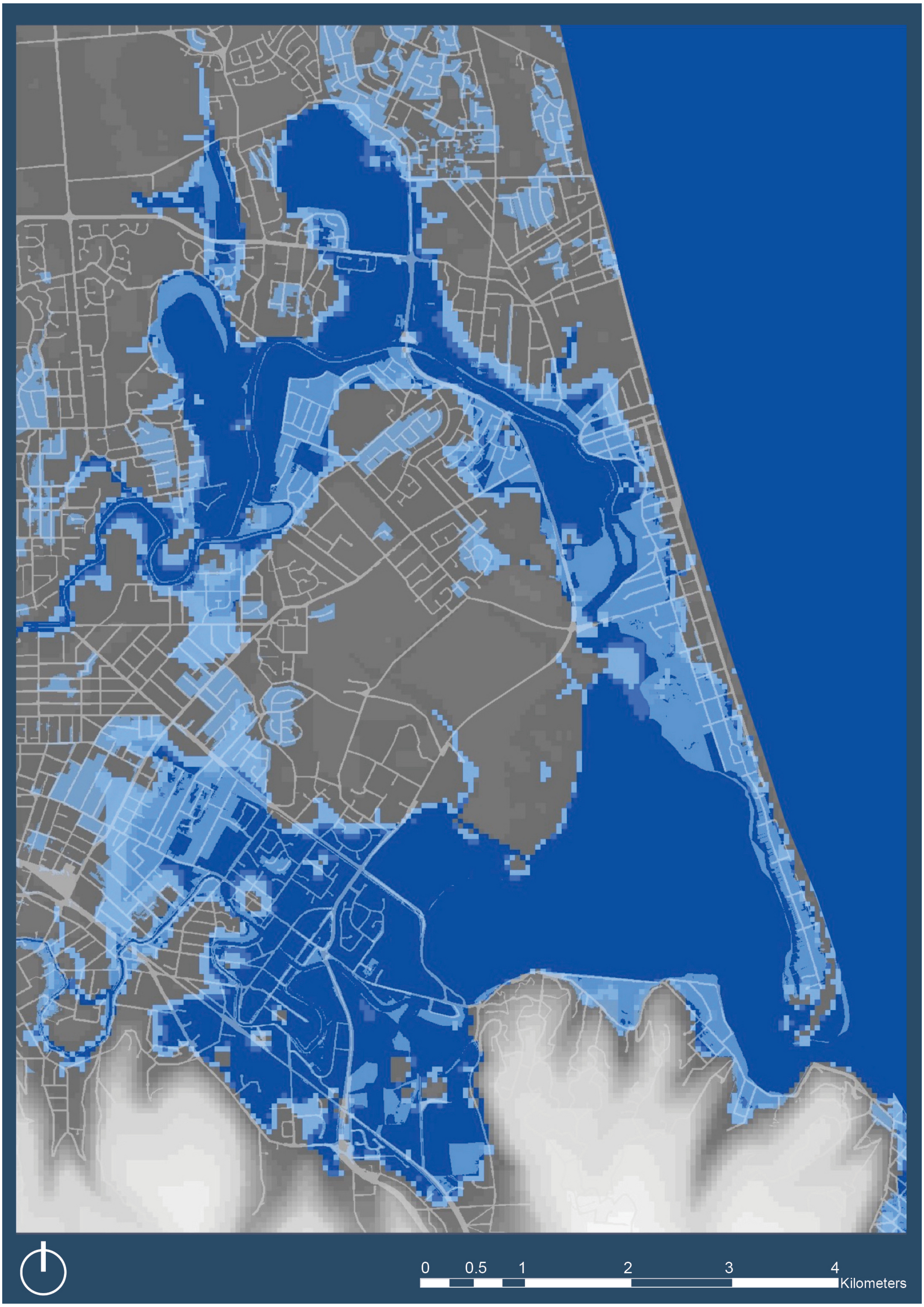

Image created based on rising sea levels, high tides and Christchurch flood level map associated with a 50-year storm (image by Suphicha Muangsri, 2023, retrieving data and images from Tonkin & Taylor Ltd (2017) and Christchurch City Council (2022)).

LANDSCAPE
REVIEW

Adaptive flood mitigation planning: harnessing the maximum capability of strategic green stormwater infrastructure

Suphicha Muangsri, Wendy McWilliam and Gillian Lawson

Flooding in low-lying coastal cities is expected to worsen with climate change, and planning for long-term flood mitigation is challenging due to high uncertainty in projections. Risks are associated with under- or over-investment in expensive grey infrastructure. Implementing green stormwater infrastructure (GSI) on strategically large private properties may be a lower-risk alternative. In our previous studies published in 2022 and 2024, we found that the capability of industrial properties to supplement city flood mitigation was substantial. They could offset climate change impacts in the long term, even under a major climate change scenario, and reduce flood probabilities. In this paper, we restate their potential as a case study of large private properties to draw more attention from practitioners and transfer scientific knowledge into practice. The maximum flood mitigation capabilities of large private properties can be met through networks of GSI facilities and a long-term adaptation plan that considers all possible approaches to implementing GSI over time. However, government regulations and policies are needed to support their implementation to the maximum capabilities.

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KEY WORDS
green stormwater infrastructure; flood mitigation; low-lying coastal city; adaptive planning; climate change

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Challenges in flood mitigation planning in low-lying coastal cities

Low-lying coastal cities have been confronting challenges in flood management, which will be exacerbated by climate change in the future (Dedekorkut-Howes, Torabi and Howes, 2020; Terry, Winspear and Goff, 2021). The challenges involve three main problems: increases in surface runoff, decreases in stormwater holding capacity and increases in the level of exposure (figure 1). Surface runoff into rivers has increased because impermeable surfaces in cities have expanded and intensified (Adnan et al, 2020) while storm events have increased in intensity and frequency with climate change (Martel et al, 2021). At the same time, climate change is causing more seawater to enter rivers due to higher sea levels, which will reduce the capacity of rivers to carry water and consequently will increase flooding (Moftakhari et al, 2017). Groundwater levels will increase with these rising sea levels (Vitousek et al, 2017), and thus reduce the storage capacity for holding stormwater in-ground (Davtalab et al, 2020). Moreover, some coastal cities, like Christchurch, are confronting high land subsidence rates that further increase their flood risk (Bagheri-Gavkosh et al, 2021).

Determining long-term solutions for protecting cities from this flooding is challenging for planners. Building higher and stronger defensive structures (for example, levees and sea walls) to prevent water from entering urban areas comes with the risks associated with under- or over-investment (Radhakrishnan et al, 2018) as we do not know how long their capacities are going to last. In addition, the longer the projection period, the greater the variations between different scenarios, making it challenging to determine the most suitable scenario to prepare for (Yousefpour and Hanewinkel, 2016) (figure 2). While retreat strategies are considered a cost-effective option to sustainably reduce flood risk in the long term (Diaz, 2016; Haasnoot, Lawrence and Magnan, 2021; Temmerman et al, 2013), they are very difficult to implement in communities (Lawrence et al, 2020) as many land owners do not want to leave their land. However, in the far future, under a major climate change scenario, retreat strategies might be the only option available to avoid the impacts of flooding. While accommodation strategies are preferable to handle near- to mid-term flood impacts, the large facilities needed to hold large amounts of water, like underground storage tanks, will be very expensive to build and maintain (Chen and Mehrabani, 2019; Saraswat, Kumar and Mishra, 2016; Tsuchiya, Tortajada and Ratra, 2018).

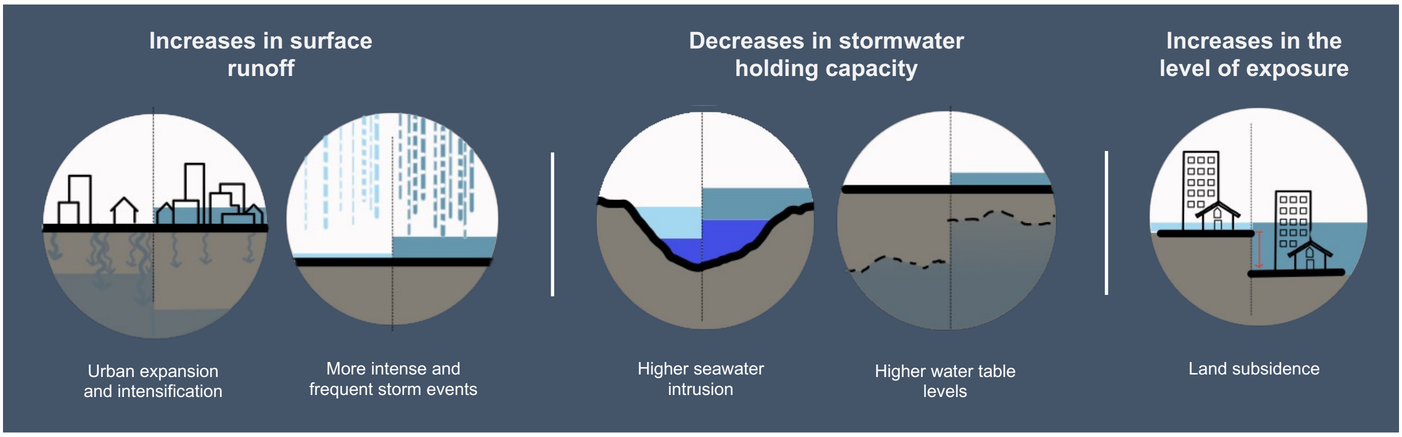

Figure 1. The problems causing challenges in coastal city flood management (image by Suphicha Muangsri, 2023).

Figure 2. Substantial flooding is projected to occur in many low-lying coastal cities of Aotearoa New Zealand. In Christchurch by 2050, runoff volumes corresponding to different rainfall events were projected to increase by between 6 per cent under the minor scenario (+1 degree Celsius by 2100) and 8 per cent under the major scenario (+4 degrees Celsius by 2100). While the impact associated with the minor scenario would remain steady after the middle of this century, increases in runoff volumes would reach about 10 per cent under the moderate scenario (+2 degrees Celsius by 2100) and 25 per cent under the major scenario by the end of this century (image by Suphicha Muangsri, 2023).

Implementing accommodation strategies through green stormwater infrastructure (GSI) is less risky and is considered more cost-effective than one-time and expensive flood mitigation investments (Haasnoot et al, 2013; Lawrence et al, 2021). GSI can be adaptively implemented to provide supplemental flood mitigation alongside the current system as climate change evolves (Haasnoot et al, 2012; Kirshen et al, 2015; Xu et al, 2019). Implementing GSI can enable planners to delay decision-making on investments in large engineering structures until the cost-effectiveness of those structures becomes better informed (Aerts et al, 2014). However, the extent to which GSI can effectively mitigate flooding depends on its ability to collect runoff from a wide area (Schubert et al, 2017).

The greater the area that GSI facilities control, the more they can reduce catchment runoff volume.

Due to limited space in already developed cities, only small-scale GSI facilities (for example, green roofs, permeable surfaces, and rain gardens) are likely to be implemented on limited public land, particularly along streets, or on small plots of private properties as an alternative. However, their effectiveness is limited under extreme storm events, particularly those induced by climate change (Joyce et al, 2017; Pappalardo et al, 2017; Tao et al, 2017; Zahmatkesh et al, 2015). As these facilities have limited storage capacity, they can only control runoff from small drainage areas. This means most private properties are required to retain their on-site runoff in these GSI facilities in addition to public land in order to substantially intercept a large amount of catchment runoff (Schubert et al, 2017). However, there are several barriers to implementing GSI on private land in general. Notably, many land owners do not want GSI facilities located on their land (Dai, Wörner and van Rijswick, 2017; Perry and Nawaz, 2008). Government management of GSI facilities to ensure they continue to function is also difficult given private property rights (Dai et al, 2017; Dhakal and Chevalier, 2017). The size and shape of available space in small lots may not be able to accommodate GSI facility installation (Aparicio Uribe, Bonilla Breenes and Hack, 2022; D'Ambrosio et al, 2022). Furthermore, it is very difficult and time-consuming for governments to work with too many private land owners (Backhaus and Fryd, 2012).

Targeting strategic private properties capable of implementing large-scale GSI facilities (for example, detention or retention basins, wetlands and stormwater storage) may be a viable alternative. Given large-scale facilities are more effective per unit area (Damodaram et al, 2010), they can be strategically allocated on large lots with sizable areas that have potential for installing GSI. This means fewer land owners would be required to achieve a flood protection objective, and planners could target land owners who are highly capable of providing flood mitigation and the most likely to benefit from implementing GSI facilities.

Potential of large private properties to supplement city flood mitigation

The landscape characteristics of large private properties, such as industrial, commercial and institutional land, could facilitate the installation of large-scale GSI facilities, resulting in a greater reduction in stormwater discharge (Aparicio Uribe et al, 2022; D'Ambrosio et al, 2022; Smith et al, 2015). For example, the results of our previous study highlighted the potential of implementing GSI on existing industrial land in Christchurch, as a case study of large private properties, to provide supplemental city flood mitigation under different climate change scenarios up to the end of this century (Muangsri, McWilliam and Davies, 2023). The existing industrial land in four out of six catchments ranged in size from 3.3 per cent to 28 per cent of the catchment area. This land could offset climate change–induced flooding up to the middle of this century under a minor climate change scenario (+1 degree Celsius by 2100). Two catchments could mitigate the impacts of a major climate change scenario (+4 degrees Celsius by 2100) up to the end of this century. Moreover, they could reduce the runoff volume of more infrequent (80-, 100- and 200-year) storms to below the volume of a storm for which current drainage and flood protection systems are designed (namely, a 50-year storm), although not under all climate scenarios (figure 3).

The findings of our study also indicated that GSI on large private properties could collect not only on-site runoff volume but also off-site runoff from upstream. However, these properties must have large upstream contributing areas, large potential GSI areas and significant depths to the high water table (Muangsri et al, 2023). For example, our study found that collecting runoff from 7.5 per cent (as the area of the industrial land) of the Heathcote River catchment could offset climate change–induced flooding under a moderate climate change scenario (+2 degrees Celsius by 2100) up to the end of this century. GSI on this industrial land could reduce the impacts of a major climate change scenario if it collected the runoff from an additional 23 per cent of the catchment that was upstream of the industrial land (figure 3).

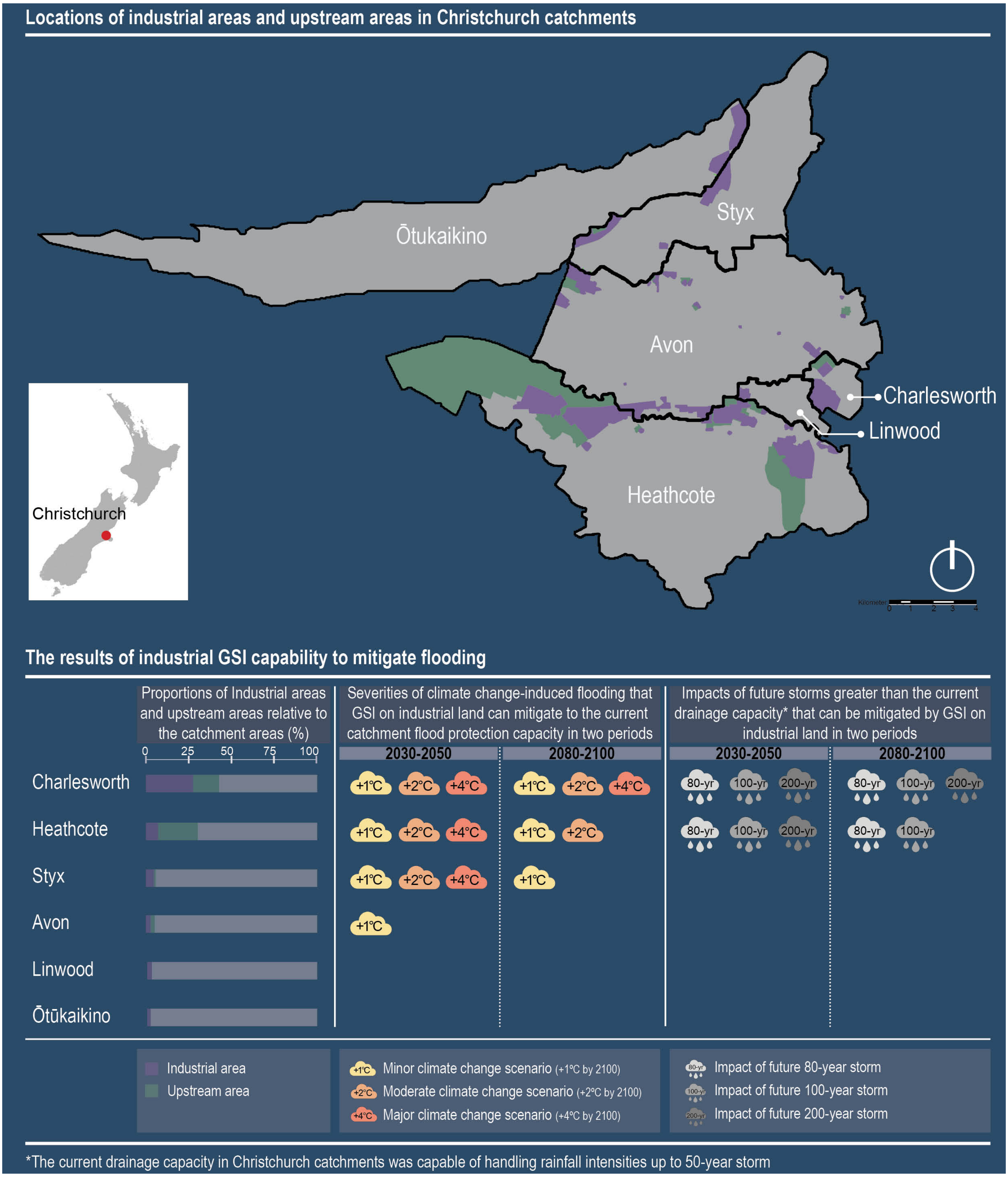

Figure 3. The capabilities of existing industrial land in Christchurch catchments to offset climate change–induced flooding and to reduce runoff volumes of storms larger than the design storm of current drainage capacity (the 50-year storm) vary with the percentage of the catchment occupied by industrial properties and whether they also capture runoff from upstream (image by author, 2023). The findings in Muangsri and colleagues (2024) refer to the data presented here.

The need for a green stormwater infrastructure network

A network of GSI is needed to take full advantage of the land capability to mitigate flooding. Storing off-site runoff from upstream would only be possible with a network to convey runoff from upstream to large properties downstream. Runoff volume exceeding GSI facilities may be transferred from one drainage area to others that have excess storage capacity, and where geography is capable of diverting water from one waterway to another.

For example, industrial zone 2B in the Heathcote River catchment had a large upstream area from which it could collect runoff (Muangsri et al, 2022a). However, the amount of water was larger than its potential in-ground storage capacity; therefore, it could only mitigate increased catchment runoff volume under the moderate climate change scenario up to the end of this century. The catchment flood mitigation capability could be enhanced if its excess runoff volume could be transferred to zones 2A and 2C, which were geographically connected with zone 2B. The capabilities of these zones combined could mitigate flooding just under that associated with the major climate change scenario (figure 4). In addition, a GSI network could allow the properties, having excess storage capacity beyond what is required, to trade their capability with the land owners who find it challenging to accommodate GSI facilities with their existing land uses (Fu et al, 2019). This could help municipalities achieve their flood protection objective while minimising the number of land owners involved.

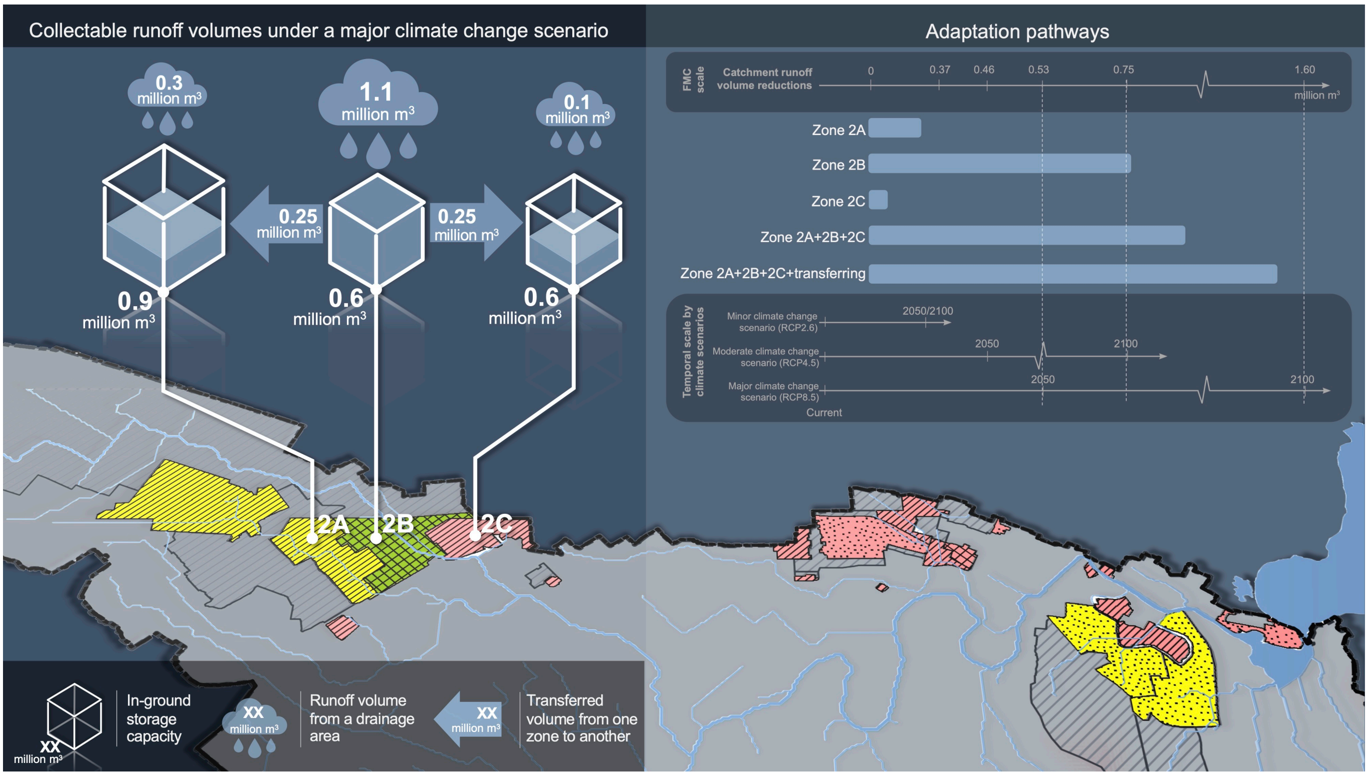

Figure 4. The summary of results from Muangsri and colleagues (2022a) demonstrates that a GSI network consisting of industrial zones 2A, 2B and 2C in the Heathcote River catchment, Christchurch, was almost able to mitigate climate change–induced flooding corresponding to a major scenario, when the capabilities of those zones were optimally utilised (image by author, 2023).

Long-term adaptive planning with climate change

GSI can be implemented through three possible approaches: retrofit, redesign and relocation. Each approach is appropriate for different circumstances and times.

A *retrofit approach*, where GSI facilities can be installed in existing available space to collect stormwater near the source, is the preferred approach as it allows for the immediate rollout of GSI while causing less disruption to current land uses (Shafique and Kim, 2017).

However, planners can only implement GSI facilities in areas that are currently considered the most suitable, which may not achieve maximum capability in cases where all potential GSI areas are needed. Conversely, in cases where only a small proportion of potential GSI area is needed to achieve the maximum flood mitigation capability, retrofitting would be the most appropriate.

A *redesign approach* involves altering the current site plan to better accommodate GSI facilities. This approach may result in having more areas that are suitable for GSI, where they may have been considered unsuitable before the redesign, and in turn maximising flood mitigation (Rogers et al, 2020). As it requires significant changes, it would not be a preferable option for near-term flood mitigation when the increased impacts of climate change can be managed through a retrofit approach (Rosly and Rashid, 2013). However, this approach would become attractive as climate change impacts continue to increase and existing land uses need to be changed to better serve future functions (Jaroszewska, 2019).

A *relocation approach* would be more applicable in areas with high flood risk when climate change impacts on coastal and groundwater floods cannot be mitigated in the far future under more severe climate change scenarios (May, 2020; Rey-Valette, Robert and Rulleau, 2019; Rogers et al, 2020). These flood-prone areas are likely to be located near rivers and coastlines and have a shallow water table (Doberstein, Fitzgibbons and Mitchell, 2018). In the long term, planners may need to relocate development in these areas and replace them with wetlands.

GSI networks can be implemented incrementally as climate change impacts increase to provide long-term supplemental flood mitigation. Therefore, implementation does not need to be limited to a retrofit approach. For instance, for near- to mid-term protection, GSI could be implemented in properties where retrofitting involves limited land-use disruptions. Where possible, these facilities could be expanded as needed to provide further protection. Then properties that are more capable but require redesign and relocation to achieve their substantial flood mitigation capability could be targeted for GSI implementation to provide mid- to long-term protection as needed (figure 5).

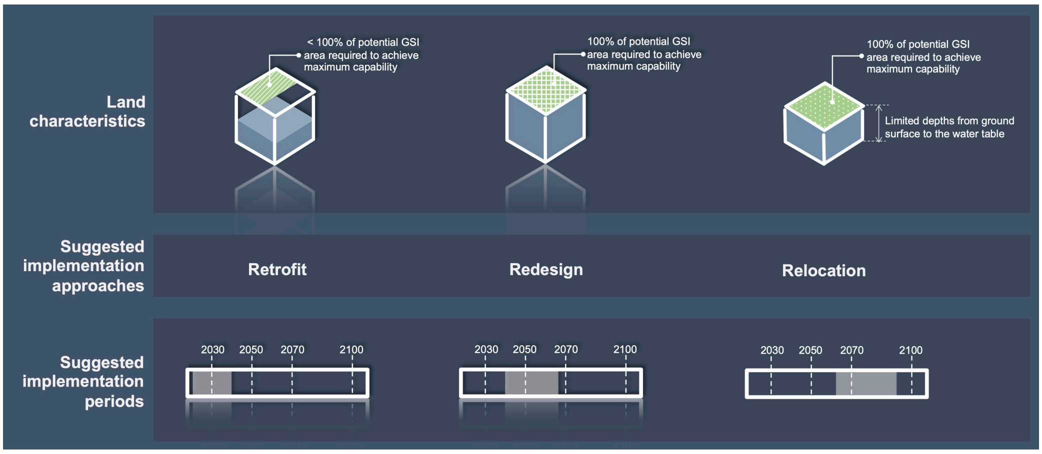

Figure 5. Muangsri and colleagues (2022b) classified large private properties into three groups based on the proportion of potential GSI area required to achieve maximum flood mitigation capability and the water table level. This classification can assist planners in determining an appropriate approach and period for implementing GSI (image by author, 2023).

A call to action!

Coastal city governments need to undertake the following three key actions to realise the potential of large GSI facilities on private property to protect our cities from flooding under climate change.

Enhance the value of GSI implementation

To leverage the value of implementing GSI, regulation and policy changes are needed to encourage land owners to implement GSI facilities. As a first step, policy-makers should ensure that every private land owner has a share in the responsibility for controlling surface runoff quantity and quality (Cote and Wolfe, 2014; Johns, 2019; van der Sterren et al, 2009). For instance, Melbourne Water requires all developable properties to pay a drainage contribution on the basis of the size and type of a development when it occurs (Melbourne Water, 2020).

Another change to consider is whether to remove regulations that prevent off-site stormwater management (Dhakal and Chevalier, 2017). For example, in cities where water is often abundantly available (like Christchurch), providing free access to, or low-priced, municipal water does not give land owners any incentive to store stormwater for reuse (Labadie, 2011).

In addition, financial incentives are needed to encourage owners of highly capable properties to collect off-site runoff where this is possible (Dhakal and Chevalier, 2017). Municipalities might provide financial incentives by:

1. offering an incentive to implement GSI through programmes that share costs and management (Parikh et al, 2011) or through reduced taxes (Dudula and Randhir, 2016)
2. establishing markets for allowance trading of runoff discharge at the catchment scale, which could enable off-site runoff collection (Fu et al, 2019). The trading market would not only motivate those who have a high potential for flood mitigation to store more runoff but also allow those with limited capability to meet minimum regulatory requirements
3. subsidising the cost of applying sustainable land development certificates (Cease et al, 2019) such as LEED and BREEAM (Saiu, Blečić and Meloni, 2022) when GSI facilities are implemented. Alternatively, cities could develop their own certification programmes requiring GSI for flood mitigation.

Designate stormwater management zones in city plans

Defining large private properties with high capability as a special zone for stormwater water management (SWM) would enable planners to make specific regulations for individual zones to maximise the effectiveness of GSI implementation (Christchurch City Council, 2016; de Moel, van Vliet and Aerts, 2014; Doberstein et al, 2018). Policies specific to individual SWM zones will inform land owners of the long-term flood management plans so that they do not inadvertently develop their lands in ways that may impede GSI redesign and land use relocation in the future (Hetz and Bruns, 2014; Mathews, Surminski and Roezer, 2021). In Australia, for example, the Queensland Reconstruction Authority (2019) proposed a non-statutory guide for delivering a coordinated approach to managing flood risk across the Brisbane River floodplain. It set out a range of strategies and actions, including land use planning, for state and local governments to consider in order to strengthen the flood resilience of the region. Moreover, a city plan must designate SWM zones so that planners can play a key role in GSI monitoring and management, as zone policies can specify the scope of a municipal authority to access private properties. This action could help to overcome government concerns that land owners do not manage GSI facilities (Dai et al, 2017; Johns, 2019; Mukhtarov et al, 2019).

Designating SWM zones can also provide land owners with financial support through schemes such as transfer of development rights (TDR) programmes. A TDR programme allows a municipality to restrict development density in an SWM zone below that permitted in the building code. In return, land owners are compensated for losing the right to develop their land at its maximum density (McGuire and Goodman, 2020).

Establish new governing bodies

Governing bodies are needed to ensure that properties in an SWM zone can work together, as well as cooperate with upstream communities and other SWM zones, to maximise flood mitigation capability.

First, a governing body at the SWM zone level is a necessity to implement a GSI network across properties within the zone. While land owners of selected properties should be key members of these bodies, city officials should also be included so that GSI networks are effectively integrated with the public stormwater management system and follow flood management plans (van Buuren et al, 2018). For example, Melbourne Water has some regional powers across catchments to designate areas where development is not permitted. Local drainage schemes in a specific catchment area guide the standards that developers need to meet for flood protection, water quality and waterway health. (Melbourne Water, 2020).

In addition, a governing body at the catchment level is needed to orchestrate the development of GSI networks in different zones to meet the goals of the catchment flood mitigation plan over time. This governing body should consist of the representatives of each strategic SWM zone, local agencies related to city flood management and community stakeholders. Given the uncertainty surrounding climate change, this governing body should have the autonomy to make decisions on implementing and managing GSI networks; however, regional and/or central government must oversee it and provide direction and support (van Buuren et al, 2018).

For governing bodies at both levels, disciplinary experts, such as hydrologists, engineers, planners and/or landscape architects, may also be valuable to provide guidelines for developing the GSI networks in support of multiple ecosystem services and in the most efficient way (van Buuren et al, 2018).

Conclusions

This paper demonstrates that strategically implementing GSI on large private properties can provide essential cost-effective supplementary flood mitigation to protect low-lying coastal cities from flooding with climate change. Because the degree and timing of impact cannot be predicted with certainty, long-term adaptive planning is essential to implement GSI networks incrementally using a range of approaches. However, regulation and policy changes will be needed to facilitate their implementation among land owners.

About the Authors and Collaborators

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Gillian Lawson is an Associate Professor in the School of Landscape Architecture, Lincoln University. Her interests are in landscape pedagogy, landscape visualisation and landscape sociology in Australia, Aotearoa New Zealand and other Asia-Pacific countries, and on water and food as catalysts for improving the adaptation of our cities to climate change. Her work has focused on the sociology of education, social practices in public and private open spaces, green infrastructure and waterfront communities in landscape planning and design.

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Data availability statement: The data about the assessment of industrial land in the Heathcote River catchment are openly available in Data@Lincoln at:

- 10.25400/lincolnuninz.21300507 for the characteristics of industrial SWM zones
- 10.25400/lincolnuninz.21358338 for runoff volume calculation
- 10.25400/lincolnuninz.21300522 for the estimation of in-ground storage capacity
- 10.25400/lincolnuninz.21358455 for flood mitigation capability assessment and classification.

Conflicts of interest: Gillian Lawson, a co-author of this paper, is a member of the *Landscape Review* editorial team. To ensure anonymity and the independence and integrity of the peer-review process, all her editorial responsibilities for this paper (including initial assessment, peer-review and the final decision-making process) were delegated to another member of the journal's editorial team.

REFERENCES

Adnan, M.S.G.; Abdullah, A.Y.M.; Dewan, A.; Hall, J.W. (**2020**) The effects of changing land use and flood hazard on poverty in coastal Bangladesh. *Land Use Policy*, 99, art 104868. DOI: 10.1016/j.landusepol.2020.104868.

Aerts, J.C.J.H.; Botzen, W.J.W.; Emanuel, K.; Lin, N.; de Moel, H.; Michel-Kerjan, E.O. (**2014**) Evaluating flood resilience strategies for coastal megacities. *Science*, 344(6183), pp 473–475. DOI: 10.1126/science.1248222.

Aparicio Uribe, C.H.; Bonilla Brenes, R.; Hack, J. (**2022**) Potential of retrofitted urban green infrastructure to reduce runoff: a model implementation with site-specific constraints at neighborhood scale. *Urban Forestry & Urban Greening*, 69, art 127499. DOI: 10.1016/j.ufug.2022.127499.

Backhaus, A.; Fryd, O. (**2012**) Analyzing the first loop design process for large-scale sustainable urban drainage system retrofits in Copenhagen, Denmark. *Environment and Planning B: Planning and Design*, 39(5), pp 820–837. DOI: 10.1068/b37088.

Bagheri-Gavkosh, M.; Hosseini, S.M.; Ataie-Ashtiani, B.; Sohani, Y.; Ebrahimian, H.; Morovat, F.; Ashrafi, S. (**2021**) Land subsidence: a global challenge. *Science of the Total Environment*, 778, art 146193. DOI: 10.1016/j.scitotenv.2021.146193.

Cease, B.; Kim, H.; Kim, D.; Ko, Y.; Cappel, C. (**2019**) Barriers and incentives for sustainable urban development: an analysis of the adoption of LEED-ND projects. *Journal of Environmental Management*, 244, pp 304–312. DOI: 10.1016/j.jenvman.2019.04.020.

Chen, H.-P.; Mehrabani, M.B. (**2019**) Reliability analysis and optimum maintenance of coastal flood defences using probabilistic deterioration modelling. *Reliability Engineering & System Safety*, 185, pp 163–174. DOI: 10.1016/j.ress.2018.12.021.

Christchurch City Council (**2016**) *Christchurch District Plan*. Christchurch: Christchurch City Council. Accessed 5 March 2024, https://districtplan.ccc.govt.nz/pages/plan/book.aspx?exhibit=DistrictPlan.

Christchurch City Council (**2022**) Floor level requirements. Accessed 20 October 2022, https://ccc.govt.nz/services/water-and-drainage/stormwater-and-drainage/flooding/floor-level-requirements/.

Cote, S.A.; Wolfe, S.E. (**2014**) Assessing the social and economic barriers to permeable surface utilization for residential driveways in Kitchener, Canada. *Environmental Practice*, 16(1), pp 6–18. DOI: 10.1017/S1466046613000641.

D'Ambrosio, R.; Balbo, A.; Longobardi, A.; Rizzo, A. (**2022**) Re-think urban drainage following a SuDS retrofitting approach against urban flooding: a modelling investigation for an Italian case study. *Urban Forestry & Urban Greening*, 70, art 127518. DOI: 10.1016/j.ufug.2022.127518.

Dai, L.; Wörner, R.; Van Rijswick, H.F.M.W. (**2017**) Rainproof cities in the Netherlands: approaches in Dutch water governance to climate-adaptive urban planning. *International Journal of Water Resources Development*, 34(4), pp 1–23. DOI: 10.1080/07900627.2017.1372273.

Damodaram, C.; Giacomoni, M.H.; Prakash Khedun, C.; Holmes, H.; Ryan, A.; Saour, W.; Zechman, E.M. (**2010**) Simulation of combined best management practices and low impact development for sustainable stormwater management. *Journal of the American Water Resources Association*, 46(5), pp 907–918. DOI: 10.1111/j.1752-1688.2010.00462.x.

Davtalab, R.; Mirchi, A.; Harris, R.J.; Troilo, M.X.; Madani, K. (**2020**) Sea level rise effect on groundwater rise and stormwater retention pond reliability. *Water*, 12(4), art 1129. DOI: 10.3390/w12041129.

de Moel, H.; van Vliet, M.; Aerts, J.C.J.H. (**2014**) Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, the Netherlands. *Regional Environmental Change*, 14(3), pp 895–908. DOI: 10.1007/s10113-013-0420-z.

Dedekorkut-Howes, A.; Torabi, E.; Howes, M. (**2020**) When the tide gets high: a review of adaptive responses to sea level rise and coastal flooding. *Journal of Environmental Planning and Management*, 63(12), pp 2102–2143. DOI: 10.1080/09640568.2019.1708709.

Dhakal, K.P.; Chevalier, L.R. (**2017**) Managing urban stormwater for urban sustainability: barriers and policy solutions for green infrastructure application. *Journal of Environmental Management*, 203, pp 171–181. DOI: 10.1016/j.jenvman.2017.07.065.

Diaz, D.B. (**2016**) Estimating global damages from sea level rise with the Coastal Impact and Adaptation Model (CIAM). *Climatic Change*, 137(1), pp 143–156. DOI: 10.1007/s10584-016-1675-4.

Doberstein, B.; Fitzgibbons, J.; Mitchell, C. (**2018**) Protect, accommodate, retreat or avoid (PARA): Canadian community options for flood disaster risk reduction and flood resilience. *Natural Hazards*, 98, pp 31–50. DOI: 10.1007/s11069-018-3529-z.

Dudula, J.; Randhir, T.O. (**2016**) Modeling the influence of climate change on watershed systems: adaptation through targeted practices. *Journal of Hydrology*, 541, pp 703–713. DOI: 10.1016/j.jhydrol.2016.07.020.

Fu, X.; Hopton, M.E.; Wang, X.; Goddard, H.; Liu, H. (**2019**) A runoff trading system to meet watershed-level stormwater reduction goals with parcel-level green infrastructure installation. *Science of the Total Environment*, 689, pp 1149–1159. DOI: 10.1016/j.scitotenv.2019.06.439.

Haasnoot, M.; Kwakkel, J.H.; Walker, W.E.; ter Maat, J. (**2013**) Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23(2), 485–498. DOI: 10.1016/j.gloenvcha.2012.12.006.

Haasnoot, M.; Lawrence, J.; Magnan, A.K. (**2021**) Pathways to coastal retreat. *Science*, 372(6548): pp 1287–1290. DOI: 10.1126/science.abi6594.

Haasnoot, M.; Middelkoop, H.; Offermans, A.; van Beek, E.; van Deursen, W.P.A. (**2012**) Exploring pathways for sustainable water management in river deltas in a changing environment. *Climatic Change*, 115(3), pp 795–819. DOI: 10.1007/s10584-012-0444-2.

Hetz, K.; Bruns, A. (**2014**) Urban planning lock-in: implications for the realization of adaptive options towards climate change risks. *Water International*, 39(6), pp 884–900. DOI: 10.1080/02508060.2014.962679.

Jaroszewska, E. (**2019**) Urban shrinkage and regeneration of an old industrial city: The case of Wałbrzych in Poland. *Quaestiones Geographicae*, 38(2), pp 75–90. DOI: 10.2478/quageo-2019-0023.

Johns, C.M. (**2019**) Understanding barriers to green infrastructure policy and stormwater management in the City of Toronto: a shift from grey to green or policy layering and conversion? *Journal of Environmental Planning and Management*, 62(8), pp 1377–1401. DOI: 10.1080/09640568.2018.1496072.

Joyce, J.; Chang, N.-B.; Harji, R.; Ruppert, T.; Imen, S. (**2017**) Developing a multi-scale modeling system for resilience assessment of green-grey drainage infrastructures under climate change and sea level rise impact. *Environmental Modelling & Software*, 90, pp 1–26. DOI: 10.1016/j.envsoft.2016.11.026.

Kirshen, P.; Caputo, L.; Vogel, R.M.; Mathisen, P.; Rosner, A.; Renaud, T. (**2015**) Adapting urban infrastructure to climate change: a drainage case study. *Journal of Water Resources Planning and Management*, 141(4), art 04014064. DOI: 10.1061/(ASCE)WR.1943-5452.0000443.

Labadie, J.R. (**2011**) Emergency managers confront climate change. *Sustainability*, 3, pp 1250–1264. DOI: 10.3390/su3081250.

Lawrence, J.; Boston, J.; Bell, R.; Olufson, S.; Kool, R.; Hardcastle, M.; Stroombergen, A. (**2020**) Implementing pre-emptive managed retreat: constraints and novel insights. *Current Climate Change Reports*, 6(3), pp 66–80. DOI: 10.1007/s40641-020-00161-z.

Lawrence, J.; Stephens, S.; Blackett, P.; Bell, R.G.; Priestley, R. (**2021**) Climate services transformed: decision-making practice for the coast in a changing climate. *Frontiers in Marine Science*, 8, art 703902. DOI: 10.3389/fmars.2021.703902.

Martel, J.-L.; Brissette, F.P.; Lucas-Picher, P.; Troin, M.; Arsenault, R. (**2021**) Climate change and rainfall intensity-duration-frequency curves: overview of science and guidelines for adaptation. *Journal of Hydrologic Engineering*, 26(10), art 03121001. DOI: 10.1061/(ASCE)HE.1943-5584.0002122.

Mathews, S.; Surminski, S.; Roezer, V. (**2021**) *The Risk of Corporate Lock-in to Future Physical Climate Risks: The Case of Flood Risk in England and Wales*. Centre for Climate Change Economics and Policy Working Paper 399 and Grantham Research Institute on Climate Change and the Environment Working Paper 372. London: London School of Economics and Political Science.

May, C. (**2020**) Rising groundwater and sea-level rise. *Nature Climate Change*, 10(10), pp 889–890. DOI: 10.1038/s41558-020-0886-x.

McGuire, C.J.; Goodman, M. (**2020**) Coastal resiliency through value capture and transfer: a framework proposal. *Coastal Management*, 48(2), pp 57–76. DOI: 10.1080/08920753.2020.1728205.

Melbourne Water (**2020**) Drainage Schemes Explained. Accessed 3 December 2023, www.melbournewater.com.au/building-and-works/developer-guides-and-resources/drainage-schemes-and-contribution-rates/find-0.

Moftakhari, H.R.; Salvadori, G.; AghaKouchak, A.; Sanders, B.F.; Matthew, R.A. (**2017**) Compounding effects of sea level rise and fluvial flooding. *Proceedings of the National Academy of Sciences*, 114(37), pp 9785–9790. DOI: 10.1073/pnas.1620325114.

Muangsri, S.; McWilliam, W.; Davies, T. (**2024**) The potential of industrial green stormwater infrastructure to provide long-term supplementary flood mitigation for low-lying coastal cities under climate change. *Landscape and Urban Planning*, 243, art 104967. DOI: 10.1016/j.landurbplan.2023.104967.

Muangsri, S.; McWilliam, W.; Davies, T.; Lawson, G. (**2022a**) Effectiveness of strategically located green stormwater infrastructure networks for adaptive flood mitigation in a context of climate change. *Land*, 11(11), art 2078. DOI: 10.3390/land11112078.

Muangsri, S.; McWilliam, W.; Lawson, G.; Davies, T. (**2022b**) Evaluating capability of green stormwater infrastructure on large properties toward adaptive flood mitigation: the HLCA+C methodology. *Land*, 11(10), art 1765. DOI: 10.3390/land11101765.

Mukhtarov, F.; Dieperink, C.; Driessen, P.; Riley, J. (**2019**) Collaborative learning for policy innovations: sustainable urban drainage systems in Leicester, England. *Journal of Environmental Policy & Planning*, (3), pp 288–301. DOI: 10.1080/1523908X.2019.1627864.

Pappalardo, V.; La Rosa, D.; Campisano, A.; La Greca, P. (**2017**) The potential of green infrastructure application in urban runoff control for land use planning: a preliminary evaluation from a southern Italy case study. *Ecosystem Services*, 26, pp 345–354. DOI: 10.1016/j.ecoser.2017.04.015.

Parikh, P.; Taylor, M.A.; Hoagland, T.; Thurston, H.W.; Shuster, W. (**2011**) At the intersection of hydrology, economics, and law: application of market mechanisms and incentives to reduce stormwater runoff. In *Economic Incentives for Stormwater Control*, H.W. Thurston, Ed., Baton Rouge, LA: CRC Press.

Perry, T.; Nawaz, R. (**2008**) An investigation into the extent and impacts of hard surfacing of domestic gardens in an area of Leeds, United Kingdom. *Landscape and Urban Planning*, 86(1), pp 1–13. DOI: 10.1016/j.landurbplan.2007.12.004.

Queensland Reconstruction Authority (**2019**). *Brisbane River Strategic Floodplain Management Plan*. Brisbane: The State of Queensland. Accessed 17 March 2024, www.qra.qld.gov.au/brcfs/brisbane-river-strategic-floodplain-management-plan.

Radhakrishnan, M.; Pathirana, A.; Ashley, R.M.; Gersonius, B.; Zevenbergen, C. (**2018**) Flexible adaptation planning for water sensitive cities. *Cities*, 78, pp 87–95. DOI: 10.1016/j.cities.2018.01.022.

Rey-Valette, H.; Robert, S.; Rulleau, B. (**2019**) Resistance to relocation in flood-vulnerable coastal areas: a proposed composite index. *Climate Policy*, 19(2), pp 206–218. DOI: 10.1080/14693062.2018.1482823.

Rogers, B.C.; Bertram, N.; Gersonius, B.; Gunn, A.; Löwe, R.; Murphy, C.; Pasman, R.; Radhakrishnan, M.; Urich, C.; Wong, T.H.F.; Arnbjerg-Nielsen, K. (**2020**) An interdisciplinary and catchment approach to enhancing urban flood resilience: a Melbourne case. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 378(2168), art 20190201. DOI: 10.1098/rsta.2019.0201.

Rosly, D.; Rashid, A.A. (**2013**) Revitalizing urban development in Malaysia through the implementation of urban regeneration programme. Paper presented at the 43rd Annual Conference of the Urban Affairs Association, San Francisco, CA, USA, 3–6 April.

Saiu, V.; Blečić, I.; Meloni, I. (**2022**) Making sustainability development goals (SDGs) operational at suburban level: potentials and limitations of neighbourhood sustainability assessment tools. *Environmental Impact Assessment Review*, 96, art 106845. DOI: 10.1016/j.eiar.2022 .106845.

Saraswat, C.; Kumar, P.; Mishra, B.K. (**2016**) Assessment of stormwater runoff management practices and governance under climate change and urbanization: an analysis of Bangkok, Hanoi and Tokyo. *Environmental Science & Policy*, 64, pp 101–117. DOI: 10.1016/j.envsci.2016.06.018.

Schubert, J.E.; Burns, M.J.; Fletcher, T.D.; Sanders, B.F. (**2017**) A framework for the case-specific assessment of green infrastructure in mitigating urban flood hazards. *Advances in Water Resources*, 108, pp 55–68. DOI: 10.1016/j.advwatres.2017.07.009.

Shafique, M.; Kim, R. (**2017**). Retrofitting the low impact development practices into developed urban areas including barriers and potential solution. *Open Geosciences*, 9, pp 240–254. DOI: 10.1515/geo-2017-0020

Smith, B.K.; Smith, J.A.; Baeck, M.L.; Miller, A.J. (**2015**) Exploring storage and runoff generation processes for urban flooding through a physically based watershed model. *Water Resources Research*, 51(3), pp 1552–1569. DOI: 10.1002/2014WR016085.

Tao, J.; Li, Z.; Peng, X.; Ying, G. (**2017**) Quantitative analysis of impact of green stormwater infrastructures on combined sewer overflow control and urban flooding control. *Frontiers of Environmental Science and Engineering*, 11, art 11. DOI: 10.1007/s11783-017-0952-4.

Temmerman, S.; Meire, P.; Bouma, T.J.; Herman, P.M.J.; Ysebaert, T.; De Vriend, H.J. (**2013**) Ecosystem-based coastal defence in the face of global change. *Nature*, 504(7478), pp 79–83. DOI: 10.1038/nature12859.

Terry, J.P.; Winspear, N.; Goff, J. (**2021**) Is Bangkok at risk of marine flooding? Evidence relating to the historical floods of AD 1785 and 1983. *Natural Hazards*, 105(1), pp 1013–1030. DOI: 10.1007/s11069-020-04347-4.

Tonkin & Taylor Ltd (**2017**) *Coastal Hazard Assessment for Christchurch and Banks Peninsula (2017)*. Christchurch: Tonkin & Taylor Ltd. Accessed 17 March 2024, www.ccc.govt.nz/assets/Documents/Environment/Land/Costal-Hazards/2017-Coastal-Hazards-Report.pdf.

Tsuchiya, N.; Tortajada, C.; Ratra, S. (**2018**) Flood disaster prevention: lessons from Tokyo. Accessed 17 March 2024, https://globalwaterforum.org/2018/01/22/flood-disaster-prevention-lessons-from-tokyo.

van Buuren, A.; Lawrence, J.; Potter, K.; Warner, J.F. (**2018**) Introducing adaptive flood risk management in England, New Zealand, and the Netherlands: the impact of administrative traditions. *Review of Policy Research*, 35(6), pp 907–929. DOI: 10.1111/ropr.12300.

van der Sterren, M.; Rahman, A.; Shrestha, S.; Barker, G.; Ryan, G. (**2009**) An overview of on-site retention and detention policies for urban stormwater management in the Greater Western Sydney Region in Australia. *Water International*, 34(3), pp 362–372. DOI: 10.1080/02508060903115175.

Vitousek, S.; Barnard, P.L.; Fletcher, C.H.; Frazer, N.; Erikson, L.; Storlazzi, C.D. (**2017**) Doubling of coastal flooding frequency within decades due to sea-level rise. *Scientific Reports*, 7(1) art 1399. DOI: 10.1038/s41598-017-01362-7.

Xu, T.; Li, K.; Engel, B.A.; Jia, H.; Leng, L.; Sun, Z.; Yu, S.L. (**2019**) Optimal adaptation pathway for sustainable low impact development planning under deep uncertainty of climate change: a greedy strategy. *Journal of Environmental Management*, 248, art 109280. DOI: 10.1016/j.jenvman.2019.109280.

Yousefpour, R.; Hanewinkel, M. (**2016**) Climate change and decision-making under uncertainty *Current Forestry Reports*, 2(2), 143–149. DOI: 10.1007/s40725-016-0035-y.

Zahmatkesh, Z.; Burian, S.J.; Karamouz, M.; Tavakol-Davani, H.; Goharian, E. (**2015**) Low-impact development practices to mitigate climate change effects on urban stormwater runoff: case study of New York city. *Journal of Irrigation and Drainage Engineering*, 141(1), art 04014043. DOI: 10.1061/(ASCE)IR.1943-4774.0000770.