014; CIRIA 2015; Kunapo et al. 2018).

This study has also focussed on evaluating uniform strategies so as to familiarise a wide range of stakeholders with a simplified version of the scenario exploration and to communicate the relative benefits of a diverse range of intervention types and strategies. This is particularly beneficial to disseminate a direct demonstration of the utility of green infrastructure versus more traditional hard engineered approaches to stakeholders from a range of backgrounds. It is recommended that future developments of this methodology expand the scenario development to include the effectiveness of combinations of interventions to explore the synergies and compounding benefits of heterogeneous strategies. Further refinement of the work would also consider the effect of antecedent conditions on runoff capture.

Conclusions

This study successfully implemented real-world application of a research-based framework to determine the positive effect catchment scale application of green infrastructure can convey upon urban flood management. The efficient implementation of the framework in collaboration with catchment stakeholders provided a clear and concise strategic intervention development mechanism to explore multiple intervention scenarios. Analysis of interventions indicated a range of strategies which were effective at reducing flooding when built up across the catchment, and that multiple smaller intervention strategies accumulate towards catchment scale benefits. This poses a future research question regarding where the tipping point for catchment-scale benefits lies.

Rapid simulation times achieved using the framework enabled a collaborative and efficient option screening process. The simplified development of intervention strategies provided a clear communication tool which supported the multi-disciplinary investigations required for screening urban planning in a complex environment. Future research should develop the utility of the rapid scenario screening approach to include cost-effectiveness, including multiple benefits.

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Supplementary material

Supplemental data for this article can be accessed here.

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Submission on the

Christchurch City Council

Ihutai-Estuary & Coastal Draft Stormwater Management Plan

25 April, 2022

Ōpāwaho Heathcote River Network Inc.
[redacted]
Website: www.ohrn.nz
Facebook: OpawahoHeathcoteRiver
[redacted]

Thank you for the opportunity to make a submission on the Christchurch City Council (CCC) Ihutai-Estuary & Coastal Draft Stormwater Management Plan.

The Ōpāwaho Heathcote River Network – Who are we?

The Ōpāwaho Heathcote River Network (OHRN) is a community-based catchment group that cares deeply about the health and mauri of the river; about connecting the community around the river and about advocating for the river. We facilitate and support the values, efforts and needs of our local river care organizations and communities along the river.

We have become a voice for the river and a recognised player in the community-led delivery of collaborative actions to support the work carried out by both ECan and the CCC, to improve the health of the river and to strengthen the community connection to the river.

Our Vision is:
An ecologically healthy river that people take pride in, care for and enjoy.

Our Purpose is:
We are a voice for the Ōpāwaho Heathcote River, advocating on its behalf to:

- **promote the regeneration of the health and mauri of the awa, and**
- **connect with and support communities within the river catchment.**

The Ihutai-Estuary and the Ōpāwaho Heathcote River

The Ōpāwaho Heathcote River, including many of its tributaries, has some of the poorest water quality in the city of Christchurch. The river has a complex catchment which includes part of the Port Hills, industrial areas, and concentrated urban and residential zones.

It flows into the Ihutai-Estuary where increased salinity and reduced speed means that much of the sediment is deposited. The loss of water quality and ecological health has resulted in a loss of cultural wellbeing, mahinga kai and indigenous biodiversity and a loss of mauri for the Ōpāwaho Heathcote River and the Ihutai-Estuary.

From its inception, the Ōpāwaho Heathcote River Network has included the Ihutai-Estuary in its field of endeavour, seeking to improve the water quality from the headwaters of the river to where those waters meet the sea. Issues for the Ihutai-Estuary are equally issues for the Ōpāwaho Heathcote River. Indeed, the Avon Heathcote Estuary Ihutai Trust was a foundation member of Ōpāwaho Heathcote River Network and continues to be an important member of the Network.

The Ihutai-Estuary Principal Issues

We **support** the plan’s indication that the principal issues for the the Ihutai-Estuary are:

- Poor **water quality and ecological health** caused by 160 years of contamination by metals and sediment combined with the effects of oxygen depletion and elevated nutrient levels.
- **Flood risk** caused by sedimentation, land subsidence, increased inundation from climate change and the imminent effects of sea level rise.

Since all of these issues arise in part from the Ōpāwaho Heathcote River, we take a particular interest in this Ihutai-Estuary & Coastal Draft Stormwater Management Plan.

Feedback on the Ihutai-Estuary & Coastal Draft Stormwater Management Plan

1. The OHRN commends the Council for the comprehensive detail provided in the background information sections of the Stormwater Management Plan (SMP) and for the clarity with which that information has been presented.

2. In general, the OHRN **supports** the Ihutai-Estuary & Coastal Draft Stormwater Management Plan's goals.

    a. In particular, we **support** the comment, "To make a difference to the existing fair to poor water quality in receiving waters, it will be necessary to not only mitigate any adverse effects from new urban growth, but also implement stormwater quality mitigation measures in existing developed areas."[1]

    b. We **seek** greater commitment through funding in the Long Term Plan (LTP) to "implement stormwater quality mitigation measures in existing developed areas".

3. We **encourage** the Council to implement measure to reduce the numbers of Canadian geese on the river as a means of reducing E. coli.

    a. The OHRN **will support** the Council when it "seeks a mandate from the community to reduce water fowl numbers"[2] by culling Canadian geese on the river and elsewhere.

4. We **encourage** the Council to continue the process of naturalising the City Outfall Drain as a long-term renewal project to "assist in future-proofing this catchment against growth"[3] by means of property acquisition.

    a. While we **encourage** naturalisation of all waterways where possible, this will do little in itself to address the issue of water quality.

[1] Ihutai-Estuary and Coastal Draft Stormwater Management Plan 2022, p16
[2] Ibid, p52
[3] Ibid, p59

b. The phrase “future-proofing this catchment against growth” appears to mean in this context an increase in the capacity of this waterway to cope with increased stormwater drainage. Is this the intended meaning?

c. We **seek** greater clarity within the plan as to what is meant by the phrase “future-proofing this catchment against growth” for the City Outfall Drain.

d. We **encourage** the Council to investigate improving the water quality in the City Outfall Drain by treatment in wetlands, or if this is not feasible, to trial use of a bioreactor to treat the water.

e. We **seek** the renaming of this waterway to remove the pergorative name “Drain” and to help focus the community on improving the water quality in this waterway through elevating the name of this waterway to that of “Stream”.

5. We **encourage** the Council to accelerate the creation of a wetland on the Linwood Paddocks to treat stormwater from the Bromley industrial area. We believe that this important project deserves greater priority in the Long Term Plan.

6. We **support** *Objective 1: Control sediment discharges* with the following qualifications:

a. **Objective 1.2**: We believe that this objective should cover not only new treatment facilities but also the operation and maintenance of previously constructed treatment facilities.

i. While the Council can control new treatment facilities through the normal Council planning, design and procurement process, it also has taken to itself through the new 2022 Stormwater and Land Drainage Bylaw, clause 24, the power to require property owners to ensure that private stormwater systems are maintained and operated as consented.

ii. We **seek** that this SMP objective should reflect this new power and indicate that the Council will use it to enforce proper operation of private stormwater facilities.

iii. We **urge** the Council to build into its processes some appropriate degree of inspection, monitoring and/or enforcement of such private stormwater facility consents over time to ensure that erosion and sediment control measures continue to perform adequately particularly on hillside properties.

b. **Objectives 1.3 and 1.4**: We **seek** reassurance that building inspectors are indeed monitoring and enforcing the sediment and erosion prevention measures on building sites. The reduction of sediment from these sources is vital. The strategy adopted and highlighted in these objectives depends ultimately on the actions of individual building inspectors being of sufficient importance to builders. At a time when the pressure on building inspections is acute, casual observation indicates that this strategy may be undermined by time constraints and greater priorities experienced by the building inspection team.

c. **Objective 1.6**: We **seek** greater priority and funding for the creation of rain gardens and similar for treatment of runoff from busy roads.

d. **Objective 1.7**: We **strongly support** the planting of “severely eroding natural areas of the Port Hills from Heathcote Valley to Hoon Hay Valley”.

   i. We **seek extension** of this strategy to planting of areas above and wider than “severely eroding natural areas” to help to reduce the erosion pressure that the “severely eroding natural areas” experience.

   ii. We **seek extension** of this strategy to planting of areas which may at this time not be “severely eroded” but which are at risk of becoming so. Such a preventive programme would make ecological as well as economic good sense.

   iii. Such a significant planting project will require adequate resourcing for not only the propagation and preparation of plants from locally sourced seed but also the maintenance and protection of planted areas over years of establishment.

   iv. We **seek** appropriate priority of funding for all aspects of this vital project in the Council LTP.

7. We **support** *Objective 2. Control zinc contaminants* with the following qualification:

   a. Objectives 2.2 & 2.3: We **support and encourage** the Council to embark on a programme encouraging commercial property owners in particular to paint bare zinc-plated roofs. We are prepared to assist the Council in this regard.

8. We **support** *Objective 3. Control copper contaminants* with the following qualification:

   a. We **strongly support** the Council investigating a Regional Rule change to eliminate the use of architectural copper. The time scale for NZ-wide legislation or District Plan rule changes to achieve this is much too long and the river should not have to experience this contamination while we wait.

9. We **support** *Objective 4. Control industrial site contaminants* with the following qualification:

   a. We **seek** the extension of “Industrial site contaminants” to include zinc contamination of stormwater from roof and wall runoff.

      i. Industrial buildings are often of extensive size and covered with the cheapest cladding possible which is too often unpainted zinc-plated steel.

ii. It follows, therefore, that unlike residential areas, industrial sites will be the creators of the greatest zinc contamination of stormwater. To ignore this source of zinc contamination is to ignore the most identifiable source.

10. We **strongly support** *Objective 5. Engagement and education*

   a. As one of the community groups endeavoring to engage with the public and our membership on the subject of prevention of contamination, we look forward to an even closer relationship with the Council on this and related matters.

   b. In particular, we look forward to a close understanding of Council planning and assistance with disseminating the messages that will assist the community to feel involved in reducing contamination of stormwater.

Thank you for the opportunity to provide a submission on the Ihutai-Estuary & Coastal Draft Stormwater Management Plan.

We wish to be heard on this submission

.

Annabelle Hasselman
Chair
Ōpāwaho Heathcote River Network

Tonkin+Taylor

Job No: 29847.2000
26 April 2022

Christchurch City Council
53 Hereford Street
Christchurch 8154

Attention: Hannah Ballantyne

Dear Hannah

Ihutai-Estuary and Coastal Draft Stormwater Management Plan

New Zealand Steel Limited (NZ Steel) is a major supplier of roofing products nationwide and the largest supplier in Christchurch. NZ Steel produce a range of zinc/aluminium coated roofing and cladding products which have significantly reduced zinc loads from roofs when compared to traditional galvanised products.

NZ Steel made a submission in relation to the Christchurch City Council's (the Council) Comprehensive Stormwater Network Discharge Consent CRC190455 (CSNDC) and presented evidence at the hearing. NZ Steel was disappointed that the issues identified in their submission and reiterated at the hearing were not addressed at the same time the CSNDC was granted. Many of these concerns were carried through to the SMPs for the Ōpāwhao/Heathcote River and Huritini/Halswell River which NZ Steel also submitted on.

This submission on the draft SMP has been prepared by Tonkin & Taylor Ltd (T+T) on behalf of NZ Steel.

1 Changes since previous Draft SMPs

As above, NZ Steel made submissions on both the Draft SMPs for the Ōpāwhao/Heathcote River and Huritini/Halswell River. These submissions outlined the concerns held by NZ Steel including the terminology used in the SMPs and the reference to NZ Streel propriety products.

NZ Steel is pleased to see the reference to NZ Steel propriety products, including ColorSteel® was removed from and does not appear in the Ihutai-Estuary and Coastal draft SMP.

2 Engagement with NZ Steel

The Council's methods to progressively improve stormwater under the CSNDC will be set out within the relevant SMPs and the future Surface Water Improvement Plan (SWIP). The SMP for Ihutai-Estuary and Coastal makes reference to consulting with key stakeholder to identify a long-term zinc strategy which is consent with current technologies. Excluding the opportunity to comment on the draft SMPs through this process, NZ Steel is unaware of any opportunities to provide comment on the SWIP to date or in the future. As the largest supplier of roofing product in Christchurch, NZ Steel is a key stakeholder in this matter.

NZ Steel has undertaken considerable research on the environmental effects of its produces and would welcome involvement in the cost/benefit analysis evaluating best practicable options and development a long-term zinc strategy. Given the timeframes set out in the SMP and in relation to the SWIP, engagement with NZ Steel should commence expediently.

3 Draft Ihutai-Estuary and Coastal Draft Stormwater Management Plan

The SMP notes that roofing creates approximately ¾ of urban zinc while roads create approximately ¼. Other sources include galvanised steel fencing, fungicides, paint pigments and wood preservatives. Table 2: Contaminant Sources, identifies three roof-derived sources of zinc, being bare galvanised roofs, old painted roofs, bare zinc-aluminium coated streel roofs. For all roof-derived sources, the possible mitigation methods identified are the same: replacing the roof with a non-metal roof; a pre-pained zinc-aluminium coated steel roof; or painting with a low zinc paint.

NZ Steel is concerned with this approach for a number of reasons.

- Requiring bare zinc-aluminium coated steel roofs be replaced (or painted) effectively requires that low-cost building products be substituted for higher cost building products resulting in additional expense with questionable environmental benefits.
- Specifying the replacement roof type potentially reduces the use of new or recently developed products.

The CSNDC requires the Council to use best practicable options to mitigate the effects of the stormwater discharge. In relation to zinc, the best practicable options is to investigate the feasibility and legality of zinc control measures for building cladding. The SMP notes that considerably more information, such as the long-term costs and benefits of maintain roof coatings or substituting roof material, would be required before Council would consult on and select a best practicable option.

The SMP indicates that Council will have investigated zinc mitigation measures and carried out cost/benefit analyses towards identifying their effectiveness and best practicable options by 2022. By 2025 the Council aims to have consulted with key stakeholders and identified a long-term zinc strategy consistent with current technologies. NZ Steel considers that evaluation and identification of a best practicable option should occur in conjunction with consultation with key stakeholders and identification of a long-term zinc strategy, not in advance of this work. Investigating possible zinc mitigation measures and undertaking analyses without engaging with key stakeholders during this evaluation reduces the robustness of any best practicable options identified. As previously stated, NZ Steel considers genuine consultation should occur throughout the process to ensure options identified meet the relevant objectives are truly the best practicable i.e. they are consistent with current technologies and do not preclude future technologies.

Table 5 identified potential at-source mitigations for contaminants. NZ Steel is interested in potential control options for zinc from bare steel roofs and poorly maintained painted roofs. NZ Steel considers and approach addressing both new and existing roofs is more equitable than focusing solely on new roofs, which make a significantly smaller contribution to zinc contamination in runoff.

In relation to bare steel foods, potential control measures include potential District Plan rules to require roof runoff to be treated on site; and discouraging the use of bare zinc roofing. NZ Steel oppose both of these options. The requirement for onsite stormwater treatment facilities would potentially require significant additional land area to be provided to treat runoff, resulting in inefficient use of land for little or no environmental benefits. This is a significant concern for a city that is seeking to contain its urban footprint and is experiencing a high demand for new housing on increasingly smaller sites. For the reasons stated previously NZ Steel opposes any requirement to replace bare zinc aluminium coated roofs.

In relation to poorly maintained painted roofs, the potential control options include a possible incentive to repaint them. The SMP notes that investigations are underway regarding the cost and benefits of painting poorly maintained roofs when compared to replacing roods or civic scale stormwater treatment. NZ Steel is generally supportive of incentives to replace old or poorly maintained pained roofs and would welcome a suitable partnership arrangement to help achieve this.

Overall, NZ Steel remains concerned that the SMP creates uncertainty around the ongoing use of steel roofing products in Christchurch. Based on the timeframes set out within the SMP, it appears the uncertainty might continue until 2025. It is important that potential mitigation is effective and achieves the best practicable option, rather than being ideologically based and that various steel roof types are correctly and consistently identified. NZ Steel is well places to assist with these investigations and welcomes all opportunities for meaningful engagement with the Council in this regard.

We would be happy to meet with you and discuss NZ Steel's submission. If you wish to take up this offer, please contact the undersigned.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Nicolle Vincent Planner	Peter Cochrane Project Director

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