Ōtākaro Avon River Corridor Regeneration Plan

Land Use Assessment Report – Flood Mitigation

October 2017

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REGENERATE CHRISTCHURCH
TE KŌWATAWATA

Contents

1 Introduction

1.1 Purpose of this report

This report has been prepared alongside a number of Land Use Assessment Reports to inform the shortlist of options and ultimately the preparation of the Ōtākaro Avon River Corridor Regeneration Plan (Plan).

The purpose of the Land Use Assessment Reports is to define the scope and establish the specific drivers, benefits and objectives for the land use/s that will best contribute to the overarching vision and objectives of the Plan.

1.1 Context

This report investigates the potential for the provision of flood mitigation works with a focus on the Ōtākaro Avon River Corridor Regeneration Area[1] (Area).

This report has been informed by the ideas, suggestions and proposals received by Regenerate Christchurch that relate to flood mitigation in addition to facilitated discussions with key stakeholders and organisations. Strategic alignment with other available reports and assessments (where available) has also been undertaken.

This report sets out:

- The problems and opportunities that need to be addressed by any investment and the benefits that will be achieved if the problems are adequately addressed. The key problems/opportunities, benefits and risks connected with providing flood mitigation works, as supported by an investment logic map (ILM), see Appendix 4.
- The critical success factors to achieving the successful implementation of flood mitigation works within the Area and the identification of options that best balance the achievement of the desired benefits and costs for consideration in the broader planning process.

It is noted that although this report is not intended to consider locations outside of the Area, the flood mitigation works required may need to extend beyond the boundaries of the Area to be effective. Further, this report recognises the Christchurch City Council's (Council's) wider responsibility regarding hazard management for Christchurch and the need for alignment between any potential flood mitigation works.

[1] See the Ōtākaro Avon River Corridor Regeneration Area Map in Appendix 1 of the approved Outline for the Ōtākaro Avon River Corridor Regeneration (April 2017)

While not a complete indicative business case, this report follows some steps from the Treasury's guidelines for "Better Business Cases for Capital Proposals: Indicative Business Case"[2], such as critical success factors, and benefits, risks, constraints and dependencies. Applying this approach provides a structure to test, refine and further develop the theme of flood mitigation, which in turn will inform the shortlist of land use combinations.

[2] See: http://www.treasury.govt.nz/statesector/investmentmanagement/plan/bbc/guidance

2 Land use description

2.1 Overview

Developing the Plan presents an opportunity to implement flood mitigation works within the Area that can have long lasting financial and community benefits for areas within the Ōtākaro Avon River catchment.

The predominantly vacant nature of the land within the Area means there is the potential to undertake the mitigation with minimal impact on local residents, that integrates effectively with future uses of the land while ensuring alignment with the regeneration objectives. This report explores the potential options for managing flood risk with respect to water that comes from the reach of the Ōtākaro Avon River that passes through the Area.

The geographic focus of this report is the Area which is located within the wider Ōtākaro Avon River catchment. This catchment extends up past the Christchurch Airport to the west, to about QEII Drive to the north, the Heathcote and Avon Rivers/Ihutai Estuary (Estuary) to the east and the suburbs of Bromley, Addington, Riccarton and Sockburn to the south. The catchment is mainly urban but also includes the central business district (CBD) and other commercial and industrial areas. The catchment is typically drained through engineered piped networks which discharge directly into the Ōtākaro Avon River or one of its tributaries, including Wai-iti Stream, Wairarapa Stream, Dudley Creek, Number One Drain and Snellings Drain.

The Ōtākaro Avon River has a long history of infrequent flooding with records of flood events inundating the CBD dating back to 1886[3], with significant events in 1925 and 1930. Historically, flooding of the Ōtākaro Avon River has been considered more of an issue in the lower reaches within the influence of the tide (as evidenced by the extent of the existing stopbank system). More recently, investigations using hydraulic models (DHI 2011) have identified areas of potential flooding throughout the system.

The flood risk in the Area has been exacerbated by the Canterbury earthquake sequence beginning in September 2010, which significantly altered ground levels in the Area and damaged existing flood mitigation infrastructure, ie stop banks and pumping stations. Council's immediate response to the increased flood risk was to construct temporary stopbanks. The stopbanks are described as "temporary" because they are mostly on weak foundations so do not have an indefinite life and cannot be raised to meet sea level rise. The present Ōtākaro Avon River stopbanks are mainly designed to reduce the risk to properties from tidal flooding (as distinct from rainfall flooding).

[3] "Notes and Comments on the Christchurch Drainage and Sewerage Systems", E. F. Scott, Christchurch Drainage Board, Oct. 1963.

The stopbanks will soon be strengthened and heightened as an interim measure to secure their effectiveness until Council adopts a long-term solution to flood management within the Ōtākaro Avon River catchment. The current status of the land within the Area provides an opportunity to address this risk in a way which has minimal disruption for residents and before further works take place that may impact on the ability to implement effective flood mitigation measures. The lowering of ground levels increases flood risk – more flooding will occur without further enhancements to the flood management system.

Note that flood mitigation is different to the role of stormwater treatment through detention basins or wetlands. These facilities detain runoff from the smaller events that occur more regularly to remove contaminants.

2.2 River characteristics

The Ōtākaro Avon River is a low energy system with flat grades. Low flows are $2m^3/s$ at the Carlton Road Bridge, increasing to approximately $35m^3/s$ at Bridge Street, as a result of the tide. The main channel has significant capacity and as a result the flows are sedate with low velocities. The lower reach is influenced by the tide with reverse flows occurring upstream beyond Porritt Park.

The hydraulic response of the river can be broken into two broad extents (or reaches) which are defined by flood behaviour. The upper reach upstream of Barbadoes Street has a steeper hydraulic grade, which is defined by channel shape and structures. The lower reach between Barbadoes Street to the Estuary has a much flatter grade, where the influence of extreme tide levels controls the predicted flood level. The shape of the main channel is much wider within this section and flooding is controlled more by storage on the floodplain than flow capacity within the river.

2.3 Terminology

Expressing the level of flood risk is challenging as it is based on incomplete data, model predictions and complex inter-relationships. The likelihood of a flood occurring is a probability calculation based on the statistical theory of extreme events and is not necessarily intuitive to understand and interpret.

This report uses the terminology of average recurrence interval (ARI), as it provides a more easily accessible articulation of likelihood. It is the average period between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random. So, if ARI is the average time period between floods of a certain size, a 100-year ARI flow occurs on average once every 100 years.

Related is the annual exceedance probability (AEP), used in the Christchurch District Plan, which is a more technically correct terminology but less easy to understand intuitively. So, since AEP is the probability of a certain size of flood flow occurring in a single year, 1 per cent AEP flood flow has a 1 per cent, or 1-in-100 chance of occurring in any one year, and a 10 per cent chance of occurring in any 10 year period. Therefore, the 100-year ARI flow and 1 per cent AEP flow are different terms to describe a flow of the same size in any given river.

2.4 Extent of flood risk

The figure below shows the impact of rising sea levels and increased rainfall intensity on flooding in Christchurch. The number of properties predicted to be at risk of a flooding event due to sea level rise is approximately 8,000 – which is double the amount currently considered to be at risk. Appendix 1 provides a similar A3 version of the map in the figure below and Appendix 2 sets out further detail on the flood risk.

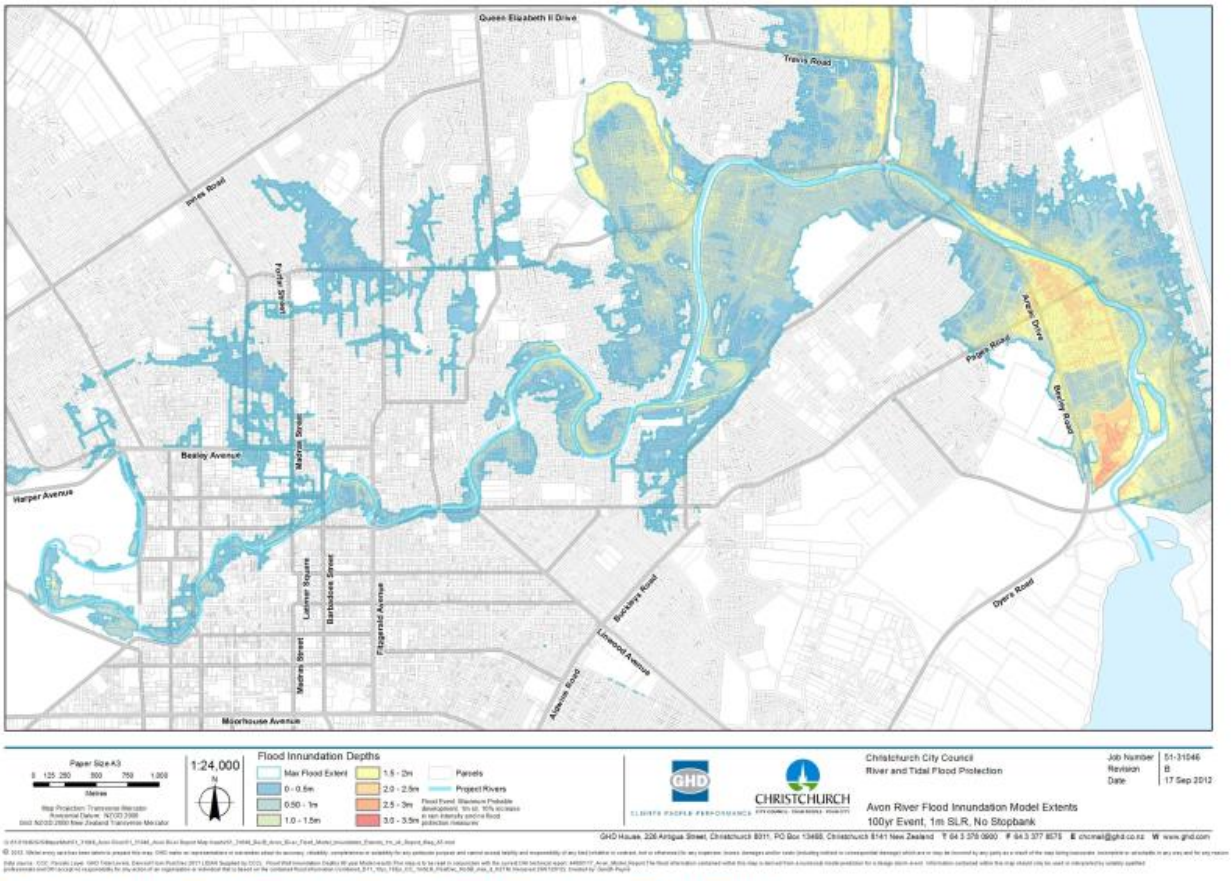


Figure 9 1/100 AEP flood inundation in the Avon catchment with 1 m sea level rise and without flood protection

2.5 Uncertainties and assumptions

This report has been prepared with the following uncertainties and assumptions.

Uncertainty	Assumption
Impact on potential land uses	That flood mitigation and management is an essential consideration for any future land use options and will be able to be integrated into the overall land use spatial plan for the Area.
Regulatory level of mitigation	That the Building Act (50 year ARI) for individual buildings and the Christchurch District Plan High Hazard Areas are retained.
Implementation of Plan	It is assumed that implementation of the Plan is enabled, including funding, land ownership, governance, management and delivery responsibilities.
Capital costs	Indicative forecasted capital costs have been developed based on limited and generic information. A range of potential costs has been provided. The cost will depend on the implementation options and plans pursued. These figures are for comparative purposes only and will require a concept design, implementation approach and more defined cost estimation to establish a more robust budget.

3 Strategic assessment

3.1 Purpose

This section outlines the case for change, by addressing:

- Strategic context
- Problem definition
- Investment objectives, existing arrangements and business needs
- Potential investment scope
- Benefits, risks, constraints and dependencies

This section has been informed by the community ideas, suggestions and proposals received by Regenerate Christchurch.

3.2 Strategic context

The Greater Christchurch Regeneration Act 2016 established Regenerate Christchurch's purpose to "support a vibrant, thriving Christchurch that has economic, social and lifestyle opportunities for residents, businesses, visitors, investors and developers". The overarching vision and objectives for the Area are:

Our Shared Ōtākaro Avon River Vision

The river is part of us and we are part of the river.

It is a living part of our city.

A place of history and culture

where people gather, play, and celebrate together.

A place of learning and discovery

where traditional knowledge, science and technology meet.

A place for ideas and innovation

where we create new ways of living and connecting.

OUR VISION IS FOR THE RIVER TO CONNECT US TOGETHER –

with each other, with nature and with new possibilities.

Our Shared Ōtākaro Avon River Objectives

For Christchurch

- Support safe, strong and healthy communities that are well-connected with each other and with the wider city.
- Provide opportunities for enhanced community participation, recreation and leisure.
- Create a restored native habitat with good quality water so there is an abundant source of mahinga kai, birdlife and native species.
- Create opportunities for sustainable economic activity and connections that enhance our wellbeing and prosperity now and into the future.

For New Zealand

- Develop the Ōtākaro Avon River Corridor Regeneration Area as a destination that attracts a wide range of domestic and international visitors.
- Establish a world-leading living laboratory, where we learn, experiment and research; testing and creating new ideas and ways of living.
- Demonstrate how to adapt to the challenges and opportunities presented by natural hazards, climate change and a river's floodplain.

The ultimate purpose of the Plan is to enable long-term uses of land within the Area that will contribute to, and support, the regeneration of east Christchurch and *greater Christchurch*[4]. The vision and objectives have been developed in order to achieve this.

3.3 The case for change

The case for change has been mapped in an investment logic map, see Appendix 4. That process is described in the following sections. The case also encompasses the following discussion around likelihood and consequence.

The water level in the Ōtākaro Avon River will exceed the bank level during extreme storm events when it coincides with high tides

The likelihood and consequences of this have been modelled by Council and the flood areas identified in the District Plan.

There are a large number of properties and essential infrastructure at risk from the fluvial (river) and tidal flooding from the Ōtākaro Avon River

[4] All terms in italics have the meaning given to those terms in the Greater Christchurch Regeneration Act 2016.

Council reports that up to 8000 properties may be at risk in very extreme events. This will be made worse with the effects of climate change.

The existing stopbanks reduce the risk of flooding for existing properties, which rely on the stopbanks in relation to the standards established by the Building Act.

The use of the Ōtākaro Avon River Corridor will be strongly influenced by the flood regime and location of stopbanks

Ecosystems will be different depending on the frequency of inundation. Land uses that require protection from floodwaters will need to consider how to provide that protection.

As such, it is important to determine the location and extent of flood mitigation in the future to inform the Plan.

There are temporary stopbanks alongside the river to mitigate the risk of flooding from the Ōtākaro Avon River

These are located immediately adjacent to the river. They were installed immediately after the earthquakes and are being upgraded to have a 20-year life.

As such, new stopbanks or other measures will need to be implemented in the medium term and so decisions will need to be made as part of the planning for the future use of the Area, so they can be accommodated in the future.

3.3.1 Investment drivers (problems/opportunities)

The first step in establishing a case for change is to identify drivers for investment. These drivers encompass the problems that need to be addressed, their causes and the related opportunity if they are addressed.

The following table provides an overview of the investment drivers which will help guide any decisions around flood mitigation in the Area.

Land use driver	Causes of problem	Opportunity
1. Damage to houses and business due to tidal and fluvial flooding during major events damages social and community wellbeing.	• The effect of flooding entering properties has a financial and economic impact on property owners – however there are equivalent or potentially greater impacts on the social wellbeing of a community. • These effects include mental health, community connections and sense	Future proofing Christchurch in terms of flood risk brings ongoing financial and community benefits.

Land use driver	Causes of problem	Opportunity
	of vulnerability, leading to adverse impacts on crime, health and other outcomes.	
2. Thousands of existing properties are at risk of tidal and fluvial flooding that comes from the lower Ōtākaro Avon River leading to property damage, reduced property value and economic disruption.	• This problem was present pre-quakes, but the lowering of the land, changes to the shape of the land form and narrowing of the channel has increased the number of properties at risk of flooding and made some properties more likely to be flooded. • The water level is controlled by the tide, and hence will increase over time due to sea level rise.	The Area currently includes a large expanse of bare land which has the potential to allow significant flood mitigation works without having to remove existing housing or infrastructure and create a benefit for the wider Ōtākaro Avon River catchment.
3. Tidal and fluvial flooding from the lower Ōtākaro Avon River during major storm events will damage property and disrupt critical lifeline infrastructure, including Pages Road and ANZAC Drive.	• Some key lifelines infrastructure, including roads, bridges and wastewater pipes and pumping stations, are susceptible to damage or being out of service for extended periods following an event. This would lead to loss of escape routes, connections to key infrastructure such as the Port, discharge to the river from the wastewater system or loss of telecommunications or electricity service.	The ability to have a combined approach to transport and services infrastructure provide efficiencies and creates future-proofed solutions.
4. Use of land within the Area is restricted by the hazard of tidal and fluvial flooding from the Ōtākaro Avon River.	• Options for the future land use in the Area include uses that would need mitigation from the risk of flooding. • The threat of flooding limits the uses of the land and the contribution it can make to the wellbeing of Christchurch.	There is the potential to incorporate flood mitigation infrastructure in a way which enhances the future land use of the Area while addressing existing flood risks.

3.3.2 Flood mitigation investment objectives

Flood mitigation investment objectives have been formed to guide the assessment of the various flood mitigation options and inform the assessment of how flood mitigation could contribute to achieving the overarching objectives and Land Use Assessment Criteria for the Area.

These flood mitigation investment objectives are to:

- Substantially reduce the number of homes within the Ōtākaro Avon River catchment likely to be flooded above floor level in a 200-year ARI event, including allowance for climate change.
- Ensure all new developments within the Area are constructed above the 200-year ARI flood water level (including climate change).
- Mitigate the effects of flood risk on lifelines infrastructure so that people can escape in emergencies and economic activity can re-establish quickly after a flood event.
- Integrate flood mitigation with the future uses of the Area.

3.3.3 Benefits

To be able to measure the success of any flood mitigation land use, these benefits have been established:

- Increase in level of economic, housing and community resilience to flood risk and future climate change.
- Enable a greater range of uses in the Area to be considered that contribute to the vision and objectives.

3.3.4 Contribution to overarching vision and objectives

Flood mitigation is considered to contribute to the overarching vision by supporting the river as a place of learning and discovery as well as a place for ideas and innovation.

Flood mitigation could contribute to the overarching vision and objectives in these ways.

Overarching vision and objectives	Link to flood mitigation benefits
For Christchurch	

Overarching vision and objectives	Link to flood mitigation benefits
Support safe, strong and healthy communities that are well connected with each other and with the wider city.	Increase in level of economic, housing and community resilience to flood risk and future climate change.
Provide opportunities for enhanced community participation, recreation and leisure.	No material benefit.
Create a restored native habitat with good quality water so there is an abundant source of mahinga kai, birdlife and native species.	No material benefit.
Create opportunities for sustainable economic activity and connections that enhance our wellbeing and prosperity now and into the future.	Enable a greater range of uses in the Area to be considered that contribute to the vision and objectives.
For New Zealand	
Develop the Ōtākaro Avon River Corridor Regeneration Area as a destination that attracts a wide range of domestic and international visitors.	No material benefit.
Establish a world-leading living laboratory, where we learn, experiment and research; testing and creating new ideas and ways of living.	No material benefit.
Demonstrate how to adapt to the challenges and opportunities presented by natural hazards, climate change and a river's floodplain.	Increase in level of economic, housing and community resilience to flood risk and future climate change.

3.3.5 Scope assessment

All scope definitions are limited to the flood hazard from water coming from the Ōtākaro Avon River between Barbadoes Street and Bridge Street (ie, through the Area.) The location and extent of measures to mitigate this flood hazard is not limited by geographic scope, but by its ability to affect the flood hazard presented by water coming from the river.

To assess the different options or opportunities put forward with respect to flood mitigation works, an initial scope has been developed with respect to the level of residual risk providing the definition of scope. The scope is to help assess each option or opportunity:

- Minimum scope (minimum, core service requirements only): up to 50-year level of mitigation for water entering properties with risk currently more likely than from the 10-year ARI event.
- Intermediate scope (minimum plus desirable service requirements – if value for money): up to 200-year ARI level of mitigation for water entering properties.
- Maximum scope (minimum, desirable and optional service requirements): up to 200-year level of mitigation, with substantial additional mitigation against structural failure.

3.3.6 Risks

It is also important to identify and record any potential risks around provision of flood mitigation works, and their mitigations.

Risk	Mitigation process	Residual risk rating
The design of flood mitigation works does not align from a design or regeneration perspective leading to a missed opportunity for the Area.	Ensure design is an important element of any flood mitigation works and appropriate weighting is given to the interaction with other projects.	Moderate
Timing of funding does not align with development of land.	Progress through Council's Long-Term Plan process.	Low
The capital cost is greater than forecast.	The costs included in this assessment are indicative only. Progress more detailed studies before establishing budgets and establish a robust project management methodology.	High
Operating costs are greater than forecast.	The costs included in this assessment are indicative only. Progress more detailed studies before establishing budgets and establish a robust project management methodology.	High

3.3.7 Interdependencies

These interdependencies have been identified for flood mitigation works.

Interdependency	Description
Current and planned land uses	The decision on the form and location of flood mitigation works needs to integrate with the overall planning and spatial design of the Area. Some land uses would likely require a higher level of mitigation than others, and also be better able to integrate stopbanks and other forms into the landform of the land use.
Current stopbanks	Extensive stopbanks alongside the Ōtākaro Avon River were established immediately following the February 2011 event. These are currently being refurbished to extend their life for at least another 20 years. However, they are not grounded on stable foundations and carry continued risk of damage due to groundwater seepage of more extensive ground failure, so cannot be considered long-term assets for the city.
Uses that require land filling	Other investigations into the use of the land in the Area include raising of the land to enable future land uses that need to be located above the flood water level. Area-wide filling of the land to an equivalent level as a stopbank provides an equivalent effect of containing the water in the river as a stopbank. The greater width of fill will mean that this mitigation is significantly less likely to fail as compared with a flood wall of normal width stopbank. Secondary flow paths would also need to be considered. Due to the flood mechanism in the river corridor, where the tide level rather than flood conveyance capacity controls the water level, filling behind the stopbank does not affect flood water levels.
Land use assessment reports	Land uses cannot be considered in isolation, and all land use assessments must be considered together.
Land	The geotechnical and flood plain footprint of the land will affect what can be developed or built in the Area.
Other regeneration and urban master plans	Any flood mitigation needs to consider other projects undertaken by Regenerate Christchurch, Development Christchurch Ltd and Christchurch City Council in nearby areas, including New Brighton and the central city.
The Plan	The Plan which sets out proposed land uses is being prepared under the Greater Christchurch Regeneration Act. The Minister

	makes the final decision on whether to approve the draft Plan. In making this decision, the Minister must have regard to/consider matters set out in section 38 of the Act. This includes considering the fiscal and financial implications of the draft Plan and whether the draft Plan is in the public interest.
The Crown's investment in land	The Crown has made a significant investment in this land and is the critical decision maker in determining the future use of the Ōtākaro Avon River Corridor. The overall return on investment (financial and non-financial) is a critical issue for the decision makers.
Stormwater treatment	Provision of basins and wetlands to treat urban stormwater runoff as identified in the water Quality Improvements Land Use Assessment Report will not address fluvial or tidal flood risk due to their scale, however will assist in storing overland flow prior to over pumping during the proud when the river is high.

4 Flood mitigation options

4.1 Purpose

The purpose of this section is to:

- Establish the critical success factors for flood mitigation
- Explore the preferred way forward
- Provide a summary of the global options available for mitigating flood risk from tidal and fluvial flooding

4.2 Critical success factors

Critical success factors are considered to be the attributes that are essential for ensuring any flood mitigation land use types align with the overall vision and objectives for the Area. The key point is that critical success factors are crucial, not desirable. Further, it is important to differentiate between critical success factors and design principles.

The following factors are considered essential to the successful implementation of flood mitigation works within the Area.

Critical success factor	Description
Confidence in forecast water levels and effect on properties	Robust and well-founded predictions of water level with accurate data on floor levels.
Resilience to other hazards	Able to resist or accommodate the effects of other hazards, including the effects of earthquakes, and being adaptable to these impacts over a long time horizon.
Allowance for climate change	Meets or exceeds Ministry for the Environment guidelines for adapting to the effects of climate change.
Acceptable environmental impact	Does not cause an unacceptable environmental impact and aligns with spatial design for Area.
Effective	Offers mitigation of flood risk with low risk of failure.
Affordable	Affordable in terms of offering a long-term solution for the city that is supported through financial data.

4.3 Summary of options

There is a range of global options for mitigating flood risk from tidal and fluvial flooding related to the Ōtākaro Avon River by GHD ("Investigation into the River and Tidal Flood Protection needs for Christchurch", 51/31046/ GHD, Feb 2014). The global options for flood management are summarised below and draw on this and other technical studies including GHD's "Avon-Heathcote Barrier Pre-feasibility Study" (July 2015).

Inland destination flood detention basins[5] have been considered and discarded as not effective in this catchment as they are unable to reduce flood levels due to the large volume of water contributed by the incoming tide.

	Option	Description	Capital cost	Comment
A	Upstream storage	Storage in Hagley Park	$18-25m[6]	Addresses only the central city. Requires diverting river water from the Avon into an impoundment area in Hagley Park approximately 173,000 m^2.
B	Estuary barrage	Estuary mouth	$310m	High potential for unacceptable environmental effects. Less flexible with climate change. Stopbanks still required.
C	Bridge Street barrage	At Bridge Street	Unknown: Approx. $320– 350m	Coastal process, limited river flood flow storage upstream of Bridge Street, so unlikely to be effective, Less flexible with climate change. Stopbanks still required.
D	Reduced level of service to 50-year ARI	Reduce return period	Unknown	More frequent flooding of houses, and greater numbers of housing affected in an event.

[5] www.habitat.noaa.gov/pdf/sir_workshop_report_november_2011
[6] Based on work done for the Te Papa Ōtākaro/Avon River Precinct for the Canterbury Earthquake Recovery Authority.

	Option	Description	Capital cost	Comment
E	Retreat from flooded area	Managed retreat	Up to $4b[7]	8000 properties at risk. Acquisition of all properties.
F (i)	Flood walls and stopbanks near river bank	Stopbanks adjacent to edge of the river	$272–292m	Construct stopbanks at the river's edge/top of bank – more expensive because the foundation and crest height are greater.
F (ii)	Flood walls and stopbanks set back from river bank	Stopbanks and walls towards outer edge of the Area	$141–171m	Construct stopbanks away from the river's edge/top of bank – less expensive because the foundation and height are lower.
G	Floor level raising	Use the existing flood management areas in the Christchurch District Plan to regulate new floor levels and raise existing floor levels where they are below flood level	Unknown Approx. $160–240m[8]	Location of "rebuilds" is unknown and likely to employ existing use rights so residual risk is uncertain but may be ineffective unless funded. Requires local drainage system upgrades to match climate change to retain existing levels of services.
H	Do nothing	Accept the flood risk	Nil	Ongoing social and economic disruption.

[7] 8000 houses at an average value of $500k each.
[8] 8000 properties at $20–40k per property.

5 Conclusion

The Plan presents an opportunity to implement flood mitigation works that can have long lasting financial and community benefits for areas within the Ōtākaro Avon River catchment. The predominantly vacant nature of the land means that there is the potential to undertake the mitigation with minimal impact on local residents, integrate with new future uses of the land and ensure alignment with the regeneration objectives.

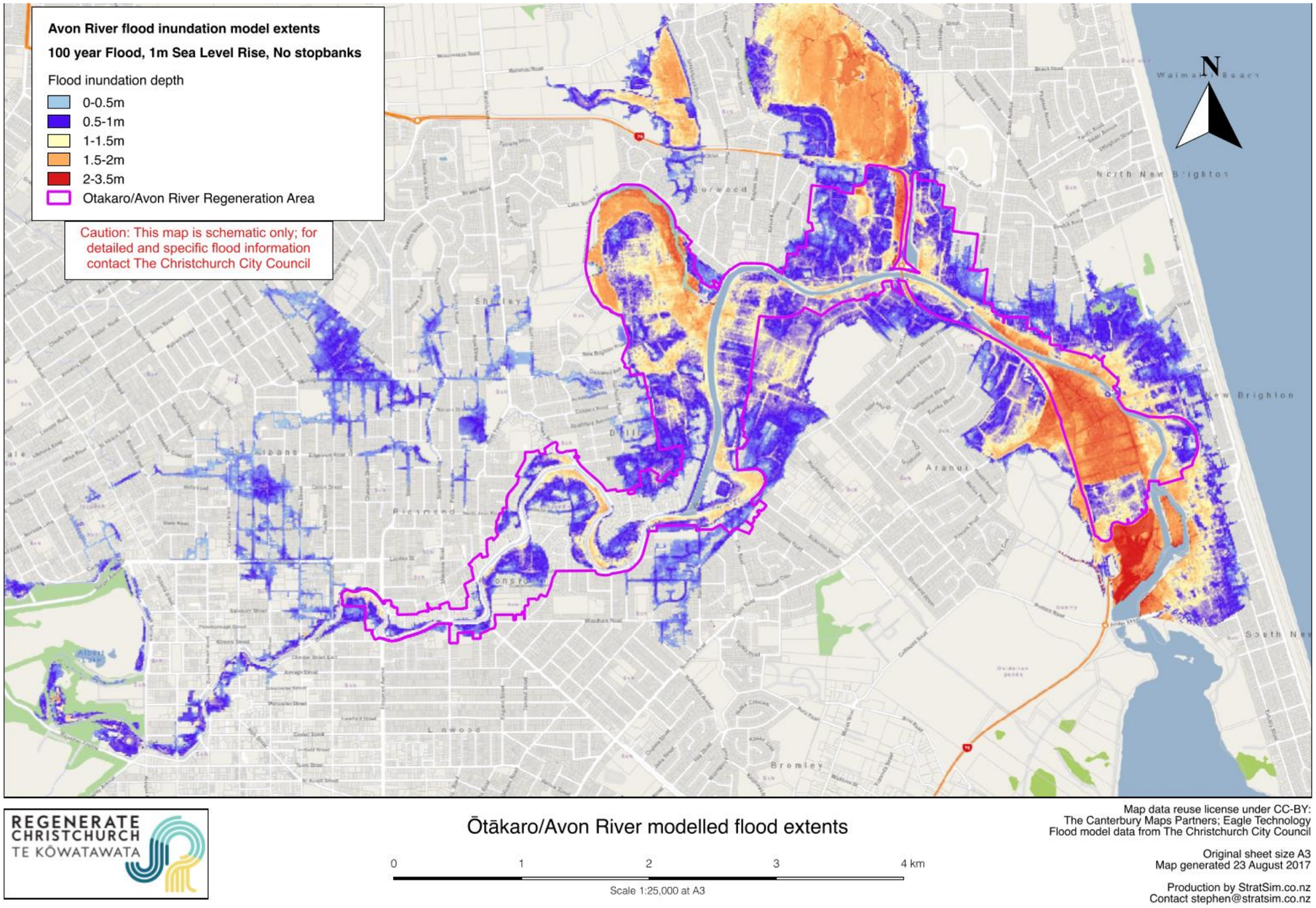
- The technical studies and consideration already undertaken by the Council have concluded that:
  - an estuary barrage was not cost effective at this stage and presented high environmental impacts, but could be considered if sea level rises exceed current forecasts
  - stopbanks and floodwalls presented the most effective and affordable approach, coupled with floor level raising as the opportunities arise through the District Plan provisions.

- Options from the longlist that do not enhance the level of flood mitigation, or that leave a large number of properties affected during a single event, are not considered to meet the overarching objectives and, therefore, have been rejected.

- The managed retreat option is likely to be unaffordable. However, it remains a viable option in the future if the risk continues to increase with climate change and the community's risk tolerance reduces sufficiently to the point where there is appetite for this significant cost.

As such, options F (i) and F (ii) will be further considered to determine the overall option for the Area. The difference between the two options relates to the alignment of the stopbanks, the consequential costs, and the degree of integration and impact on the future use of the Area. These decisions will need to be addressed at a more detailed level through the spatial design process to optimise the balance between the competing drivers.

Appendix 1: Flood extent map



Appendix 2: Further detail on flood hazard

Overview

A large portion of Christchurch is located on flat, low lying terrain which is vulnerable to flooding from surface water, its rivers (Ōtākaro Avon, Ōpāwaho/Heathcote, Huritini/Halswell and Pūharakekenui/Styx) and the sea. The city is particularly vulnerable in the east around Ihutai/Avon-Heathcote Estuary and near the river mouths. Flood risk has, historically, given rise to flood mitigation infrastructure, such as stopbanks, pump stations and sea walls. As Christchurch has grown, further flood mitigation infrastructure has been required to reduce the physical, financial and emotional impact on residents, communities and businesses.

The earthquakes significantly increased the potential of river and tidal flooding in the city, because ground levels lowered relative to the sea.

Christchurch City Council's investigations on the impacts of the earthquakes and predicted climate change conclude that the quakes significantly increased river and tidal flooding potential in Christchurch. The quakes lowered ground levels relative to sea level in some parts of the city, with land levels dropping by up to 1m in places but typically 200–300mm near the major rivers. Many of the worst areas affected border, or are close to, the residential red zone. There are also areas outside the Ōtākaro Avon River Corridor which are now significantly more susceptible to flooding, with some low-lying areas now being below high tide level. Ongoing presence of flood defences will be essential to maintain residential development of these areas.

Land deformation from the earthquakes has disrupted many of the Ōtākaro Avon tributary drainage catchments affecting piped and open networks as well as open drains. Established secondary flow paths have been cut off by new emergency stopbank measures. This has caused significant localised flooding as stormwater can no longer drain from some streets after even quite modest rainfall events. For Swans Rd to south Bexley for example, 60 out of the 215 outfalls into the Ōtākaro Avon River have been damaged, either buried by bank collapse/lateral spreading or drowned below new water levels.

Climate change

Climate change will affect Christchurch by increasing the intensity of rainfall events and sea level. Under the Christchurch District Plan, Policy 5.2.2.2.1 Flooding, the risks from flooding

are managed based on an allowance for 1 metre of sea level rise and an increase in rainfall intensity by 16% through to 2115 (as a result of climate change).

The Council's investigations (which provided the evidence base for that policy) concluded that the predicted increase in sea level could affect the low-lying areas of the city, mainly in the east, in a significant way. To date, the Council has adopted a flood management approach of a combination of defence (construction of stopbanks) and adaptation to potential flooding (flood management areas providing development controls and requiring floor levels to be raised above flood levels).

Both sea level rise and the intensity of rainfall events will have a significant impact on the potential for flooding events within the city and will place an increased burden on stormwater networks. In the absence of remedial measures, the level of service of the stormwater drainage system will decline over time due to the backwater effects of higher river/tide levels reducing the capacity of stormwater networks and increasing the need for stormwater pumping. Currently, stormwater pump stations typically operate only in larger rainfall events, but as tide levels rise these pump stations may need to operate more frequently, making them more important.

Coastal erosion

Coastal erosion will increase with climate change (Tonkin and Taylor, 2013), and will pose a risk to much of the Area if left unmitigated. The coastal environment is facing a number of significant impacts and this has given rise to a policy and planning framework which includes the New Zealand Coastal Policy Statement 2010 (Department of Conservation). Objective 5 of the Coastal Policy Statement states:

> "To ensure that coastal hazard risks taking account of climate change are managed by: locating new development away from areas prone to such risks; considering responses, including managed retreat, for existing development in this situation; and protecting or restoring natural defences to coastal hazards."

As summarised by Tonkin and Taylor (2015) a number of the policies also relate to coastal erosion, including:

- Policy 3 – requires a precautionary approach in the use and management of coastal resources potentially vulnerable to effects from climate change, so that avoidable social and economic loss and harm to communities does not occur.

- Policy 24 – identifies areas in the coastal environment that are potentially affected by coastal hazards (including tsunami) and giving priority to the identification of areas at high risk of being affected. These should take into account national guidance and the best available information on the likely effects of climate change for each region.
- Policy 25 – promotes avoiding increasing the risk of social, environmental and economic values to erosion hazard in areas potentially affected by coastal hazards over at least the next 100 years.
- Policy 27 – promotes reducing hazard risk in areas of significant existing development likely to be affected by coastal hazards.

This cascades down to the Regional Policy Statement (Canterbury Regional Council, 2013) and the Regional Coastal Environment Plan for the Canterbury Region (Canterbury Regional Council, 2005) which calls for new habitable buildings to be located away from areas that have the potential to be subject to coastal erosion or inundation. The Christchurch City Council, through its District Plan, is required to give effect to these Plans, through preparation of the Coastal Hazards part of the Natural Hazards chapter. This chapter is currently under review and planned to be notified in 2018.

Ongoing management and maintenance of defences against coastal erosion will be required if the land is redeveloped. The risk will increase with time and could be very costly for the community to manage.

Groundwater

Groundwater seepage beneath the existing stopbanks will be an increasing issue with time as sea level continues to rise (Wright, 2015). There are areas behind the stopbanks where control of groundwater might be desirable, and in the future, required to maintain function of the land. Control measures might include shallow groundwater interception (field drains), draw down wells and impermeable barriers (sheet piling). The alternative to controlling the groundwater may be to raise the ground. Christchurch City Council is currently undertaking a project to enhance the understanding of current and future groundwater levels across the city as this may be a key factor in establishing the future use of land in lower lying areas.

The ongoing costs to manage groundwater could be significant, depending on the development ground levels. If pumping is required to manage groundwater, then it is possible that these pumps would need to operate continuously. The effectiveness of any groundwater management system could be impeded by efforts placed in ground stabilisation. The possible effects of compaction on groundwater movements would need to

be carefully considered as part of the design work, as experience has shown that compaction may lead to unintended consequences.

Tsunami

Environment Canterbury has investigated the tsunami risk to Christchurch from near field and far field earthquakes (Canterbury Regional Council, 2017). These investigations show significant areas of the lower Ōtākaro Avon River at risk (NIWA, 2014). Further investigations are now underway to understand the potential impacts of river water levels and flows on tsunami propagation up the Ōtākaro Avon River. The current approach to management of this risk is based around early warning and evacuation (sirens for far-field earthquakes and significant earthquake shaking from near-field earthquakes). Catastrophic property damage could result from a tsunami, particularly if it arrived during high tide.

Appendix 3: References

Environment Canterbury, 2009. Assessment of the impacts of sea level rise on floodplain management planning for the Avon River. Prepared for NZ Climate Change Office, Ministry for the Environment.

GHD (Pty Ltd), 2013. Investigations into the River and Tidal Flood Protection needs in Christchurch Estuary and Sumner Stage 1.

GHD (Pty Ltd), 2015. Avon Stopbank Refinements Report.

GHD (Pty Ltd), 2015. Avon-Heathcote Barrier Pre-feasibility Study.

Hydrodynamic model of the Avon Heathcote Estuary: Model build and calibration, NIWA Client Report CHC2013-116. NIWA. Report prepared for Environment Canterbury.

GNS Science Consultancy Report 2013/131. Review of Tsunami Hazard in New Zealand (2013 Update).

Tonkin and Taylor, 2013. Effects of Sea Level Rise for Christchurch City. Report prepared for Christchurch City Council.

Appendix 4: Investment logic map

The investment logic map process provides a framework for identifying the problems which need to be resolved, the potential benefits from addressing the problems and the development of investment objectives with respect to a potential project or land use.