# Mitigating flood risks: analysis of different types and quantity of green infrastructure

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Climate change is likely to intensify the effects of extreme weather events and increase their impacts on urban areas. A major emerging challenge for urban areas is how to address these uncertainties without neglecting the need to manage development and population growth. Green infrastructure (GI) is a promising strategy aiming to alleviate climate change impacts and address flood risks. The assessment of GI performance in minimising flood risk can be a major challenge due to time and costs involved in addressing multiple potential scenarios (e.g. different combinations of types and quantities of GI, suitable locations, different temporal scales). Additionally, the development of an efficient plan to mitigate urban flood risks may require an optimal combination of GI types, locations and quantity. In general, bio-retention cells (BR), rain gardens (RG) and permeable pavements (PP) are solutions that can be conveniently implemented in urban areas. In particular, these options are suitable for retrofitting urban areas because they demand small spaces to be implemented and are not affected by land tenure issues. However, the effectiveness of GI alternatives in alleviating extreme rainfall impacts is not entirely known. In this study, the extent to which GI can minimise flood risks was investigated. Feasible scenarios for placing GI units and different combinations for optimal design have been developed, analysed and compared with baseline scenarios for assessing their flood mitigation effects. A regional and a metropolitan case study location in Aotearoa-New Zealand were chosen to provide a more holistic analysis of GI performance applied to different urbanisation patterns. To this end, Gore, in the South Island, and Auckland, in the

North Island, were selected, respectively. Scenarios were developed based on information related to climate change impacts and associated flood risk, and GI distribution and types. Future climate change scenarios used RCP4.5 and RCP8.5 (range year 2031-2050) data. Concerning the duration of the rainfall, short and long-term events were selected (1-hour and 120-hours of rainfall) to evaluate GI performance under different situations. Different types and quantities of GI were added to the current urban fabric of selected catchments. Selected GI types included bio-retention cells, permeable pavement and rain gardens. Based on the availability of areas to be converted into GI alternatives, 5% and 10% of GI were tested. To narrow down the number of sub-catchments and define which ones would be suitable for implementing GI options, the following screening criteria were applied: (i) sub-catchment with more than 50% of its total area occupied by residential areas; (ii) sub-catchment where residents have lower median annual income (0-$30,000) compared to the national average annual income; and, (iii) sub-catchment not meeting the accessibility criteria established by the Access to Natural Greenspace Standard's – that is, green areas of at least 2 hectares in size and no more than 300 metres from any given residence. The evaluation of GI performance was addressed using two different spatial scales, catchment and sub-catchment levels. The most significant indicators used to assess the efficiency of the flood management performance of the scenarios were: (i) total flood volume; (ii) maximum runoff (catchment and sub-catchment); and, (iii) total runoff volume (catchment and sub-catchment). Reducing indicators values would mean increasing flood reduction because flood risk would be minimised. Findings indicated that GI alternatives are efficient in reducing flood risks, but their performance is highly dependent on quantity, urbanisation patterns, and rainfall intensity and duration. The results on the catchment total flood volume for 10% of GI implementation and considering 1-hour of rainfall showed a better performance using PP followed by BR+PP both in Auckland and Gore. Considering longer rainfalls (120 hours), single options such as PP and BR and combination of BR+PP showed best results for the two case study locations. The lower decrease was accomplished by RG for all rainfall scenarios and durations. The individual implementation of PP and the combination of BR+PP comprised the best solutions when 5% of sub-catchments were converted to GI alternatives for 1-hour of rainfall in Auckland. The 120-hours of rainfall scenarios showed performance comparable to the 1-hour scenarios, but BR was also identified as one of the best results for minimising flood volume. The combination of RG+BR performed better in Gore for 1 hour of rainfall, and RG+PP were the best solutions for 120 hours of rainfall. Again, the lower reduction in total flood volume was shown by RG as a single alternative. When 10% of the sub-catchment area was covered by GI, the reduction on the catchment runoff peak rate was best accomplished by BR, PP and BR+PP and the worst performance was achieved by RG for both case study locations in all rainfall scenarios. Scenarios that considered 5% of GI in the selected sub-catchments yielded similar results. In Auckland, the highest reduction in runoff peak rate was obtained by BR, PP and BR+PP for all rainfall scenarios; while in Gore, RG+BR figured as the best alternative to reduce runoff peak rate at the catchment scale. The lower effectiveness was presented once again by RG. The reduction in runoff peak rate measured at the sub-catchment scale differed greatly when compared to the whole catchment. For example, for both rainfall scenarios, when 10% of GI was implemented on the selected sub-catchments area there was a reduction in runoff peak rate varying from around 49% to 72% (Auckland) and from 44% to 71 % (Gore). While converting 5% of the sub-catchment area into GI alternatives represented a reduction in runoff peak rate ranging from around 25% to around 41% in Auckland, and from around 25% to 42% in Gore. The best GI alternatives for lowering runoff peak rate varied from sub-catchment to sub-catchment. When implementing 10% of GI with 1-hour rainfall scenario, overall runoff volume in Auckland and Gore was better reduced if applying PP and BR+PP. For both case studies, BR showed the highest results for the 120-hours of precipitation. Auckland also provided a good performance relating to runoff peak rate when adopting BR and PP as single options. There was a significant improvement in the runoff reduction when focusing on the sub-catchments scale. The studied sub-catchments presented a very similar performance relating to runoff total volume compared to the results for lowering runoff peak rate. In Auckland, in the 1-hour scenario, the decrease in runoff total volume varied from around from 50% to 74% (10% of GI) and about 25% do 43% (5% of GI); and from 50% to 75% (10% of GI) and from around 25% to 42% (5% of GI) in the 120-hours of rainfall. Interestingly, in all sub-catchments, PP was among the best solutions for reducing total runoff volume. Likewise, the best solutions for both rainfall scenarios were BR+PP and PP, deploying 5% of GI on the selected sub-catchments in Auckland. In the 120 hours of rainfall, BR showed a strong capacity to minimise total runoff volume. On the other hand, a

peculiar outcome was provided by Gore. The best results were obtained by RG+BR and PP on the 1-hour of rainfall and by RG+PP on the 120-hours. The hypothetical scenarios have demonstrated that most of the evaluated parameters (total flood and total runoff) were reduced the most on the 1-hour-rainfall scenario relative to the 120-hours scenario. Although some parameters had similar results for both rainfall duration (to know runoff peak rate and total runoff), the 1-hour results appeared to be slightly more effective than the 120-hours rainfall scenarios. In conclusion, these results indicate that when there is limited budget to invest in GI alternatives, it is worthwhile to consider a social-equity dimension and greenspace accessibility criteria to prioritise areas for GI implementation. This can assist decision-makers to prioritise areas whose population is more vulnerable to flood risks. Finally, multiple combinations of GI alternatives should be implemented within the catchment area to maximise their potential in minimising flood risks whilst accommodating different urbanisation pressures.

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