Ōpāwaho/Heathcote River Floodplain Management Plan

Christchurch City Council

Options to Mitigate Post-Earthquake Frequent Flooding

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Ōpāwaho/Heathcote River Floodplain Management Plan

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Contents

Executive Summary

Flooding has long been a significant issue along the Ōpāwaho / Heathcote River and the Canterbury Earthquake Sequence has increased both the severity and frequency of flooding. In addition to requiring mitigation of increased runoff from new subdivisions, management of flooding prior to the earthquakes was through a mixture of river management (e.g. weed removal) and planning controls to reduce property damage (e.g. District Plan floor level setting).

Following the earthquakes, Christchurch City Council ('the Council') initiated investigations into post-earthquake floodplain management. As a result of the early outcomes of the investigations, the Council has fast-tracked land purchase, design and construction of upstream storage basins, which store water during the peak of a storm and release it gradually afterwards. However, the basins will take several years to complete and will not alone return the catchment to pre-earthquake levels of flood risk along the full length of the river to Radley Street.

Using the planned upstream storage as a baseline, options for managing post-earthquake flooding along the Ōpāwaho / Heathcote River upstream of Radley Street are being developed. This report short-lists those of the options which are most relevant to mitigating frequent flooding occurring in the current hydrological climate, in flood events similar to that which occurred in the Heathcote catchment on 21-22 July 2017. These proposed options could form a foundation on which management of more extreme flooding, as well as frequent flooding with climate change and sea level rise, can be developed.

From a long list of possible options, the following are proposed as options to manage post-earthquake frequent flooding in the current climate along the Ōpāwaho / Heathcote River upstream of Radley Street, in addition to the planned upstream storage:

- Dredging the river between Hansen Park and into the Woolston Cut;
- Construction of 'low' stopbanks along sections of the river between Hunter Terrace and Hansen Park to minimise underfloor and road flooding; and
- Application of the Council's Flood Intervention Policy, which includes offer of voluntary purchase, for those at frequent flood risk which has been exacerbated by the earthquakes.

Flood benefits are primarily assessed in terms of the reduction in numbers of flooded residential dwellings. If, in addition to the upstream storage, the proposed options are implemented, no dwellings would remain at risk of overfloor flooding in a frequent flood in the current climate, which is an improvement on the pre-earthquake level of risk. These same measures also substantially reduce – but do not eliminate - pre-earthquake levels of flood risk in more extreme events in the current climate.

An indication of likely cost is provided for the options. For each option, high level information is provided to inform future assessment of the non-drainage impacts of each option (including ecology, landscape, recreation, heritage, and culture).

Based on this initial assessment, it is recommended that the Council continues with planned upstream storage, and develops each of these three additional options, and makes decisions on their implementation within the context of the ongoing work to manage more extreme flooding, as well as frequent flooding with climate change.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to provide assessment including hydraulic modelling where relevant of various options to address frequent flooding in the Ōpāwaho */Heathcote River Floodplain as it relates to developing short to medium term options for managing frequent flood risk in accordance with the scope of services set out in the contract between Jacobs and Christchurch City Council ('the Client'). That scope of services, as described in this report, was developed with the Client.*

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. This report contains analysis of the flood risk to individual buildings which is based on data received from the following key sources: (i) the Council floor level database (latest version issued August 2017) (ii) Rateable Value database (2016 valuations) (iii) RiskScape building depth-damages (2016 delivery of 2011 data). Together, these data provide the best available snapshot of property information across the city at a point in time and are updated at different intervals, including within the timescales of this project and report. Reasonable effort has been made to report property metrics using the latest available data and on-site observation has been used in some situations to clarify uncertainties in the data. However, these data are liable to change in the future. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report is a supplementary project deliverable agreed in a variation to the scope of services between Jacobs and the Client. The scope of services contains future deliverables which have not been developed at the date of issue of this report.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, the Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party

1. Introduction

1.1 Background to Floodplain Management in the Heathcote Catchment

Flooding has been a significant issue along the Ōpāwaho / Heathcote River since human settlement along the river corridor intensified, particularly when the lower river terraces were settled in the early 20th century. Management of flooding by the Christchurch Drainage Board (prior to 1989) included dredging[1] and raising some houses, in addition to studies recommending upstream storage, localised stopbanks and policies.

Subsequently, in addition to ongoing river maintenance and implementing a number of these recommendations, flooding has primarily been managed through stormwater management plans (SMPs), the South-West Area Plan (SWAP) and other planning controls to reduce property damage, such as the District Plan. These plans manage flood impacts by setting minimum floor levels, restricting development in flood prone areas, and requiring mitigation of increased runoff from new subdivisions.

The Canterbury Earthquake Sequence ('earthquakes') increased both the severity and frequency of flooding. The key effects for the Ōpāwaho / Heathcote River were:

- Loss of channel capacity due to bank slumping, lateral spread, and increased sedimentation due to liquefaction;
- Tectonic uplift at the mouth of the river resulting in a reduced capability to drain upstream; and
- Land settlement in places resulting in a drop of land levels adjacent to the river.

For example, between Colombo and Radley Streets, the number of houses at risk of frequent flooding (greater than a 10 year Average Recurrence Interval, ARI)[2] event is now more than five times greater, and the number of at risk of flooding in a more extreme 50 year ARI[3] event has almost doubled. Some houses along the Ōpāwaho / Heathcote River have been reported to have flooded four times since the earthquakes, as a result of the earthquakes and a particularly wet period. Other impacts of the post-earthquake flooding are wastewater contamination on property and restriction of access for hundreds of properties. The impact of the earthquakes on buildings at risk of flooding are quantified in Table 1.1.

In Table 1.1, the number of buildings at risk of overfloor flooding as a result of earthquake impacts in each event (either 10 year or 50 year ARI) is greater than the total difference between pre-earthquake and post-earthquake. This is because the flood risk at a number of buildings upstream of Colombo Street actually dropped as a result of the earthquakes.

Table 1.1 : Number of buildings with overfloor flooding pre-earthquake and immediately post-earthquake, and identifying those which were not at risk pre-earthquake

Area	10 year ARI (current climate)			50 year ARI (current climate)		
	PreEQ	PostEQ	PostEQ but not preEQ	PreEQ	PostEQ	PostEQ but not preEQ
Radley Street to Hansen Park	0	16	16	27	69	44
Hansen Park to Colombo Street	4	7	4	58	83	34
Upstream of Colombo Street	3	1	1	90	70	21
Totals	**7**	**24**	**21**	**175**	**222**	**99**

[1] http://docs.niwa.co.nz/library/public/MRFD27.pdf

[2] An event with a 10 year average recurrence interval (ARI) is equivalent to a 10% annual exceedance probability (AEP) event. That is, it has a 10% probability of occurring each year. This is commonly referred to as a "1 in 10 year event".

[3] An event with a 50 year average recurrence interval (ARI) is equivalent to a 2% annual exceedance probability (AEP) event. That is, it has a 2% probability of occurring each year. This is commonly referred to as a "1 in 50 year event". However, it is important to remember that an event of this magnitude can occur a number of times in a 50 year period as it is based on long term averages.

One of the principal methods of reducing flooding is to store water during the peak of a storm. As such, the Upper Heathcote storage scheme forms the foundation of post-earthquake flood management response. It is based on constructing four basins which were identified in previous floodplain management strategies[4] (dating back to at least 1985). Christchurch City Council ('the Council') has confirmed their post-earthquake viability and has worked to fast-track land purchase, design and construction. However, the basins will take several years to complete and will not alone return the catchment to pre-earthquake levels of flood risk along the full length of the river to Radley Street.

Therefore, to restore pre-earthquake levels of flood risk, the Council commissioned Jacobs to develop local and catchment-wide floodplain management plans, incorporating engineering and policy options and taking into account other natural hazards, to address fluvial, pluvial and tidal flood risk. The study focuses on achieving flood management benefits in the catchment between Halswell Road and Radley Street, although options outside of this area will be considered.

The options presented in this report are a short-list of those from the wider study which are most relevant to mitigating post-earthquake frequent flooding which occurs in the current hydrological climate (i.e. without climate change; hereafter referred to as 'current climate'). These proposed options could form a foundation on which management of more extreme flooding, as well as frequent flooding with climate change and sea level rise, can be developed.

Indeed, it is noted that climate change and sea level rise will have a more significant impact on flooding – particularly downstream of Hansen Park - than the earthquakes. The options presented in this report can be designed not to compromise any longer-term measures to address more extreme flooding, or more frequent flooding with climate change. The wider floodplain management study will propose adaptive means to manage flooding into the future in a separate report.

1.2 July 2017 Flooding

On 21 – 22 July 2017, a deep low pressure system over the upper South Island resulted in a storm-tide/flood event in Christchurch and, in particular, the Heathcote catchment[5]. In terms of likely magnitude of the event, it is considered to have an average recurrence interval of less than 10 years (e.g. lower magnitude than a '1 in 10 year' event). In the context of this report, this is considered as a frequent flood event.

The July 2017 event resulted in confirmed flooding above floor level at 12 houses between Colombo and Radley Streets. It also resulted in a significant amount of underfloor flooding, cut off access to residences, resulted in wastewater overflows, required clean-up of contaminated property and removal of sediment from roads, and resulted in declaration of a state of emergency[6,7,8]. This event follows a number of other rainfall events which resulted in roads being closed in this area, most notably as a result of Cyclones Cook and Debbie and caused significant community distress.

1.3 Scope of Work

This report summarises options focussed on mitigating post-earthquake frequent flooding (i.e. those occurring with an annual recurrence interval of 10 years), as well as the results of the modelling and floor level analysis to assess their flood management benefit. The summary includes a preliminary Multi-Criteria Analysis (MCA) for each.

In terms of flood characteristics, the Heathcote catchment can be considered in the following reaches:

- Upstream of Colombo Street: majority of properties at risk will benefit from the upstream storage;
- Between Colombo Street and Hansen Park: upstream storage benefits this area although properties remain at risk from river flooding and, increasingly, the influence of sea level rise;

[4] https://www.ecan.govt.nz/document/download/?uri=301630
[5] NIWA (2017) Analysis of the 21-22 July 2017 coastal storm-tide. Letter from Ben Robinson to Justin Cope
[6] https://www.stuff.co.nz/the-press/news/95009929/heathcote-residents-surrounded-by-water
[7] http://www.stuff.co.nz/the-press/news/95005138/Christchurch-residents-evacuated-by-boat-as-Heathcote-River-floods
[8] https://www.stuff.co.nz/national/95003616/Flooding-road-closures-and-sewerage-leaks-as-rainfall-lets-up

- Between Hansen Park and Radley Street: minimal benefits of upstream storage which are dominated by increasing tidal flooding with sea level rise; and
- Downstream of Radley Street: increasingly dominated by sea level rise.

Upstream of Colombo Street, the planned upstream storage mitigates all post-earthquake flood risk up to the 50 year ARI event in the current climate, and eliminates almost all pre-earthquake flood risk. Therefore, this report is focussed on areas along the Ōpāwaho / Heathcote River between Colombo and Radley Streets. Options to manage flooding downstream of Radley Street are being developed in a separate study looking at the impact of multiple natural hazards on floodplain management.

2. Methodology for Developing and Appraising Options

2.1 Baseline: Upper Heathcote Storage

The Council is part way through implementing the Upper Heathcote flood storage scheme, comprisingflood storage basins upstream of Colombo Street, located in the Cashmere-Worsley valley, Hendersons Basin, adjacent to Curletts Stream and in Wigram Wetpond (Figure 2.1). These storage basins are in addition to those being constructed to mitigate the impacts of subdivision runoff. The 1985 Drainage Board study identified the flood management opportunity offered by these basins, and they were also a core part of the 1998 Heathcote Floodplain Management Study. However, while the Wigram Basin was built prior to the earthquakes (although smaller than originally intended), the other basins were not constructed for various reasons, including lack of funding.

Figure 2.1 : Location of storage basins in the Upper Heathcote storage scheme

It is anticipated that these basins will largely be completed by the end of 2018. The Council has estimated the storage scheme to have a total cost of approximately $40M. The storage basins are considered to be the foundation of all other options as they lower water levels such that the benefits of the other options are enhanced, and the costs for other options are lower. However, even with the upstream storage there will remain many buildings at risk of overfloor and underfloor flooding, and this risk will increase with climate change, particularly in the lower catchment.

The purpose of the storage basins is to store flood waters during the peak of a storm and to slowly release the stored water after the water levels downstream have dropped. The effect of this is to result in a lower peak water level than would have occurred if there was no storage upstream. It is estimated (Table 2.1) that the upstream storage will protect over 100 buildings currently at risk of overfloor flooding in more extreme floods (i.e. a 1 in 50 year ARI event), including the majority of those upstream of Colombo Street and over two thirds of those between Colombo and Radley Streets. This will reduce the risk of flooding above floor in extreme events upstream of Radley Street to below pre-earthquake levels. In frequent floods (i.e. 1 in 10 year ARI event in Table 2.1), the upstream storage will protect half of the buildings at risk of overfloor flooding upstream of Radley Street. This reduces the risk of flooding in frequent events upstream of Hansen Park to below pre-earthquake levels, but does not eliminate all the increased risk which resulted from the earthquakes downstream of Hansen Park.

Table 2.1 : Number of buildings with overfloor flooding pre-earthquake, immediately post-earthquake and with the planned upstream storage

Area	10 year ARI (current climate)			50 year ARI (current climate)		
	PreEQ	PostEQ	PostEQ with storage	PreEQ	PostEQ	PostEQ with storage
Radley Street to Hansen Park	0	16	8	27	69	61
Hansen Park to Colombo Street	4	7	4	58	83	51
Upstream of Colombo Street	3	1	0	90	70	2
Totals	**7**	**24**	**12**	**175**	**222**	**114**

Figure 2.2 and Figure 2.3 plot the distribution of properties at residual risk of flooding (i.e. those not protected by the planned upstream storage) between Colombo and Radley Streets, both in the current climate (Figure 2.2) and with climate change of +1m sea level rise (Figure 2.3).

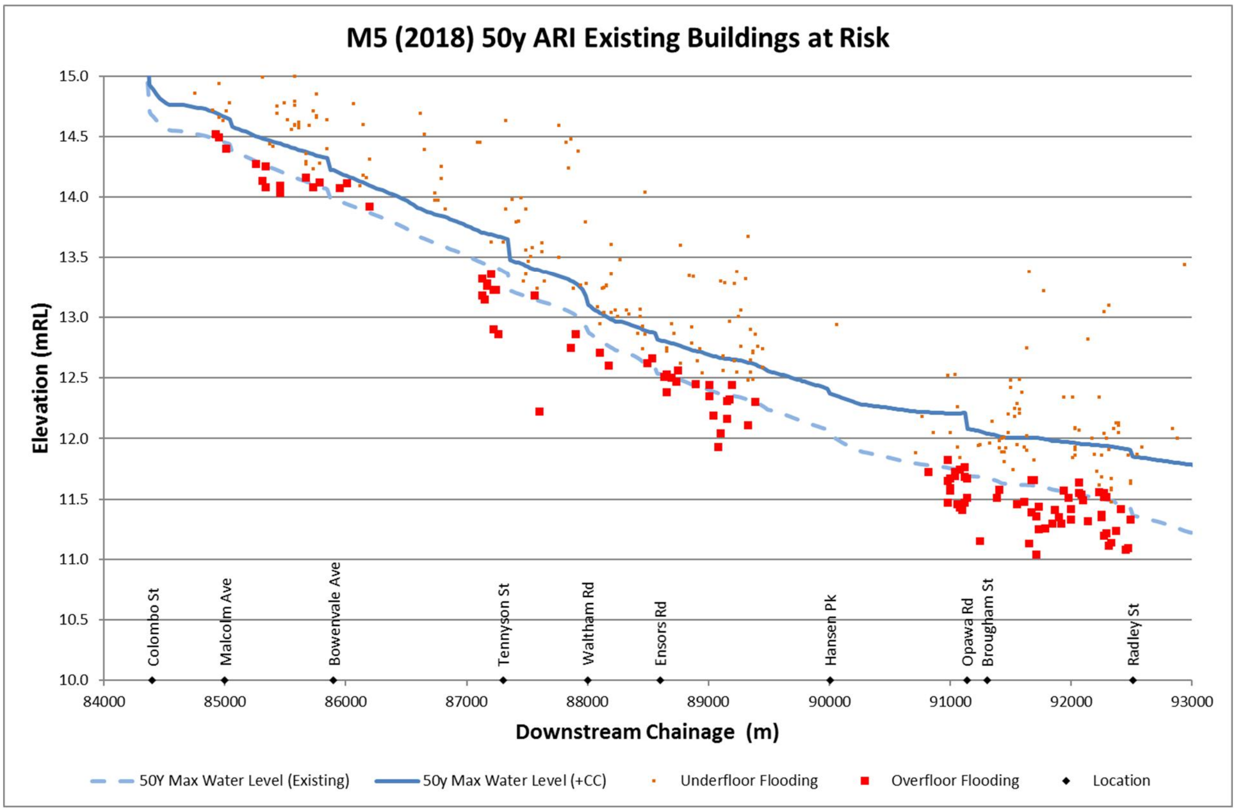

Figure 2.2 : Residual flood risk in the 50 year ARI event in the current climate

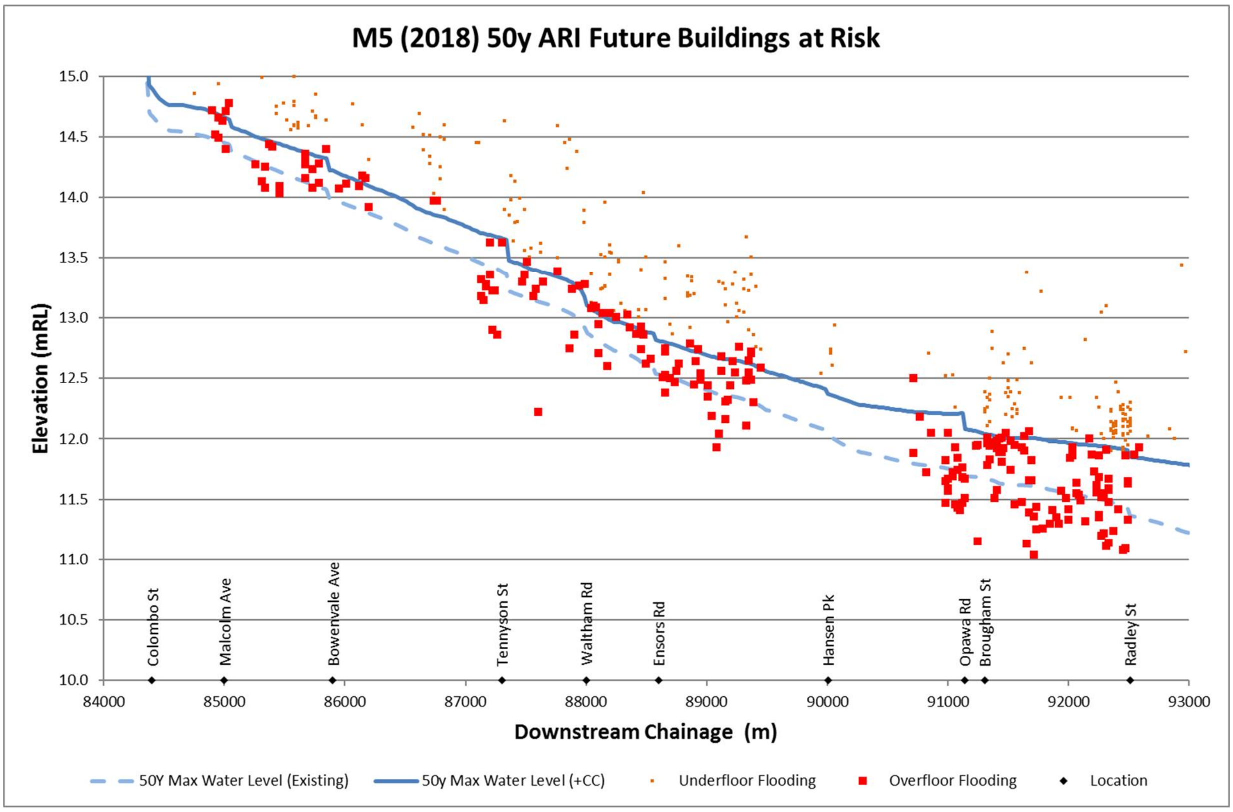

Figure 2.3 : Residual flood risk in the 50 year ARI event with climate change

2.2 Additional Options Development

In addition to the already planned upstream storage, the long list of options initially considered are listed in Table 2.2. In addition to policy responses, the options are grouped within the source-pathway-receptor framework (Figure 2.4), which is:

- **Policy:** Applying statutory codes and plans.
- **Source:** Reducing or attenuating the flood sources.
- **Pathway:** Improving the capacity of the river or keeping the river within the banks
- **Receptor:** Reducing flood damages to people, buildings, infrastructure and the environment

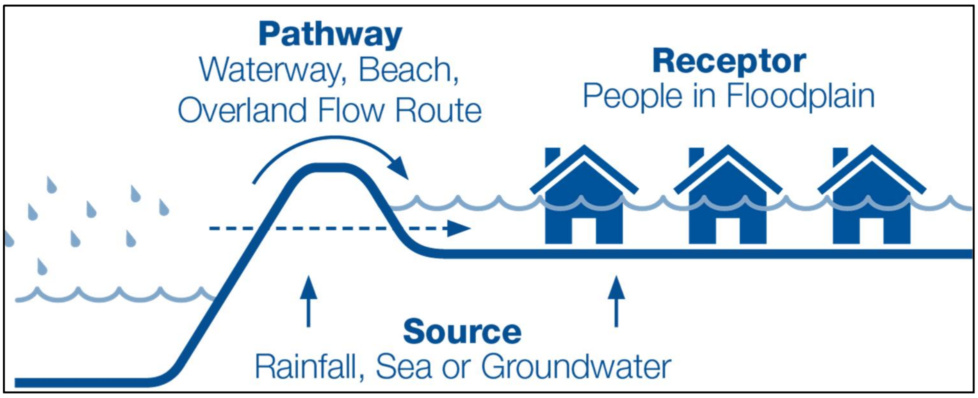

Figure 2.4 : Schematic showing interaction of flood sources, pathways and receptors

From the long list in Table 2.2, the following three primary options were identified to provide most benefit for post-earthquake frequent flooding in the current climate, able to be implemented relatively quickly and, potentially, affordable. The work undertaken to date on these options is summarised in the following Sections:

- Section 3: Dredging
- Section 4: Low stopbanks
- Section 5: Flood Intervention Policy

The remainder of options listed in Table 2.2 were judged not to be as relevant to managing frequent flooding in the current climate, for the primary reasons stated in the table. However, some are being considered within the wider study to manage more extreme flooding, as well as frequent flooding with climate change.

It is noted that community development and strengthening the resilience of communities to hazards such as flooding must be the cornerstone of any floodplain management response. The Council's Resilience Strategy[9] sets out a framework for developing resilient communities. Community development staff in relevant ward areas are therefore engaged so that the Council's overall flood management encompasses all the necessary aspects of developing the community's ability to live with flooding in this area.

Table 2.2 : Long list of options considered for managing flooding

Framework	Option Group	Description of Option	Notes
Policy	Upper Heathcote storage only	Planned completion of upstream storage followed by ongoing maintenance across the catchment but no further engineering or policy interventions.	Not considered alone as a proactive option to restore pre-earthquake levels of flood risk, or to address frequent flooding in the mid and lower reaches of the river.
	Flood Intervention Policy (FIP)	Modification (removal, raising or protection) of dwellings at risk of frequent flooding, where the risk has been increased through the earthquakes	ü **Considered for management of post-earthquake frequent flooding**
	Room for the River	Remove infrastructure from flood-prone areas and naturalise	Longer-term, removal of structures on the floodplain could increase the river capacity and remove people from areas at risk of flooding. This may have to be considered to manage future flooding which increases with climate change.
Source	Further upstream storage	In Upper Heathcote in addition to already planned storage	Further storage in Hendersons Basin will be high cost (requiring land purchase and pumped transfer) to achieve benefit at the upper end of the Colombo to Radley Street reach.
		Eastern Port Hills runoff control	Attenuating runoff from the eastern Port Hills will be technically challenging and delaying the peak by only a few hours may cause flood peaks to further coincide and exacerbate flooding.
	Tidal control	Barrier to supress estuary levels	These options may be relevant when sea/estuary levels have risen to impede effective discharge from the Heathcote, and will be sized to manage extreme rather than frequent floods.
		River mouth pump station	
	Catchment-wide micro storage	Property-level water tank storage implemented through policy	Reasonable-sized tanks would likely be already full and therefore ineffective during the peak of a regular flood event.
Pathway	Mid catchment storage	Utilise existing open space at Hansen Park, Waltham Park, Beckenham Park	Open space areas are relatively small and typically high, and would therefore require substantial excavation, bunding and/or pump stations at high cost to achieve likely moderate impact.

9 http://greaterchristchurch.org.nz/projects/resilient-greater-christchurch/

Framework	Option Group	Description of Option	Notes
	Channel Dredging	Channel widening and lowering	ü **Considered for management of post-earthquake frequent flooding**
	Bridge Enlargement	Enlarging bridges which pose a hydraulic constraint to high flows	In frequent floods, the Opawa Road bridge poses the largest hydraulic constraint between Colombo and Radley Streets. However, the minor hydraulic benefit achieved was not judged sufficient to justify the likely high cost.
	Floodplain Widening	Lowering of land along the river corridor between Colombo Street and Hansen Park	Major road narrowing, bridge enlargement and floodplain widening works would be required, typically along both banks of the ~6km channel between Colombo Street and Hansen Park, to obtain increased conveyance of flood flows. There is a minor hydraulic benefit which could be achieved if the works were done to implement the Mid-Heathcote River / Ōpāwaho Linear Park Masterplan, but the significant cost of works is unlikely to be justified by flood benefits alone.
	Channel Diversion	Path length reduction at large meanders via culvert or secondary flow paths	The costs of diversions are high, and are unlikely to be justified due to the current limited flood benefits achieved. However, they may have relevance for managing the increased flooding due to climate change in the future. The most effective diversion is along Sandwich Road.
	Stopbanks / flood walls	Raised adjacent to the river	Stopbanks to protect against more extreme flooding are likely to be high and could destroy the character of the river environment. Therefore, due to the height and likely high cost, stopbanks for more extreme floods are not considered viable. However, low stopbanks are considered here for the management of frequent flooding. ü **Low stopbanks considered for management of post-earthquake frequent flooding**
	Temporary defences	Deploying barriers or other temporary defences adjacent to the river upon receipt of a prediction of flooding	There are locations where temporary defence alignments could provide benefit, especially in the period before any more permanent options are implemented. However, they are not considered here as a stand-alone option to manage flooding between Colombo and Radley Streets due to the long lengths of defences required at this scale, and the uncertain availability of resources to deploy them in time.
Receptor	Individual Property Protection	House raising or local defence options on a wider scale than the Flood Intervention Policy	Implementation on a wider scale than offered by the Flood Intervention Policy would require development of a policy by the Council which will not offer timely protection for those most at risk.

2.3 Options Appraisal

Options have been assessed based on their flood management benefits, and against a number of criteria representing the values of ecology, landscape, recreation, heritage, and culture.

2.3.1 Flood Management Benefits

Flood management benefits are primarily measured as the number of buildings protected from overfloor flooding (defined as the flood level being within 100 mm of habitable floor level) and underfloor flooding (defined as the flood extent touching the building). However, the lengths of roads causing restricted access has also been measured where possible. For the purposes of managing frequent flooding, these benefits are predicted for the 1 in 10 year ARI design flood event, although it is emphasised that larger flood events may still occur to cause flooding.

Climate change will increase rainfall intensity and sea level over the coming decades, and the impact of this up to approximately the middle of the century on the flood management benefits is predicted by examining a future scenario with a +0.25m rise in sea level and +5.8% rise in rainfall[10]. In some cases, the impact on flood benefits of further climate change anticipated around the end of the century (sea level rise of +1 m matched with a rainfall increase of +16%) is also tested.

Although not explicitly reported due to the need to maintain confidentiality, this report has used analysis of flood risk to individual buildings which is based on the current best available understanding of property information. However, these data are continually updated and the metrics are liable to some change during further analysis.

2.3.2 Other Important Criteria (Multi-Criteria Analysis)

Each of the three primary options considered in this report is initially assessed against the criteria previously used and agreed with the Council which are reproduced in Table 2.3. A Multi-Criteria Analysis (MCA) provides a useful framework for (i) comparison of options which provide similar hydraulic benefit, (ii) to record important opinions which can be used to guide any further development of the options, and (iii) to identify any ‘showstoppers’ which mean the option is not considered further.

The initial assessments in this report will inform discussion with the Council and other stakeholders and have not been agreed as the final appraisal. The final appraisal should involve weighting the criteria and summing the product of the scores and weights.

Table 2.3 : MCA criteria used

	Outcome	Criteria	Definition	Measurement/Assessment
1.	**Environment**	**Ecology**	The impact on the self-sustaining process and inter-relationships among plants, animals and insects. It is noted that the Heathcote and its tributaries are recognised as sites of ecological significance under the District Plan.	The degree of change compared to the existing and proposed future environment
2.		**Landscape**	The impact on the special character of sites and places, their aesthetic qualities and their meaning to the community	
3.		**Heritage & Cultural**	The impact on sites and activities of historical and natural significance. The impact on Ngai Tahu and the community’s perception of a resource and its values, indicated by community involvement in management, celebration of past events and planning for the future	
4.		**Community impact**	The option provides for people’s wellbeing and sense of community (includes recreation)	Qualitative assessment of impact – quality of life, community cohesion, recreation, health & wellbeing
5.		**Construction**	Effects of constructing the option on the natural environment, traffic, pedestrians, noise, disruption to public and services, health and safety risks, damage	The degree of adverse effect from construction activities

[10] Under the International Panel on Climate Change RCP4.5 stabilisation pathway projection, temperature increase and climate change leading to a +0.25m rise in sea level and associated 5.8% rise in rainfall, could occur in 2050. The +1m sea level rise matched with the 16% increase in rainfall is the New Zealand standard for considering impacts of climate change, which could be reached within 100 years from now.

	Outcome	Criteria	Definition	Measurement/Assessment
			to other assets, access to private property.	
6.	**Long Term Sustainability**	**Long term hydraulic sustainability**	Ability to future proof the solution for climate change, to meet demands for increased levels of service and to cope with over design events	Qualitative assessment of the ability of the adapt to meet changing hydraulic needs
7.		**Degree of adaptability**	Extent to which options lock in future decisions or overly depend on external decisions being made.	Qualitative assessment of the number of dependencies of a solution and the extent to which future options are closed down
8.	**Risk**	**Legal risk**	The extent to which there is risk around legal action, or consents required, or deviation from statutory framework	The degree of unmanageable risk
9.		**Time frame risk**	Not meeting timeframes (e.g. due to consenting or property access agreements)	The degree of unmanageable risk
10.		**Robustness**	Reliability of the option	The degree of robustness of the option and consequence of failure during a flood event
11.	**Multi-hazards**	**Impact of multi-hazards**	Considers flooding alongside other multi-hazards. Could another hazard significantly reduce any benefits achieved through the flood management option? What hazards do construction or implementation of this option need to consider in its design, and do these impact the feasibility?	Assessment of the multi-hazard overlay maps, based on engineering judgement of each hazard with a high or medium rating classification.

3. Dredging

This Section is a summary of the fuller report[11] on dredging of the Heathcote upstream of the Woolston Cut focussed on the predicted benefits during frequent floods. The Council is also removing earthquake material and sediment from the Woolston Cut, but this Section focusses on the benefits of dredging upstream of the Woolston Cut.

3.1 Description of Dredging Option

Hydraulic modelling has demonstrated that flooding upstream of Radley Street is caused in part by the inadequate capacity of the channel to convey flood flows to the Woolston Cut and out to the estuary. Dredging can increase channel conveyance, reduce water levels and frequent floods. Dredging can also reduce the length of time water occupies the floodplain, which has relevance where flooding displaces people from their homes or forces road closure and access restrictions.

Until about 1986, dredging was undertaken along the Ōpāwaho / Heathcote River, managed by the Christchurch Drainage Board (CDB). The CDB viewed silt dredging and aquatic weed removal as the main issues for drainage, with the outcomes focussed on drainage. Based on records between the late 1920's and 1989, regular dredging was carried out downstream from Colombo Street, as well as two in-stream silt traps at Ainsley Terrace and below the Radley Street bridge. The reach between Radley Street and Brougham Street was dredged particularly frequently.

Responsibilities for any further dredging passed to the Council in 1989 following dissolution of the CDB. It was suggested that dredging may have caused local bank erosion arising from over deepening of the channel and in 1989, further dredging was deferred to determine whether the channel at the time would adjust itself to a reasonably stable profile. No systematic dredging has been undertaken since 1989, although a number of waterways (e.g. Truscott's Road Drain in Heathcote Valley) have been cleared of liquefaction silt following the earthquakes.

Based on analysis of past channel profiles, the reach with the greatest raising of the bed (through sedimentation and earthquake impacts) and overall loss in cross-sectional area through sediment deposition and possibly earthquake effects, is between Hansen Park and the Woolston Cut. The effect of raising the bed and the loss of area is to reduce the ability of the channel to convey flood waters which increases in flood levels, making the impact of any flooding worse than if the full channel capacity was available.

Compared with the latest full river cross section survey in 2011, an enlarged channel profile is proposed which reduces bed elevation and increases cross-sectional area uniformly from the existing level and cross-section at Hansen Park to a proposed bed level of RL 7.5 m at the Woolston Cut. No hydraulic benefit of dredging any further upstream of Hansen Park is anticipated. Figure 3.1 shows the proposed bed profile (red line) from Hansen Park to the Woolston Cut, relative to 1962/1990 and 2011 survey. The minimum channel levels (termed 'thalweg') between these points broadly follows – but does not go deeper than – the 1962/1990 values. Because the Woolston Cut is anticipated to be lowered to a minimum level of RL 7.5 m, this is the level which has been adopted at the Woolston Barrage.

It is estimated that a volume of approx. 60,000 m^3 of material needs to be removed to achieve the proposed design channel.

[11] Jacobs (2017) Dredging Feasibility Report IZ076600-CH-RPT-0001. Issued 16 October 2017

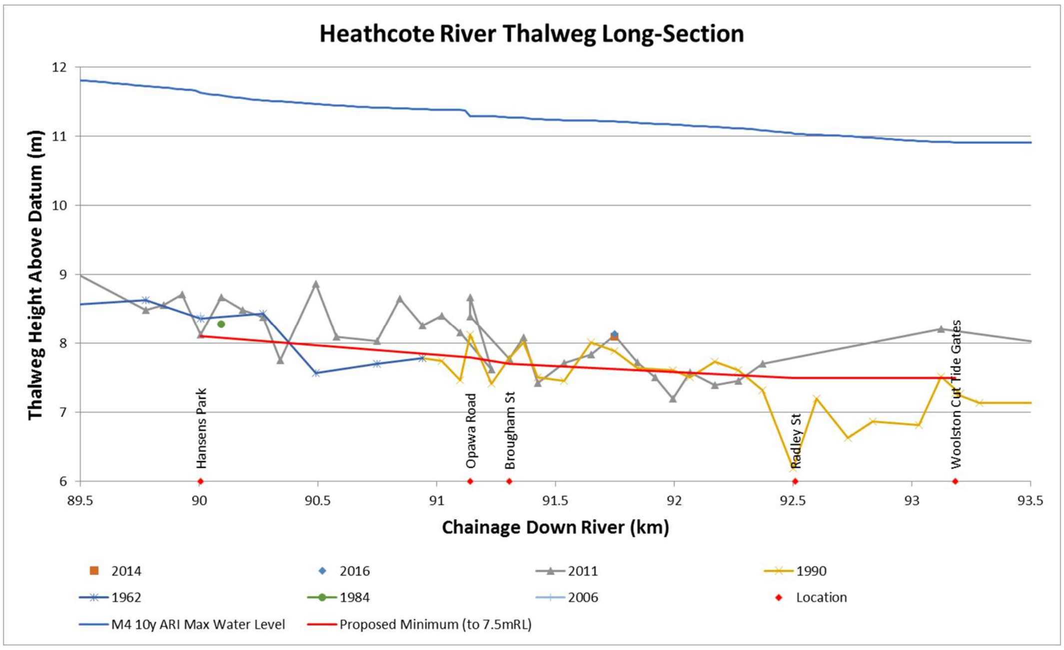

Figure 3.1 : Long section plot of minimum bed elevation (termed 'thalweg') from different surveys between Hansen Park and the Cut, showing proposed lowered bed profile tying into level of RL 7.5 m at the Woolston Barrage Tide Gates

3.2 Flood Management Benefits

The proposed channel was represented by modified cross sections in the Heathcote hydraulic model, which represents the already planned upstream storage. The same scenario was tested for frequent (Section 3.2.1) and more extreme floods (Section 3.2.2).

3.2.1 10 year ARI Events

Figure 3.2 compares long sections of water levels in the channel between the basecase (the catchment with upstream storage, labelled '10y WL Base') and with the proposed dredged scenario (labelled '10y WL Option'), in the current climate 10 year ARI event. Table 3.1 illustrates how the water level reduction predicted with the proposed dredging protects those at risk of overfloor flooding up to Ensors Road.

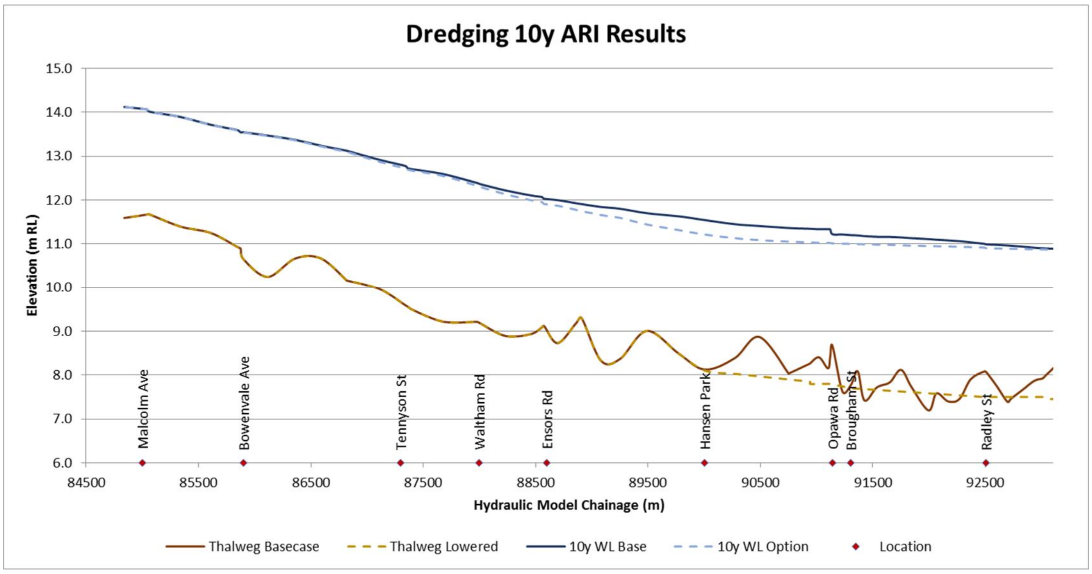

Figure 3.2 : Long sections of minimum bed levels ('thalweg') and maximum water levels in the 10 year ARI events

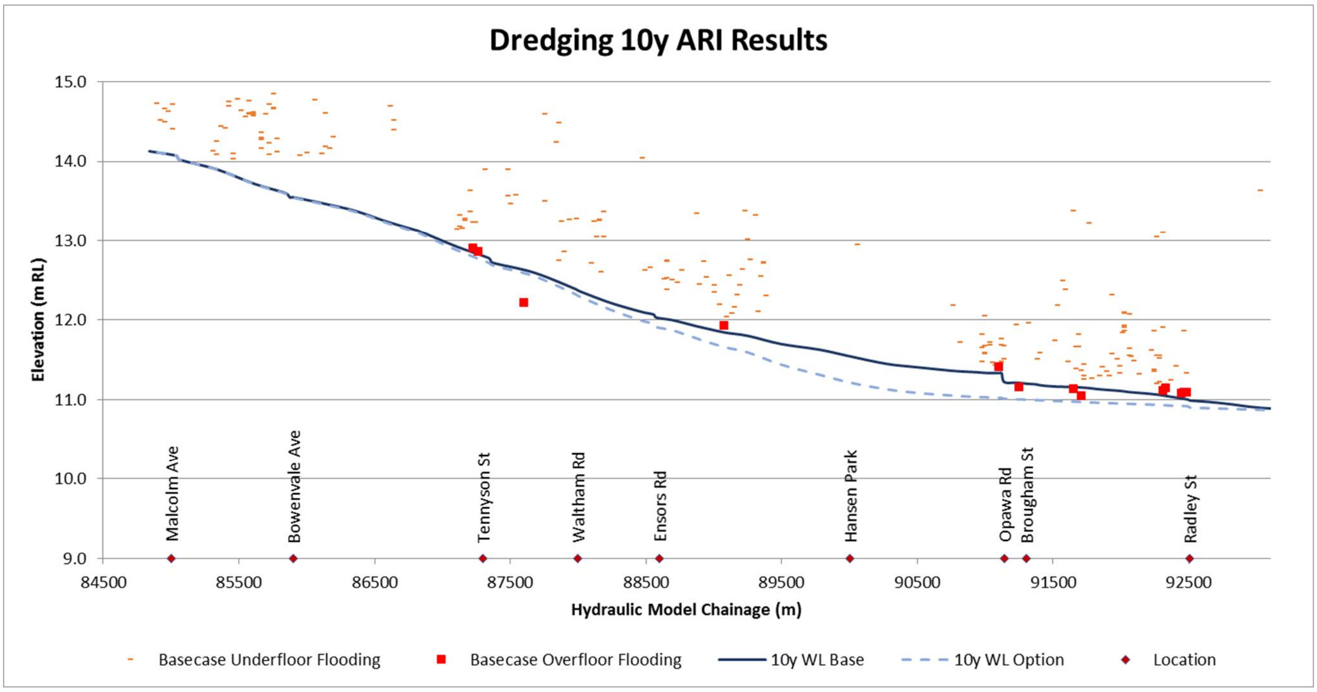

Figure 3.3 : Long section plot showing water level reduction achieved by proposed dredging

Table 3.1 : Summary of buildings at risk of overfloor flooding (flood level within 100 mm of floor level). All results include the already planned upstream storage, i.e. the number protected are in addition to the benefits of upstream storage.

Flood Risk Area	10 year ARI (current climate)			10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)			10 year ARI (climate change; +1m SLR, +16% Rainfall)		
	Basecase	Option	Protected	Basecase	Option	Protected	Basecase	Option	Protected
Radley Street to Hansen Park	8	0	8	29	8	21	80	72	8
Hansen Park to Colombo Street	4	3	1	7	5	2	17	15	2
TOTALS	**12**	**3**	**9**	**36**	**13**	**23**	**97**	**87**	**10**

Table 3.2 : Summary of dwellings at risk of underfloor flooding (flood level touching building footprint). All results include the already planned upstream storage, i.e. the number protected are in addition to the benefits of upstream storage.

Flood Risk Area	10 year ARI (current climate)			10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)			10 year ARI (climate change; +1m SLR, +16% Rainfall)		
	Basecase	Option	Protected	Basecase	Option	Protected	Basecase	Option	Protected
Radley Street to Hansen Park	97	65	**32**	127	92	**35**	212	197	**15**
Hansen Park to Colombo Street	148	139	**9**	167	155	**12**	204	195	**9**
TOTALS	**245**	**204**	**41**	**294**	**247**	**47**	**416**	**392**	**24**

Some of the key outcomes from this modelling of frequent flooding include:

- The maximum water level reduction over and above that provided by upstream storage is approximately 300 mm, around Hansen Park;
- The water level reduction resulting from the dredging reduces to less than 100 mm around Ensors Road in an upstream direction and Radley Street in a downstream direction; and
- The proposed dredging protects 9 of the 12 (~75%) buildings remaining at risk of overfloor flooding upstream of Radley Street following the upstream storage. Dredging removes all overfloor flooding upstream to Ensors Road. Some of these buildings may also be eligible for consideration under the Flood Intervention Policy.

In future scenarios considering (i) a sea level rise of +0.25 m from its current level (and rainfall increases by +5.8%) and (ii) a sea level rise of +1 m matched with a rainfall increase of 16%, the following outcomes were identified:

- The maximum water level reduction in the +0.25m sea level rise scenario, compared to the same degree of climate change with upstream storage only, is up to 250 mm around and just upstream of Hansen Park, and up to 150 mm elsewhere between Radley Street and Ensors Road. In the +1 m scenario, the reduction (again compared with the same degree of climate change with upstream storage only) is up to 200 mm around and just upstream of Hansen Park, and up to 100 mm elsewhere; and
- In the +0.25 m sea level rise scenario, more buildings are at risk of overfloor flooding in the basecase and more are protected by the proposed dredging (23 out of 36 protected), which is a drop in the relative number protected from 75% to 65%.

In the +1 m sea level rise 10 year ARI event, the proposed dredging protects 10 buildings out of 97 which would otherwise flood. This is a significant drop in relative buildings protected (70% to 10%). Those remaining at risk are concentrated downstream of Hansen Park where the influence of the sea level rise is greatest.

These future scenarios indicate that, if the proposed channel was maintained for approximately the next 100 years, the benefits (i.e. reduction in overfloor flooding) provided currently in the 10 year ARI event would diminish with rising sea level. However, they would diminish more gradually for the next 30 or so years until the sea level rises by up to +0.25 m, and then more rapidly.

In terms of underfloor flooding, Table 3.2 reports that 32 buildings out of 97 (~30%) at risk between Hansen Park and Radley Street are protected by the proposed dredging in the 10 year ARI event. These 32 may include some of the same buildings identified as being protected from overfloor flooding. With climate change, the relative number of underfloor flooded buildings protected by dredging reduces slightly to under 30% (35 out of 127) with +0.25 m sea level rise and to under 10% (15 out of 212) with +1 m sea level rise.

In terms of road flooding, information from the UK[12] and New Zealand[13] for example, indicates that 0.15 m depth of water can stall / strand a car and cars will start to float and lose control in 0.3 m depth of water. No specific guidance was identified about using velocity or duration of flooding to classify flooded roads. Road centrelines were used to identify segments of roads (within the modelled flood extent) where depths exceed 0.15 m and 0.3 m at some point along the road. The rating units adjacent to these sections of flooded roads were used to identify those with restricted access. Table 3.3 summarises the length of flooded roads and number of rating units with restricted access along the Heathcote corridor between the Woolston Cut and Colombo Street. It is noted that this initial analysis could be refined based on location-specific understanding of access routes and that some rating units represent open space (e.g. Hansen Park) rather than residential dwellings. However, the following observations provide further insight into the hydraulic benefits of dredging:

- The length of road flooded and number of rating units with restricted access increases with the earthquakes and prior to the upstream storage. The greatest increase is seen in the reach downstream of Hansen Park;
- There is a reduction in length of road flooded and number of rating units with restricted access as a result of the upstream storage. This decrease is greatest upstream of Hansen Park, since the benefit of upstream storage diminishes as you move downstream. The already planned upstream storage, therefore, has not fully returned the road/access flooding issues to pre-earthquake levels; and
- Proposed dredging in the 10y ARI event provides a further reduction in road/access flooding compared with upstream storage, and returns the whole reach between Colombo and Radley Streets largely to pre-earthquake levels of road and access flooding.

Finally, modelling suggests that the duration of flooding will be reduced through dredging. Between Radley Street and Brougham Street, flooding (i.e. water on the roads) is predicted to be reduced by up to 6 hours in a 10 year ARI event, between Brougham and Hansen Park by around 7 hours and by up to 3 hours upstream to Ensor’s Road. These reductions are relative to a baseline flood duration of approximately 16 hours with upstream storage.

[12] https://smartdriving.co.uk/Driving/Driving_emergencies/Floods.htm
[13] https://www.drivingtests.co.nz/resources/how-to-drive-through-a-flood/

Table 3.3 : Summary of lengths of road flooded and number of rating units adjacent to flooded roads with restricted access. Total length is along the Heathcote from Radley Street to Colombo Street.

Flooded Road Event (all 10 year ARI events)	Max depth > 0.15 m						Max depth > 0.3 m					
	Downstream of Hansen Park (m)		Upstream of Hansen Park (m)		Total		Downstream of Hansen Park (m)		Upstream of Hansen Park (m)		Total	
	Length (m)	Rating Units	Length (m)	Rating Units	Length (m)	Rating Units	Length (m)	Rating Units	Length (m)	Rating Units	Length (m)	Rating Units
Pre-earthquake	2,800	200	3,600	320	**6,400**	**520**	2,300	170	3,300	280	**5,600**	**450**
Post earthquake before upstream storage	4,400	250	4,700	490	**9,100**	**740**	4,400	250	4,500	470	**8,900**	**720**
Post earthquake after upstream storage	4,300	250	4,200	360	**8,500**	**610**	4,100	240	3,600	300	**7,700**	**540**
After dredging and upstream storage	3,100	200	3,800	320	**6,900**	**520**	2,800	180	3,300	280	**6,100**	**460**

3.2.2 50 year ARI Events

In a more extreme 50 year ARI flood event, the maximum water level reduction in the current climate is approximately 300 mm, around Hansen Park. The water level reduction resulting from dredging reduces to less than 100 mm around Ensors Road in an upstream direction and Radley Street in a downstream direction. Table 3.4 suggests that:

- 46 buildings (~40%) are protected by the dredging in the 50 year ARI event in the current climate. This benefit is focussed between Hansen Park and Radley Street where 50% of properties are protected (31 out of 61);
- This degree of benefit drops to ~15% (32 out of 228) between Colombo and Radley Streets with climate change (+1m sea level rise; +16% rainfall). The zone of greatest benefit shifts from downstream to upstream of Hansen Park; and

With +1 m of sea level rise, dredging no longer effectively protects those downstream of Hansen Park, and the greatest benefit occurs upstream of Hansen Park.

Table 3.4 : Number of buildings with overfloor flooding in the basecase and option scenarios

Flood Risk Area	50 year ARI (current climate)			50 year ARI (climate change; +1m SLR, +16% Rainfall)		
	Basecase	Option	Protected	Basecase	Option	Protected
Radley Street to Hansen Park	61	30	**31**	112	103	**9**
Hansen Park to Colombo Street	51	36	**15**	116	93	**23**
TOTALS	**112**	**66**	**46**	**228**	**196**	**32**

3.3 Other Important Criteria

Table 3.5 provides an initial appraisal of dredging relative to each of the agreed criteria. This represents an initial assessment to inform discussion with the Council and has not been agreed as the final appraisal. The final appraisal should involve weighting the criteria and summing the product of the scores and weights. The cells are coloured according to the following key:

Positive	
Slight Positive	
Neutral	
Slight Negative	
Negative	

Table 3.5 : Multi-criteria Appraisal of Dredging

Outcome	Criteria	Impacts of Dredging
Environment	Ecology	Fish populations have been observed which included species with a conservation status of "at risk/declining". Dredging works and bank stabilisation could impact upon Inanga spawning areas. Repeat dredging would regularly disturb establishing habitat. Dredging may increase upstream propagation.
	Landscape	The landscape is unlikely to be impacted by the dredging itself, but bank stabilisation may require removal of some existing trees. However, the landscape may be improved in the longer-term by the overall protection of the riverine environment, including planting of new trees.
	Heritage and Culture	Discharging contaminants such as sediment to water is culturally unacceptable to Ngāi Tahu. Although sediment management during dredging would be implemented, there will be some disturbed sediment entering the river. Works could be timed to avoid spawning or fishing seasons.
	Community Impact	The Ōpāwaho/Heathcote River is of high interest to the community. Given appropriate mitigation of construction impacts, improved water quality (through more regular removal of sediment) and stabilised banks to reduce slumping could offer benefits which offset the disturbance of dredging. However, the frequency of dredging may increase over time until dredging is no longer viable.
	Construction	Works on the banks and within the channel will result in temporary noise, vibration and loss of access and amenity impacting upon local residents and people accessing the river banks. Although appropriate fish management techniques would be employed, there will be some disturbance to the ecology of the river. Instream silt curtains and working from upstream to downstream would minimise temporary impacts on water quality. Inanga spawning areas are located between Hansen Park and Radley Street bridge and no works are typically allowed between 1 January and 1 May. Dewatering in stockpiles may be considered in the public areas of Hansen Park and Radley Park.
Long Term Sustainability	Long Term Hydraulic Sustainability	Maintenance dredging will be required at intervals to be determined through monitoring of how the river responds. The hydraulic benefit of dredging decreases with rising sea level and therefore this option will be time-limited.
	Degree of Adaptability	Dredging will have a hydraulic benefit for a period of time and, if ceased, the river will return to an equilibrium state. Dredging will not seek to overdeepen or overwiden the channel and therefore should not have any long-term impact on the river. Dredging is therefore adaptable to be continued as long as the hydraulic benefits are realised and does not lock the community into a maladaptive pathway.
Risk	Legal Risk	Dredging is likely to require consent as a discretionary activity and consultation will be highly important.
	Time Frame Risk	Consultation as part of consenting needs to be given appropriate time. The programme to remove 60,000 m^3 of material will be challenging, and focussed on the 8 month window between May and December which is outside the Inanga spawning season. Therefore, it may be more feasible to consider the initial dredging, as well as maintenance dredging, being undertaken in successive reaches over a longer period of time which reduces overall risk.
	Robustness	Ongoing siltation will depend on a number of factors (e.g. loading from the Port Hills) which are not currently well understood. Maintenance dredging will be required at intervals to be determined through monitoring of how the river responds. The risk of bank failure can be reduced through stabilisation works.

Outcome	Criteria	Impacts of Dredging
Multi-hazards	Impact of Multi-hazards	The increased risk of bank failure and lateral spread as a result of dredging can be reduced through stabilisation works which would result in the banks being more resilient to earthquakes. Liquefaction material could be removed by planned maintenance dredging. Any increased risk of upstream propagation of a tsunami should be understood.

3.4 Estimated Costs

Based on unit costs established from previous similar work (dredging, disposal, bank stabilisation etc.), the total capital cost of removing 60,000 m^3 of material between Hansen Park and the Woolston Cut, and undertaking a degree of bank stabilisation has been estimated at $14.2M. This includes high level estimates for design and project management (10% of construction cost), consenting (5% of construction cost) and risk (20% of construction cost). There is a risk of cost escalation if sediment with asbestos or significant levels of contamination is encountered.

Depending on survey to monitor the response of the channel, maintenance dredging undertaken every 10 years may be required to remove approximately 7,000 m^3, which could cost in the order of $1.3M every 10 years (including the 35% overheads).

More detail on the indicative costs is given in the full report.

3.5 Indicative Programme

The programme to remove 60,000 m^3 of material will be challenging, and focussed on the 8 month window between May and December which is outside the Inanga spawning season. However, the Inanga / whitebait season between 15 August and 30 November may pose additional constraints, as will high water levels during the winter and spring season. Therefore, it may be more feasible to consider the initial dredging, as well as maintenance dredging, being undertaken in successive reaches over a longer period of time.

3.6 Next Steps

It is recommended that the Council continues consideration of dredging the reach between Hansen Park and the Woolston Cut. If dredging is pursued, the following tasks are recommended:

- As far as possible, unify all work towards dredging the channel between Hansen Park and the Woolston Cut, including the Woolston Cut;
- Undertake channel survey and revised modelling to more accurately determine the channel profile to be achieved, the volume of material to be removed and to provide a baseline against which future deposition can be measured;
- Detailed design should include channel modelling to show how proposed cross sections remain stable by assessing stream power, bed shear stress and velocity against expected stable cross section profiles;
- Engage specialist ecological input to assess the effects of any bank reconstructions, changed water depths and to determine if any spawning sites are located within the proposed dredging locations;
- Undertake *in-situ* sediment sampling to confirm absence of material above recreational levels of contamination, and in particular absence of asbestos;
- Identify all stakeholders as early as possible and develop a consenting and consultation strategy; and
- On the basis of the above, refine cost estimates for the work and seek efficiencies through reuse of excavated material and other opportunities.

4. Low Stopbanks

4.1 Description of Low Stopbank Option

High stopbanks or floodwalls could be used to protect buildings at risk of overfloor flooding in more extreme 50 year events. However, the likely heights of stopbanks or walls required – and the large width if stopbanks were required – are unlikely to be technically viable or acceptable to the community without major changes occurring. In some places the stopbanks would be over 2m in height. In addition, the cost of stopbanks or floodwalls to provide this level of protection has previously been estimated[14] at several hundred million dollars; well in excess of the value of the properties protected.

As an alternative to stopbanks protecting against extreme flooding, the concept of low stopbanks has been considered. These protect only against higher frequency flood events and are targeted to prevent underfloor and deep road flooding. Underfloor flooding causes significant distress to the community. An example of this was the response to the July 2017 flood event, where some residents rescued were not flooded above floor, but requested evacuation for medical reasons or due to a fear of the waters increasing.

If built high enough, and paired with pumps to deal with ponding behind them, stopbanks are an option which should provide complete reduction of underfloor as well as overfloor flooding in events up to their design capacity or event. However, it is emphasised that the proposed option will be designed to offer this protection against frequent floods only, and flooding will still occur in any larger events, as well as potentially with frequent floods with climate change, depending on design. The siting of pumps to deal with ponding behind stopbanks/walls is not considered here but will be required if the option proceeds.

Beca developed two stopbank scenarios which, in these early stages of development, are termed ‘Priority 1’ and ‘Priority 2’. The scenarios are shown in plan on Figure 4.1 and cross section in Figure 4.2, with lengths summarised in Table 4.1. The potential heights of the stopbanks at the various locations are summarised below in Table 4.5. The locations proposed for low stopbanks overlap with the Mid-Heathcote River / Ōpāwaho Linear Park Masterplan, the Ōpāwaho River major cycle route and ongoing bank stabilisation work.

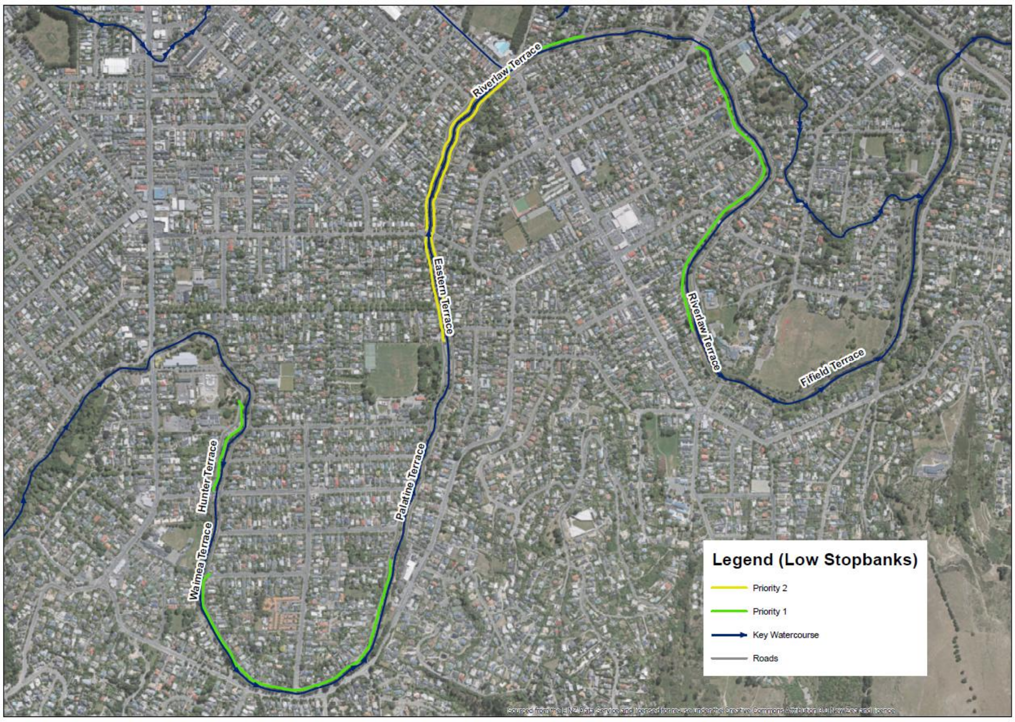

Figure 4.1 : Conceptual alignments of the ‘Priority 1’ and ‘Priority 2’ low stopbanks

[14] GHD (2014) Investigation into the River and Tidal Flood Protection needs for Christchurch. Heathcote River Stage 1 Report. 18 February 2014

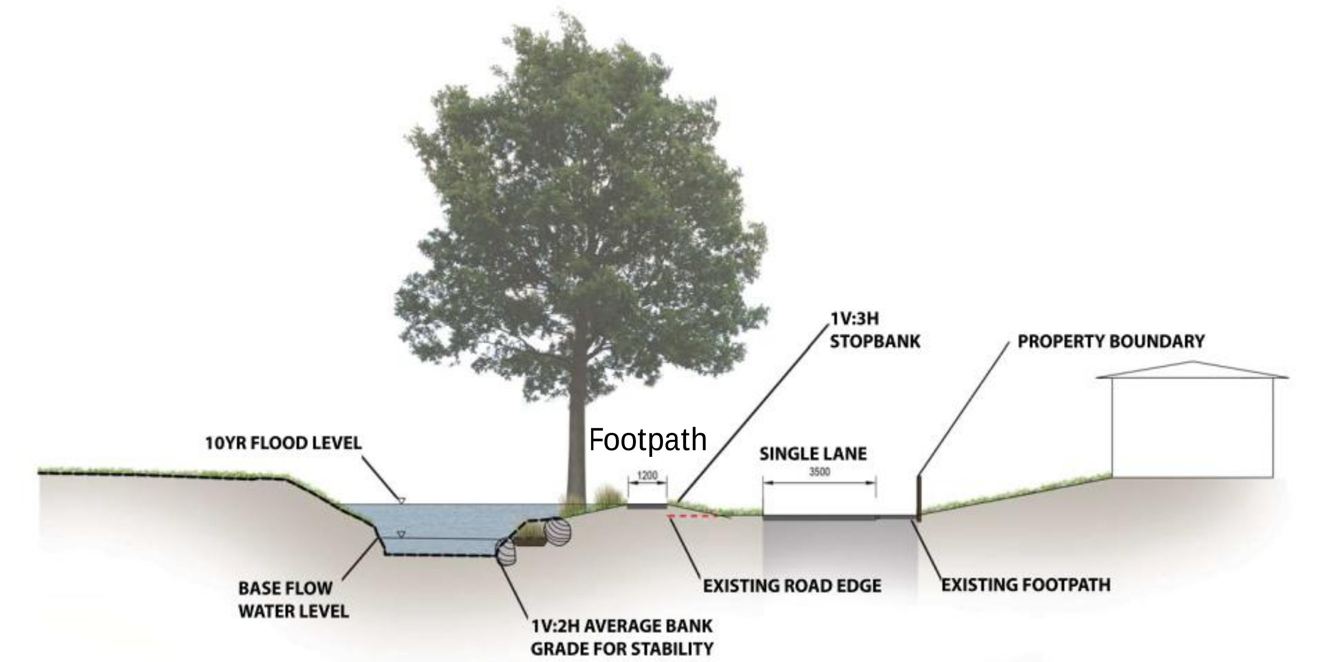

Figure 4.2 : Schematic cross-section showing a low stopbank on the **Ōpā**waho/Heathcote River (reproduced with permission from the Council)

Table 4.1 : Summary of stopbank scenarios considered

Location	Length of 'Priority 1 Stopbanks (m)	Length of 'Priority 2 Stopbanks (m)
Hunter Terrace (true right bank)	300	N/A
Waimea Terrace (true left hand bank)	1,100	N/A
Eastern / Palatine Terrace (true left and right hand banks)	N/A	1,900
Fifield Terrace (true left hand bank)	250	N/A
Riverlaw Terrace (true right hand bank)	1,100	N/A
TOTALS	**2,750**	**1,900**
OVERALL TOTAL	**4,650**	

4.2 Flood Management Benefits

The benefits are presented here for frequent flooding only. In a flood greater than this (e.g. 11 year ARI and greater), overtopping would occur and so may overfloor flooding. For this reason, flood management benefits are not reported for the 50 year ARI event.

The model including the upstream storage was used to represent the 'Priority 1' and 'Priority 2' stopbank alignments both in the current climate scenario, as well as in a future climate change scenario. Note that for the purposes of this initial modelling, all stopbank alignments were represented as infinitely high walls to determine how high the flood level in the river reaches and, therefore, how high the stopbanks actually need to be. The stopbank alignments were also tested in combination with the dredging option summarised in Section 3.

In the majority of modelled scenarios, the Fifield Terrace stopbank is showing significant ponding behind it, which is overspill from Jacksons Creek which would be mitigated through any further design of the scheme in this area. This does, however, slightly distort the property counts here by predicting an increase in overfloor flooding in this area.

The number of overfloor and underfloor flooded buildings in the base and option 10 year ARI events, with and without climate change (+0.25 m Sea Level Rise, +5.8% rainfall), are provided for the 'Priority 1' stopbank alignments in Table 4.2:

- As determined by the alignments, the 'Priority 1' stopbanks protect underfloor flooded buildings only and provide no benefit for overfloor flooding;
- Further, the stopbanks benefit a higher proportion of underfloor flooded buildings now, than with the level of climate change effects which could occur by approximately the middle of the century;
- Water levels between stopbank alignments (which are lowered by the upstream storage) are raised by up to 30 mm; and
- Maximum stopbank heights (before any freeboard allowance is added) are between 0.7 m and 1.2 m depending on location (see Table 4.5). A few decades of climate change could add around 100 mm to these heights.

Table 4.2 : Summary of hydraulic performance of 'Priority 1' stopbanks (upstream of Hansen Park only)

Flood Risk Area	Basecase				'Priority 1' Stopbanks (no dredging)			
	10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)		10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)	
	Overfloor Flooded	Underfloor Flooded	Overfloor Flooded	Underfloor Flooded	Overfloor Protected	Underfloor Protected	Overfloor Protected	Underfloor Protected
Hansen Park to Colombo Street	5	137	7	148	0	77	0	64

Table 4.3 summarises the number of overfloor and underfloor buildings protected by the combination of 'Priority 1' *and* 'Priority 2' stopbank alignments:

- Because of the introduction of the 'Priority 2' alignments along Eastern and Palatine Terraces, the stopbanks protect more underfloor and some overfloor flooded buildings;
- The greatest rise in water levels is at Beckenham Park on Eastern Terrace where over 100 mm increase in level results from the introduction of the 'Priority 2' stopbanks; and
- Maximum stopbank heights (before any freeboard allowance is added) are around 1.3 m, depending on location (see Table 4.5). A few decades of climate change climate change could add around 100 mm to these heights.

Table 4.3 : Summary of hydraulic performance of 'Priority 1' *and* 'Priority 2' stopbanks (upstream of Hansen Park only)

Flood Risk Area	Basecase				'Priority 1' & 'Priority 2' Stopbanks (no dredging)			
	10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)		10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)	
	Overfloor Flooded	Underfloor Flooded	Overfloor Flooded	Underfloor Flooded	Overfloor Protected	Underfloor Protected	Overfloor Protected	Underfloor Protected
Hansen Park to Colombo Street	5	137	7	148	4	113	6	114

Table 4.4 summarises the number of overfloor and underfloor buildings protected by the combination of 'Priority 1' *and* 'Priority 2' stopbank alignments when combined with dredging:

- Individual benefits (overfloor and underfloor) of dredging and stopbanks are largely retained with the combination run, i.e. the options are working together and not duplicating;
- The combination of dredging and stopbanks largely mitigates the rise in water levels otherwise experienced with stopbanks alone. The exception to this is at Beckenham Park where there is still a rise of over 100 mm as a result of the 'Priority 2' stopbank alignment;
- Maximum stopbank heights in locations downstream of Ensors Road are lowered by up to 200 mm through dredging. This reduction is maintained with a few decades of climate change.

Table 4.4 : Summary of hydraulic performance of ‘Priority 1’ *and* ‘Priority 2’ stopbanks with dredging

Flood Risk Area	‘Priority 1’ Stopbanks and Dredging				‘Priority 1’ & ‘Priority 2’ Stopbanks and Dredging			
	10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)		10 year ARI (current climate)		10 year ARI (climate change; +0.25m SLR, +5.8% Rainfall)	
	Overfloor Protected	Underfloor Protected	Overfloor Protected	Underfloor Protected	Overfloor Protected	Underfloor Protected	Overfloor Protected	Underfloor Protected
Hansen Park to Colombo Street	0	80	1	87	4	114	6	119

Table 4.5 : Indicative maximum heights of stopbanks (no freeboard allowance) calculated by Beca

Location	Indicative Max Height of ‘Priority 1’ Stopbanks (m)	Indicative Max Height of ‘Priority 2’ Stopbanks (m)
Hunter Terrace (true right bank)	1.0 m, increasing with climate change. No reduction with dredging.	N/A
Waimea Terrace (true left hand bank)	0.9 m, increasing with climate change. No reduction with dredging.	N/A
Eastern / Palatine Terrace (true left and right hand banks)	N/A	1.3 m, increasing with climate change. No reduction with dredging.
Fifield Terrace (true left hand bank)	0.7 m, increasing with climate change. Up to 100 mm reduction with dredging.	N/A
Riverlaw Terrace (true right hand bank)	1.2 m, increasing with climate change. Up to 200 mm reduction with dredging.	N/A

4.3 Other Important Criteria

Table 4.6 provides an initial appraisal of low stopbanks relative to each agreed criteria. This represents an initial assessment to inform discussion with the Council and has not been agreed as the final appraisal. The final appraisal should involve weighting the criteria and summing the product of the scores and weights. The cells are coloured according to the following key:

Positive
Slight Positive
Neutral
Slight Negative
Negative

Table 4.6 : Multi-criteria Appraisal of Low Stopbanks

Outcome	Criteria	Impacts of Low Stopbanks
Environment	**Ecology**	Construction of stopbanks/flood walls and any associated bank stability works would cause disruption to habitat on the banks of the river channel, possibly including to mature trees. However, there is the potential to provide ecological benefit through planting of the stopbanks and channel-bank habitat creation. The same benefits are not typically possible with flood walls.
	Landscape	Stopbanks / floodwalls of heights exceeding 1m will have a significant visual impact which could impair views of the river from the road. It is anticipated that views of the river could be maintained through public access on top of stopbanks where space permits, and their integration into the landscape softened through planting. The same benefits are not typically possible with flood walls. However, low stopbanks could also deliver the objectives of the Mid-Heathcote River / Ōpāwaho Linear Park Masterplan, in terms of providing paths and reducing road widths.

Outcome	Criteria	Impacts of Low Stopbanks
	Heritage and Culture	There are a limited number of sites of interest marked on the NZAA database. However, it is anticipated that stopbanks / floodwalls could be designed around any specific sites.
	Community Impact	Stopbanks / floodwalls of over 1m height will reduce the naturalised appeal of the river and its environs, including visually and through reduced access. However, recreational benefits could be achieved by including a walk/cycleway along the crest of a stopbank. This will not be possible for floodwalls. Single-laning of roads and different traffic patterns will take time to become accepted.
	Construction	Construction works will result in temporary noise, road closures, dust and traffic. Diversion of services from the construction zone will cause temporary disruption to residents. The scale of the construction disruption for lengths up to 4.7 km would be significant.
Long Term Sustainability	Long Term Hydraulic Sustainability	Stopbanks could be designed to protect overfloor flooding buildings in a 50 year ARI event now, and increased in height with climate change as long as the additional footprint area required is safeguarded. However, additional footprint area for stopbanks will be challenging and areas may better suit floodwalls. The capacity of pumps could similarly be increased.
	Degree of Adaptability	Once constructed, could encourage further development behind the stopbanks. Following overdesign floods, the community may seek stopbanks to be raised and/or pump capacity increased. In some situations, stopbank foundations can be built larger than required by the initial height of stopbanks, in anticipation of the stopbanks being raised over time. However, the narrow road corridor available would make future-proofing stopbanks along the Heathcote challenging. Replacement of stopbanks with higher floodwalls may be more practical.
Risk	Legal Risk	Consents will be required for construction of stopbanks and the Council will be responsible for operation (of pumps) and maintenance. Mitigations against risk of failure in a highly developed area will be important.
	Time Frame Risk	Design, consenting including consultation and construction activities will take a considerable time to complete up to 4.7 km. Construction would be completed on each individual alignment in turn to provide the desired protection.
	Robustness	Stopbanks could be over 1.5 m in places and therefore the consequences of failure in close proximity to residential areas will have to be carefully assessed. Inclusion of pump stations will reduce the overall robustness but the risk of failure should be manageable. Some mitigation would be provided if the consequences of a breach were reduced by compartmentalisation of the flood plain.
Multi-hazards	Impact of Multi-hazards	Stopbanks (and associated pump stations) would be constructed to appropriate standards to minimise risk of failure during earthquake shaking. Stopbanks would likely have to be patched and topped up following any subsidence. Long linear infrastructure remains vulnerable. Raised groundwater ponding behind the stopbanks would have to be dealt with by a series of pumps, as for surface ponding. The option itself would not exacerbate other hazards.

4.4 Estimated Costs

Construction costs for the stopbanks have been estimated by Beca at $14M. At this stage, the estimates are based on unit rates, but include allowances for site clearance, relocation of services, roading works, construction of new stormwater outlets along the bank and landscaping. Required pump stations and bank stabilisation works will substantially increase this cost.

4.5 Indicative Programme

Implementation of a low stop bank option will be relatively complex, requiring concept design, public consultation, consenting and potentially partial road closure approvals and then a design and implementation via construction contracts. The Council has current experience with such a process with the temporary stopbanks repair programme. A 2-year to 3-year timeframe is probably required, depending upon the scale of low stopbank project implemented.

4.6 Next Steps

It is recommended that the Council continues consideration of low stopbanks at the locations identified. If implementation is pursued to primarily address underfloor and road flooding, the next steps should include:

- Design of stopbank continuity across road junctions / bridges; and
- Consultation with the community based on further engineering design and visualisations.

5. Flood Intervention Policy (FIP)

5.1 Description of FIP Option

The Flood Intervention Policy (FIP)[15] addresses flooding at a property level and is designed to help property owners who are at risk of frequent above-floor flooding, where the flooding has been worsened by the earthquakes, and planned flood mitigation schemes will not offer a timely or effective reduction to their flood risk. The Council approved the Flood Intervention Policy in December 2015 which enables the Council to offer localised drainage improvements, house raising or voluntary property purchase to individual dwellings.

5.2 Flood Management Benefits

There are about 25-35 dwellings along the Ōpāwaho / Heathcote River upstream of Radley Street which, based on available hydraulic modelling and observed flooding, may be eligible for the FIP. Many of these dwellings have flooded above floor a number of times since the earthquakes, with some known to have flooded above floor four times during this period. Prior to the earthquakes, it was estimated that only seven dwellings faced a similar level of risk.

The potentially eligible dwellings Checks have been checked against the District Plan Flood Management Areas (FMAs), Flood Management Floor Level Overlay (FMFLO) and High Flood Hazard Management Areas (HFHMA). The majority of dwellings lie within the HFHMAs or another identified area where rebuilding, even at a higher floor level, will be discouraged. No checks have been made so far for (i) the consent status of habitable space areas, (ii) whether the properties have qualified for the EQC Increased Flooding Vulnerability land damage scheme.

Climate change and sea level rise will continue to worsen the flood risk faced by these residents, as they are the most vulnerable to any increase in flood levels.

5.3 Other Important Criteria

Table 5.1 provides an initial appraisal of the FIP relative to each of the agreed criteria. This represents an initial assessment to inform discussion with the Council and has not been agreed as the final appraisal. The final appraisal should involve weighting the criteria and summing the product of the scores and weights. The cells are coloured according to the following key:

Positive
Slight Positive
Neutral
Slight Negative
Negative

Table 5.1 : Multi-criteria Appraisal of the Flood Intervention Policy

Outcome	Criteria	Impacts of the Flood Intervention Policy
Environment	**Ecology**	Impacts of implementing the FIP are largely isolated from the river and will have little direct effect on the habitats. However, land use change within abandoned sections may provide some opportunity for ecological enhancement e.g. landscaping with native trees.
	Landscape	The landscape will remain largely unchanged. If buildings were raised then the increased height may cause minimal visual impairment. However, the limited number of eligible buildings will limit the overall impact. Land

[15] https://www.ccc.govt.nz/the-council/plans-strategies-policies-and-bylaws/policies/sustainability-policies/flooding-intervention-policy/

Outcome	Criteria	Impacts of the Flood Intervention Policy
		use change within empty sections may result in some naturalisation of the area.
	Heritage and Culture	There are a limited number of sites of interest marked on the NZAA database. However, it is unlikely that the designations or the proposed works would have any impact on since the houses themselves are not heritage status.
	Community Impact	As this option considers only individual dwellings, the majority of impacts will only be relevant to the owners/occupiers and limited on wider community cohesion. However, there is the potential for community division between the beneficiaries and those remaining. If dwellings are rebuilt then they may still be liable to underfloor flooding and restricted access. Re-landscaped empty sections could provide additional land for recreational facilities.
	Construction	Construction works will result in temporary noise, road closures, dust and traffic. Will cause disruption and access to private properties.
Long Term Sustainability	**Long Term Hydraulic Sustainability**	If the property was rebuilt then it would be raised above more extreme and future flood levels. If the property is removed, then so is the risk.
	Degree of Adaptability	The FIP is a policy which can be adapted to a more relevant alternative (e.g. individual property protection or making 'room for the river'). Works will not preclude future decisions for the area as future schemes and/or land use decisions could still be implemented. However, removing, raising or defending reduces the economic viability of implementing other options. House raising combined with an acceptance of residual road/underfloor flooding could increase community resilience which is an adaptable outcome. However, continuing to occupy areas may lead to the perception that these areas will always be occupied such that future land use change will be more difficult.
Risk	**Legal Risk**	The FIP is an existing Council policy which makes for more immediate implementation. Building consent will be required for alteration of the buildings.
	Time Frame Risk	Implementation is limited by the need to reach agreement with property owners and to gain consent. However, it is an existing policy designed to provide 'timely' action if other options are delayed. Once agreed with individuals, the option could be implemented relatively quickly.
	Robustness	Raising floor levels by an appropriate amount or removing the buildings are both hydraulically robust.
Multi-hazards	**Impact of Multi-hazards**	New building foundations will adhere to the latest building codes and have improved resilience to seismic hazards. Removing buildings removes exposure to other hazards. The option itself would not exacerbate other hazards.

5.4 Estimated Costs

The number of dwellings potentially eligible for the Flood Intervention Policy and, thus, the total 2016 QV capital cost for the dwellings has not been confirmed at this stage. However, the total cost of the Council acquiring, removing and turning the land to some alternate use may exceed the capital cost.

5.5 Indicative Programme

The general Flood Intervention Policy has previously been agreed and has been implemented by the Council in the Flockton area. Application in the Heathcote catchment and funding to support this has not yet been approved by Council. Following approval, local implementation will largely be determined by the time taken for the Council to reach agreement with individual property owners, which cannot be estimated here.

5.6 Next Steps

Following approval of application and funding, it is recommended that the Council undertakes the required checks for eligibility of the identified dwellings, and holds exploratory discussions with individual property owners.

6. Summary

This report has presented options to manage frequent post-earthquake flooding along the Ōpāwaho/Heathcote River in the current climate, similar to the event which occurred on 21-22 July 2017. If implemented, the options should be considered as additional to the already planned upstream storage scheme. Indeed, the upstream storage basins are considered to be the foundation of all other options for the Heathcote as they lower water levels such that the benefits of the other options are increased, and the costs for other options are lower. The additional options could form a foundation on which management of more extreme flooding, as well as frequent flooding with climate change and sea level rise, can be developed.

From a long list of possible options, this report has undertaken initial development and testing of the following three options to manage post-earthquake frequent flooding upstream of Radley Street:

- Dredging the river between Hansen Park and the Woolston Cut. This is predicted to lower water levels between approximately Ensors Road and Radley Streets, and by up to 300 mm around Hansen Park. This reduction in peak frequent flood level could reduce overfloor and underfloor flood risk to buildings, including protecting 9 buildings at risk of overfloor flooding. Whilst there are benefits in more extreme events, these are relatively less than for frequent floods. If the dredged channel profile is maintained, the benefits are predicted to be sustainable for a few decades of sea level rise, following which they will diminish more rapidly.
- Construction of 'low' stopbanks along sections of the river between Hunter Terrace and Hansen Park to minimise underfloor and road flooding. These stopbanks (along with surface water pumps) would be designed to provide protection for frequent floods only, without committing to protecting against frequent floods in the future. Stopbank alignments of over 4.5 km have been tested at this stage, with heights of over 1 m required in places to protect over 100 buildings from underfloor flooding.
- Application of the Council's Flood Intervention Policy for those at frequent flood risk which has been exacerbated by the earthquakes. This could result in the Council offering drainage improvements, house raising or voluntary property purchase to individual dwellings. Between 25 and 35 dwellings have been identified as potentially eligible upstream of Radley Street. If these dwellings are purchased, the risk to them will be eliminated even for more extreme floods.

The report identifies a number of important factors relevant to each option to inform future decision making. Table 6.1 reports the number of buildings at risk of overfloor flooding in frequent floods (i.e. a 1 in 10 year ARI event) before the earthquakes, immediately after the earthquakes, with the planned storage and then if the three options proposed in this report were to be implemented. With the upstream storage and additional options, no buildings would be at risk of overfloor flooding in a frequent flood in the current climate, which is an improvement on the pre-earthquake level of risk. Because of some overlap in properties benefitting from the three options (e.g. dredging and FIP), and that the options aim to achieve different outcomes (e.g. protection of overfloor or underfloor flooding), further work should be mindful of potential double-counting of benefits.

Table 6.1 : Number of buildings with overflor flooding in the 10 year ARI event pre-earthquake, immediately post-earthquake, with the planned upstream storage and then with the three additional options in this report

Area	10 year ARI (current climate)			
	PreEQ	PostEQ	PostEQ with storage	PostEQ with storage and additional options
Radley Street to Hansen Park	0	16	8	0
Hansen Park to Colombo Street	4	7	4	0
Upstream of Colombo Street	3	1	0	0
Totals	**7**	**24**	**12**	**0**

Table 6.2 reports the same overfloor flood metrics for the 50 year ARI event, assuming that those dwellings protected through the FIP are no longer at risk in this more extreme event. With the upstream storage and additional options, there are only 37 buildings at risk of overfloor flooding remaining upstream of Radley Street

in the current climate. As for the 10 year ARI event, this represents a substantial reduction on pre-earthquake flood risk.

Table 6.2 : Number of buildings with overfloor flooding in the 50 year ARI event pre-earthquake, immediately post-earthquake, with the planned upstream storage and then with the additional options in this report

Area	50 year ARI (current climate)			
	PreEQ	PostEQ	PostEQ with storage	PostEQ with storage and additional options
Radley Street to Hansen Park	27	69	61	13
Hansen Park to Colombo Street	58	83	51	24
Upstream of Colombo Street	90	70	2	0
Totals	**175**	**222**	**114**	**37**

Based on these results, it is recommended that the Council continues development of each of these three options to manage frequent flooding, and makes decisions on their implementation within the context of the ongoing work to manage more extreme flooding, as well as frequent flooding with climate change.